APPENDIX A: Methodology for Developing PFAS Ecological Screening

CONTENTS

1 INTRODUCTION

1.1 Objectives

Argonne National Laboratory (Argonne) is working under the interagency direction of the U.S. Air Force Civil Engineer Center (AFCEC), with advice and input provided by the Tri-Services Environmental Risk Assessment Working Group (TSERA-WG, Chemical Material Risk Management Program), which is a chartered organization under the Office of Secretary of Defense, and the U.S. Environmental Protection Agency's (EPA's) Ecological Risk Assessment Forum (ERAF), referred to here as the Interagency Staff, to develop ecological screening values (ESVs) for use at Department of Defense (DOD) facilities with per- and polyfluorinated alky substances (PFAS) releases. ESVs, which represent contaminant levels below which ecological impacts are unlikely, support remedial investigations by focusing investigations in areas with concentrations that could have ecological impacts, and present a starting point for site-specific ecological risk assessments (EPA 1997). Argonne is working with AFCEC and the Interagency Staff to identify methods for reviewing the scientific literature on the effects of PFAS on ecological resources, to develop receptor-specific exposure scenarios and dose models, and to develop biota- and media-specific ecological screening values from this information. This report describes the methodology for deriving screening levels that will be developed in this collaborative effort.

1.2 General Process for Developing PFAS ESVs

Argonne will screen and review the available literature to identify a set of research studies meeting the selection criteria of this effort from which to develop screening levels. From these qualifying papers, Argonne will develop ecological screening values to the extent that information is available on PFAS chemicals, ecological receptors, and media in the qualifying papers. The methods used and the resulting uncertainty associated with the developed screening values will vary depending on the richness of the underlying data available in the literature. Rich datasets may produce robust and reliable screening values developed from well-defined dose-response curves covering a wide variety of ecological receptors. Datasets of intermediate richness would produce screening values of intermediate reliability, according to the depth and breadth of available toxicity response information. Last, our investigations may conclude that the uncertainty would be too high to develop screening values PFAS chemicals of interest, receptors, or media when data do not meet thresholds for quality and quantity. The developed screening values will be characterized with respect to overall uncertainty to aid users in their application.

Argonne worked with the Interagency Staff to develop the methodology for developing screening values. This methodology relies foundationally on EPA's Guidance for Developing Ecological Soil Screening Levels (Eco-SSLs, EPA 2005) for developing PFAS soil screening values, and on *Guidelines for Developing Numerical Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses* (Stephan et al. 1985), as well as the 1995 *Final Water Quality Guidance for the Great Lakes System* (40 CFR 60 No. 56), referred to hereafter as the Great Lakes Water Quality Initiative guidance, or simply the GLI guidance (EPA 1995a, b) for developing surface water screening values. This report describes the development of ecological screening values for the following media and receptors:

- Soils for invertebrates,
- Soils for plants,
- Soils for wildlife,
- Surface water for aquatic species, and
- Surface water for aquatic-dependent wildlife.

Developing screening values for soils and surface waters involves variations on a common theme: identifying the point of onset of ecologically relevant effects to relevant species from estimated environmental exposures of specific PFAS. Developing screening values in soil for plants and soil invertebrates involves the following steps:

- Extract toxicity values from qualified published literature for direct soil exposures of specific PFAS to plant and invertebrate species representative the geographic region of interest (North America).
- Derive screening values as the geometric mean of toxicity values from top ranking studies with respect to bioavailability of PFAS in the test medium.

Developing soil-screening values for terrestrial wildlife involves the following steps:

- Extract toxicity values from qualified published literature for laboratory exposures of specific PFAS to test animals representing bird and mammal species.
- Develop PFAS toxicity reference values (TRVs) representing the onset of relevant effects from published toxicity values using, in descending order of preference, either a (1) benchmark dose, (2) no observed adverse effect level (NOAEL)/ lowest observed adverse effect level (LOAEL) approach, or (3) approximation approach.
- Identify the soil screening value as the soil concentration corresponding to the TRV for specific PFAS using a food-chain model that accounts for soil ingestion and the ingestion of soil-exposed prey by species representative of North American birds and mammals.

The following describes the basic steps for aquatic species in surface waters (fresh water or marine):

- Extract toxicity values from qualified published literature for exposures of specific PFAS to representative species of genera, which are, in turn, representative of aquatic systems of North America.
- Plot toxicity values in rank order for the onset of ecologically relevant effects—mortality, growth and development, and reproduction—as a species-sensitivity distribution.
- Identify the screening value as the exposure concentration resulting in the onset of effects on the roughly 5% most sensitive species and/or genera.

Identifying a surface water screening value for aquatic-dependent wildlife species involves a somewhat different approach:

- Identify toxicity values (test dose) for the onset of relevant ecological effects in tests on laboratory animals (birds and mammals).

- Identify representative receptor bird and mammal species from the geographic region of interest.
- From the test animal data, estimate a corresponding toxicity value for the representative species using uncertainty factors.
- Identify surface water screening values for representative species from estimates of water consumption and of prey consumption, accounting for uptake from surface water and bioaccumulation of PFAS in prey.

In the following sections, this report (1) identifies the data sources to be used, (2) identifies the criteria by which scientific literature will be reviewed for usability, (3) describes exposure scenarios for use in developing media- and dose-based screening values, and (4) describes how the selected data will be used to develop media- and dose-based screening values.

1.3 References

Stephen, C.E., D.I. Mound, D.J. Hansen, J.R. Gentile, G.A. Chapman, and W.A. Brungs. 1985. *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses*. PB85-227049. Prepared by U.S. Environmental Protection Agency Office of Research and Development, Environmental Research Laboratories, Duluth, MN.

EPA (U.S. Environmental Protection Agency). 1995a. "appendix A: Great Lakes Water Quality Initiative Methodologies for Development of Aquatic Life Criteria and Values." Part 132. *Water Quality Guidance for the Great Lakes System*. 40 CFR Part 132.

EPA, 1997, *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological risk Assessments*, Interim Final. EPA 540-R-97-006. June.

EPA. 2005. *Guidance for Developing Ecological Soil Screening Levels*. Washington, DC. OSWER Directive 9285.7-55.

2 DATA ACQUISITION AND EVALUATION

2.1 PFAS Study Set

Table 2-1 lists eight PFAS compounds that the U.S. Air Force identified for the development of ESVs. The study set is composed of homologs of carboxylic acids of from four to ten perfluorinated carbons and homologs of sulfonic acids of from four to eight perfluorinated carbons. Searches of ECOTOX and other databases will include both the protonated and deprotonated acids (anions), as well as various salts. For example, ECOTOX identifies six forms of PFOS, the acid and anion, plus the K, Li, Na and tetraethyl-ammonium salts. PFOA includes the acid, anion, and Na salt. Only the acid forms are shown in Table 2-1.

Table 2-1 PFAS Compounds Included in the Literature Search for ESV Development

PFAS Abbreviation and Compound Names	International Union of Pure and Applied Chemistry Nomenclature	Chemical Abstracts Service (CAS) Registry Number
Carboxylic Acids		
PFBA, perfluorobutanoic acid	2,2,3,3,4,4,4-heptafluorobutanoic acid	375-22-4
PFHxA, perfluorohexanoic acid	2,2,3,3,4,4,5,5,6,6,6-undecafluorohexanoic acid	307-24-4
PFOA, perfluorooctanoic acid	2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-pentadecafluorooctanoic acid	335-67-1
PFNA, perfluorononanoic acid	2,2,3,3,4,4,5,5,6,6,7,7,8,8,9,9,9-heptadecafluorononanoic acid	375-95-1
PFDA, perfluorodecanoic acid	2,2,3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-nonadecafluorodecanoic acid	335-76-2
Sulfonic Acids		
PFBS, perfluorobutanesulfonic acid	1,1,2,2,3,3,4,4,4-nonafluorobutane-1-sulfonic acid	375-73-5
PFHxS, perfluorohexanesulfonic acid	1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluorohexane-1-sulfonic acid	355-46-4
PFOS, perfluorooctanesulfonic acid	1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluorooctane-1-sulfonic acid	1763-23-1

2.2 Literature Sources and Literature Search

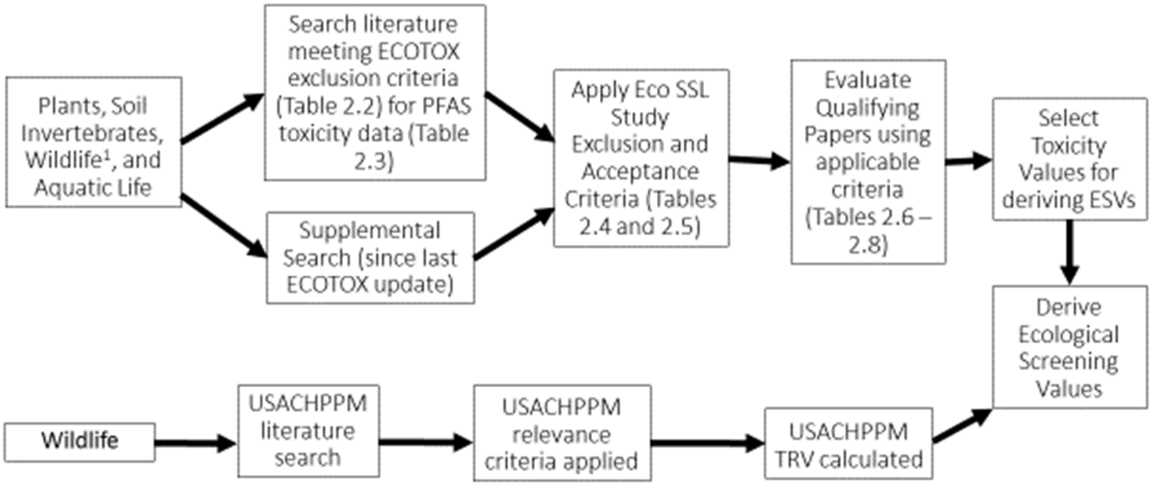
2.2.1 ECOTOX Knowledgebase for Toxicity Data Searches

The ECOTOX database (https://cfpub.epa.gov/ecotox/) will be the primary literature source used by Argonne to identify studies and datasets that will be used to develop PFAS screening levels for aquatic species, terrestrial plants, soil invertebrates, and terrestrial wildlife (birds and mammals). ECOTOX was created and is maintained by the EPA's Center for Computational Toxicology and Exposure (CCTE), Great Lakes Toxicology and Ecology Division. ECOTOX integrated three previously existing databases (AQUIRE, PHYTOTOX, and TERRETOX), and was completed in 1996 and released as a web-based interface in 2000. The literature search method used by CCTE to continue to populate the ECOTOX reference database is described in the ECOTOX User Guide (CCTE 2018). ECOTOX consists primarily of peer-reviewed literature on the effects of toxic substances on aquatic and terrestrial organisms found through online searches of scientific databases from 1970 to the present. In addition, ECOTOX incorporated external datasets, including the following:

- EPA CCTE data consisting of 30-day acute toxicity test for fathead minnow.
- Aquatic acute toxicity test results for studies conducted by the U.S. Geological Survey, Biological Resources Division, Columbia Environmental Research Center.

CCTE applied screening criteria to identified literature before it was entered into the ECOTOX database and studies not satisfying the requirements in Table 2-2 are excluded (Figure 2-1). Most of the rejection criteria relate to whether the study documents key elements of exposure (e.g., chemical name, dose, duration, pathway) and experimental design (e.g., controls and replicates).

All references incorporated into the ECOTOX database are assigned a reference number for storage and retrieval. CCTE uses various quality assurance procedures during the literature acquisition and cataloging to ensure that the study information is encoded correctly in the database (CCTE 2018).



[1]Wildlife TRVs developed by USACHPPM will be used when available; otherwise, ANL will develop PFAS TRVs.

Figure 2-1. Data Acquisition and Evaluation Process Used in Screening Level Development

Table 2-2 Study Exclusion Criteria used by the ECOTOX Knowledgebase

Parameter	Inclusion Criteria	Exclusion Criteria
Chemical	• Single chemicals relevant to environmental exposure are included. • Verifiable CAS number.	• Mixtures (petroleum fuels). • Air pollution (CO_2 and ozone).
Species	• Ecologically relevant species. • Priority species are wild (test results for terrestrial domestic and laboratory species are used to fill data gaps when needed). • Organism taxonomic information verifiable against standard taxonomic sources.	• Human, monkey, bacteria, viral and yeast.
Effect/ Response	• Biological effect on live, whole organisms. • Adverse effects are priority (beneficial, nutritional effects are lower priority).	• Dead organisms.
Concentration/ Dose	• Concurrent environmental chemical concentration/dose reported as concentration, dose or application rate. • Sediment studies must have a water concentration reported to be included.	• Inhalation dose route (including intratracheal instillation) • Lead shot • Sediment only concentration • Unverified measurement unit. • Log values

Table 2-2 Study Exclusion Criteria used by the ECOTOX Knowledgebase

Exposure Duration	• Duration reports an associated concurrent with a biological effect	• Unverifiable duration
Publication/ Data Format	• Primary data source. • Full text English (some non-English papers are encoded that have an English abstracts)	• Reviews • Full text foreign language. • Abstract only format

Source: Modified from NREERL (2018).

The ECOTOX database search interface contains multiple filters including “Chemicals,” “All Effects,” “All Endpoints,” “All Species,” “All Test Conditions,” and “All Publication.”. Within each of these filter categories are additional subfilter options to better target relevant literature. The database search filters that will be used by ANL are shown in Table 2-3. Under the “Perfluorooctane Sulfonates and Acids (PFOS/PFOA)” category in the ECOTOX database, Argonne will restrict the search to the eight specific compounds in Table 2-1.

In addition, only controlled laboratory studies will be used in most ESV development. Field-based studies will be excluded because the exposure regime and bioavailability are uncertain. However, field studies may be considered for the purposes of evaluating biomagnification and other food chain factors used in developing aquatic screening levels for wildlife (Table 2-8).

Table 2-3 ECOTOX Database Search Criteria for ESV Development

ECOTOX Parameters	ECOTOX Search Categories
Chemicals	Perfluorooctane sulfonates and acids (PFOS/PFOA)
All Effects	Growth (developmental; growth; morphological); mortality; reproduction; population
All Endpoints	Lethal concentration (LC_{xx})/lethal dose (LD_{xx}); effective concentration (EC_{xx})/effective dose (ED_{xx}); lowest observed effect concentration (LOEC); LOAEL; maximum acceptable toxicant concentration (MATC); no observed effect concentration (NOEC); NOAEL
All Species	Kingdom: Animals and plants (both)
All Test Conditions	Test Location: Laboratory Exposure Media: Water (freshwater, saltwater); soil (all categories); no substrate Exposure Type: Diet; environmental; not reported; flow through; intermittent; renewal; static Any Control Types: All ECOTOX control types and ECOTOX historical control types Any Chemical Analysis: Measured
Any Control Types	Any Independently Compiled Data: (all)

To develop PFAS ESVs, we will use only data from studies that test for ecologically relevant effects on reproduction, mortality, and growth. The following definitions are provided by ECOTOX (CCTE 2018) and EPA (2005) for growth, reproduction and mortality:

- *Growth*—Indicators of growth effects in the ECOTOX database covers specific measures of plant and animal growth (e.g., changes in organism weight, length, and biomass over time), as well as measurements of development and morphology. Development covers effects on tissue organization in growing early life stages. Morphology measurements and endpoints address the structure (bones) and form (organ/tissue development) of an organism at any stage of its life history (CCTE 2018).

- *Mortality*—Effect measurements of death include an actual count of the number dead or the percentage reduction within a population. An endpoint such as the LD_{50} estimates the effects to the population.

- *Reproduction*—Reproductive behavior, physiology, care of progeny and avian/reptile eggs measurements. Examples of measurements of reproductive effects include changes in reproductive behavior, abnormal progeny, fecundity, number of offspring produced, hatching rates, success, and/or viability; and reproductive success and/or capacity (e.g., offspring/adult/week). For plants, examples include changes in germination and seed yield.

Other effects reported in the ECOTOX database, such as physiological, cellular, biochemical/molecular and behavioral effects, will not be used in ESV development because of the difficulty of clearly and directly relating these effects to mortality, growth and reproduction.

The ECOTOX database is updated every three months. Argonne will conduct supplemental literature searches to capture any relevant literature published after the latest ECOTOX update. The literature search will generally follow the search procedure used by ECOTOX (CCTE 2018) and the U.S. Army Public Health Center (USAPHC; USACHPPM 2000; Deck and Johnson 2015) consisting of computerized searches of relevant biomedical, toxicological, and ecological databases (e.g., Google Scholar, Web of Science BIOIS, PubMed and TOXLINE). The U.S. Navy PFAS database will also be reviewed (https://intelshare.intelink.gov/sites/atlcoi/cmrm/PFAS/Forms/AllItems.aspx). As with the ECOTOX database search, Argonne will focus on controlled laboratory studies of PFAS effects on mortality, reproduction, and growth indicators.

2.2.2 USAPHC Literature Sources and Search Methods for Wildlife TRVs

Screening levels for wildlife will be based on TRVs provided by USAPHC, as available. Detailed information on literature search methods can be found in USAPHC Technical Guide No. 254 (USACHPPM 2000) and in Deck and Johnson (2015). In developing TRVs, USAPHC searches relevant databases such as ECOTOX, Web of Science, Integrated Risk Information System, Registry of Toxic Effects of Chemical Substances, and several National Library of Medicine databases (PubMed, TOXLINE, ATSDR Toxicity Profiles Hazardous Substances Data

Bank and Medline). Separate searches are conducted for birds, mammals, reptiles, amphibians, wildlife, and plants.

2.3 Initial Screening of Potentially Acceptable Literature

Studies initially identified in ECOTOX and supplemental literature searches will undergo a second screening process (ECOTOX screening being the first) based on the Eco-SSL criteria (EPA 2005) modified to reflect PFAS compounds (Figure 2-1). The overall objective will be to exclude studies not involving experimental PFAS exposures that measured defined endpoints to determine toxicological effects. Exclusions include studies of PFAS fate and transport, modeling studies, methods studies, reviews, studies of human health and in-vitro studies (Table 2-4). ECOTOX will have already screened out most such studies. The Eco-SSL criteria will also screen specifically for ESV development.

Table 2-4 Literature Exclusion Criteria

Criteria	Description
Contaminant Fate	Fate and transport of substance in the environment (only).
Human Health	Human or primate subjects.
In Vitro	In-vitro studies, including cell cultures and excised tissues.
Chemical Methods	Methods for measuring contaminants.
Modeling	Only modeling results reported.
No Species	No viable plant or animal present or tested.
No Effect	No effect was reported for a biological test species.
Published As	Study is not the primary source or author states information is published in another source.
QSAR	Data developed only from quantitative-structure activity relationships.
Review	Data reported are not primary data.
Mixture	Adverse effects are caused by a single chemical stressor (i.e., no mixture testing in laboratory studies.
Survey	Assessment of toxicity in the field over a period of time.

We will subject studies passing study exclusion criteria (Table 2-4) to a further acceptance evaluation applying the criteria listed in Table 2-5, which are modified Eco-SSL criteria (EPA 2005). Studies will not be considered acceptable for deriving ESVs if they lack key experimental information such as species, exposure concentration and duration, or if the study did not use controls (Table 2-5). We will identify literature that does not meet the acceptance criteria in our database, along with the reason for the exclusion.

Table 2-5 Study Acceptance Criteria

1. Either the test species' scientific name, common name, variety, or strain is reported.
2. The chemical form and concentration are reported.
3. Nominal and measured dose or concentration is reported, or able to be calculated from information given.
4. The duration of the exposure is reported.
5. Study used a control(s).
6. At least three treatment levels are used (i.e., control plus two chemical exposures).
7. Control mortality (or other endpoint under investigation) is acceptable based on the species and endpoint under consideration.
8. A calculated endpoint is reported (e.g., LC_{50}, LOAEL, NOAEL).
9. Study effects are ecologically relevant endpoints related to growth, mortality, and reproduction.
10. Administered doses are provided or can be calculated from the information provided in the study (wildlife only).

Literature that passes the exclusion and acceptance criteria in Tables 2-4 and 2.5, respectively, will potentially be used to derive ESVs (Figure 2-1). We will apply additional evaluation criteria to score the quality of the studies to identify the studies from which to extract toxicity values for deriving ESVs and for characterizing the uncertainty of the derived values (Figure 2-1). The following sections describe this process.

2.4 Data Extraction and Evaluation

2.4.1 Plants and Soil Invertebrates

2.4.1.1 Ecologically Relevant Endpoints for Plants and Soil Invertebrates

To develop PFAS ESVs for plants and soil invertebrates, we will extract data from studies that passed the evaluations described above for ecologically relevant effects, which is based on the process outlined in Attachment 3-1 of the Eco-SSL Guidance (EPA 2005). For soil invertebrates, relevant effects are reproduction, mortality, and growth. For plants, relevant effects are growth and effects related to physiology, which includes net photosynthesis, chlorophyll content, deformation, membrane damage, desiccation dormancy measures, flowering, and senescence (EPA 2005).

For soil invertebrates, if a particular study reports toxicity values for different effects, the order of preferred effects for computing screening values will be reproduction > growth > mortality (EPA 2005).

For plants, effects on growth, as typically determined by biomass are preferred, with the physiology effects secondary to effects on biomass (EPA 2005).

2.4.1.2 Toxicity Parameters for Plants and Soil Invertebrates

Toxicity values preferred for deriving ESVs for plants and soil invertebrates are, in order, EC_{20} > MATC > EC_{10}. The MATC (maximum acceptable threshold concentration) is the geometric mean of the NOAEL and LOAEL. $EC_x < 5$ values are less preferred, because they are difficult to measure experimentally, while LC_{50} and EC_{50} values are not sufficiently protective of ecological resources. Similarly, unbounded NOAEL and LOAEL values are not acceptable for deriving ESVs, because they do not reliably identify a threshold of effects (i.e., a dose-response). If a given study identifies more than one adverse effect, we will use the use the effect with the lowest exposure concentration.

2.4.1.3 Evaluating and Scoring Studies for Plants and Soil Invertebrates

To identify the highest quality studies on which to base our derivation of ESVs for invertebrates and plants, we will systematically evaluate and score each accepted study against the nine scoring criteria outlined in Attachment 3-2 of the Eco-SSL Guidance (EPA 2005), with minor revisions to scoring Criterion 1, bioavailability, to account for differences in uptake behavior for PFAS as compared to that for metals and non-ionic organics for which the Eco-SSL Guidance (EPA 2005) was written. The nine scoring criteria are presented in Table 2-6.

Table 2-6 Summary of Nine Study Evaluation and Scoring Criteria for Applicability to Plant and Soil Invertebrate Development of PFAS ESVs

Criterion	Rationale	Scoring
1: Testing Was Done under Conditions of High Bioavailability	Bioavailability of metals and polar organic compounds is influenced by pH and soil organic matter, cationic exchange capacity, and clay content. The scoring is intended to favor relatively high bioavailability	Scores were based on the bioavailability matrix (see Chapter 2). Scored 2 if bioavailability of natural soil was high or very high. Scored 1 for natural soil with medium bioavailability or standard artificial soil. Scored 0 for natural soil with low and very low bioavailability.
2A (laboratory) and 2B (field): Experimental Designs for Studies Are Documented and Appropriate	Experimental design can significantly influence the quality of a study. Higher quality studies will use an experimental design sufficiently robust to allow analysis of the test variables and discriminate non-treatment effects.	Scored based on experimental design and methods used for statistical analyses. Scored 2, 1 or 0. Specific criteria used provided in Attachment 3-2 of EPA (2005).
3: Concentration of Test Substance in Soil Is Reported	The concentration of the contaminant tested must be reported unambiguously.	Scored 2 if measured concentrations were reported. Scored 1 for nominal concentrations and scored 0 in all other cases.

Table 2-6 Summary of Nine Study Evaluation and Scoring Criteria for Applicability to Plant and Soil Invertebrate Development of PFAS ESVs

Criterion	Rationale	Scoring
4: Control Responses Are Acceptable	Negative controls are critical to distinguish treatment effects from non-treatment effects.	Scored 2 if a standardized procedure were used and control values were within procedural guidelines or acceptable range (if non-standard procedure used). Scored 1 if results of control were not reported or were ambiguous. Scored 0 if control results were not within an acceptable range.
5: Chronic or Life Cycle Test Was Used	Chronic toxicity tests assessing long-term adverse sub-lethal impacts on the life-cycle phases of an organism are considered superior to acute toxicity tests.	Scored 2 if chronic exposures were used. Scored 1 if acute tests were used. Scored 0 if very short-term exposures were used.
6: Contaminant Dosing Procedure Is Reported and Appropriate for Contaminant and Test	Contaminant dosing procedure may affect the outcome of a test. Dosing procedure should include: (A) the form of the contaminant; (B) the carrier or vehicle (e.g., solvent, water); (C) how the carrier was dealt with following dosing (i.e., allowed to volatilize, controls); (D) procedure for mixing of soil with contaminant (homogeneity).	Score applied based on how well the study reports the four contaminant dosing procedures (A to D). Scored 2 if study reported all. Scored 1 if information for items A and B, but not C or D; Scored 0 if details were not provided and could not be inferred.
7: A Dose-Response Relationship Is Reported or Can Be Established from Reported Data	Two methodologies can be used to identify this benchmark concentration. The first method generates a NOAEC and a LOAEC. The second method uses a statistical model to calculate a dose-response curve and estimate an effect concentration for some percentage of the population (EC_x), usually between EC_5 and EC_{50}.	Scored 2 if an EC10- EC20; or a NOEC and LOEC were within a factor of 3. Scored 1 if the difference between the NOEC and LOEC was > 3× but < 10×. Scored 0 if an ECx was not reported or the difference between the NOEC and LOEC was > 10, or only a NOEC or LOEC was reported.

Table 2-6 Summary of Nine Study Evaluation and Scoring Criteria for Applicability to Plant and Soil Invertebrate Development of PFAS ESVs

Criterion	Rationale	Scoring
8: Statistical Tests Used to Calculate the Benchmark and the Level of Significance Were Described	Statistical tests and results reported in the study should be sufficient to determine the significance of the results.	Scored 2 if ANOVA or statistical method were based on a $P = 0.05$; or the 95% CI of the EC_x. Scored 1 if an ANOVA was completed but P level not provided or >0.05; or if EC data did not include the 95% CI or used a 90% CI. Scored 0 if a NOEC, LOEC, or EC/LC_x were not reported, or were reported without a description of the method used to calculate the values.
9: Origin of the Test Organisms Is Described	The results of a toxicity test can be influenced by the condition of the test organisms. Culture conditions should be maintained such that the organisms are healthy and have had no exposure above background to contamination prior to testing (inverts) or detailed information is provided about the seed stock (plants).	Scored 2 if the source and condition of the test organisms were known and described. Scored 1 for a noncommercial source not adequately described, or if insufficient information was provided about a commercial source. Scored 0 if organisms were from a known contaminated site, or insufficient information was provided on the commercial source.

Source: EPA (2005).

For evaluating a candidate study with respect to the bioavailability of PFAS under the study conditions, we will consider the properties of the test soils, as well as the complex sorption behavior of PFAS in soils, owing to their structure composed of an acidic head and a hydrophobic fluorinated hydrocarbon tail. PFAS in the study set, with pK_a values in the range of <2, will be predominantly in anionic, or deprotonated, form at environmental pH.

Most of the other nine Eco-SSL Guidance (EPA 2005) scoring criteria will have already been addressed in the selection and screening of papers, and thus, evaluated papers will tend to score on the high end of the scale. For example, all qualifying studies will have the concentration of test substance in soil reported (Criterion 3). Likewise, study acceptance criteria already address acceptable control responses (Criterion 4).

Scoring each of the nine criteria on a scale of 0, 1, or 2 yields a maximum possible score of 18. Studies will be categorized using total score into one of the following four categories, according to total score:

- Unacceptable
- Low
- Medium
- High

Studies scoring roughly 10 or less would not be included in ESV derivation, as those studies would to be lacking sufficient detail to allow us to evaluate the quality of the data. We expect few if any studies emerging from the study identification process using ECOTOX will score 10 or less. After we have scored all studies, we will bin acceptable studies in a post hoc fashion into one of the remaining low, medium or high categories for assessing and characterizing the overall quality and uncertainty of eventually derived ESVs. If information is not available from published studies to score a particular criterion, we will evaluate overall study quality to assign a qualitative score, including of unacceptable.

2.4.2 Terrestrial Wildlife

2.4.2.1 Wildlife TRVs

Argonne will use the PFAS TRVs developed by USAPHC as they become available. Argonne will derive TRVs for PFAS compounds if not available from USAPHC (Section 4). In identifying literature for use in calculating TRVs, ANL will use the EPA (2005) scoring criteria as a guideline to evaluate key indicators of study quality such as proper experimental design, statistical analysis, and the relevance of endpoint and exposure conditions (Table 2-7). Each scoring criteria can receive a score in the range of 0 to 10 and the final score will be the sum of all 10 criteria scores (100 is the highest score). A total score 66 or higher (66%), as identified in the Eco-SSL Guidance (EPA 2005), will be used as a rough cutoff for acceptable studies for deriving TRVs. As for plants and soil invertebrate studies in the previous section, after all studies have scored, we will bin all acceptable studies into low, medium and high-quality categories for the purpose of evaluating the uncertainty of derived ESVs.

Table 2-7 Summary of Scoring Criteria for Use in Developing Wildlife TRVs for PFAS[a]

Criteria	Scoring Basis	Score
Data Source	Primary source is acquired and reviewed	10
	Primary source is not acquired and reviewed	0
Consideration of Absorption Fraction and Contaminant Form	Contaminant form is known and is the same or similar to the of medium of concern	10
	Contaminant form is irrelevant to absorption or biological activity	10
	Contaminant form is known and is different from that found in the medium of concern	5
	Contaminant form is not reported (this includes situations when the contaminant is just listed as “Lead” or “Selenium”)	4
Test Substance Concentrations	Test substance concentrations reported as actual measured values, verified nominal and/or doses administered by gavage	10
	Test substance concentrations reported as nominal values	5
	Test substance concentrations not reported	0
Dose Quantification	Administered doses reported as mg/kg body weight (includes gavage doses reported in these units)	10
	Administered doses need to be calculated and intake rates and body weights provided	7
	Administered doses need to be calculated and only one value (intake or body weight) provided (if study is gavage or another capsule, intake is “provided”)	6
	Administered doses need to be calculated based on estimated intake rates and body weights	5
	Administered doses cannot be calculated from the information provided	0
Dose Range	Both NOAEL and LOAEL are identified; values are within a factor of 3	10
	Both NOAEL and LOAEL are identified; values are within a factor of 10	8
	Both NOAEL and LOAEL are identified; values are not within a factor of 10	6
	Only NOAEL or LOAEL is identified	4
	Study lacks a suitable control group	0
Dose Route	Chemical incorporated into food (including mother’s milk)	10
	Other oral (gavage, capsule)	8
	Chemical incorporated into drinking water	5
	Not dietary, other oral, or drinking water or not reported or choice of treated and non-treated food or water	0
Endpoint	Reported endpoint is a reproductive or population effect	10

Table 2-7 Summary of Scoring Criteria for Use in Developing Wildlife TRVs for PFAS[a]

Criteria	Scoring Basis	Score
	Reported endpoint is lethality (chronic or subchronic exposures)	9
	Reported endpoint is reduction in growth	8
	Reported endpoint is sublethal change in organ function, behavior or neurological function	4
	Reported endpoint is a biomarker of exposure with unknown relationship to fitness	1
Exposure Duration	Exposure duration encompasses multiple life stages of test species	10
	Exposure duration is at least 0.1 times the expected life span of the test species or occurs during a critical life phase	10
	Exposure duration is shorter than 0.1 times the expected life span of the test species and multiple doses or concentrations are administered	6
	Exposure duration is shorter than 0.1 times the expected life span of the test species and only a single dose or concentration is administered.	3
	Exposure duration is acute or not reported	0
Statistical Power	At least 90% chance of seeing a difference that is biologically significant	10
	NOAEL and LOAEL available or LOAEL only available	10
	At least 75% chance of seeing a difference that is biologically significant	8
	At least 50% chance of seeing a difference that is biologically significant	6
	Less than a 50% chance of detecting a difference that is biologically significant	3
	Only NOAEL available; insufficient data reported to determine statistical power of study	1
Test Conditions	Follows a standard guideline and reports all test parameters	10
	Does not follow a standard guideline, but does report all test parameters	10
	Follows a standard guideline but does not report test parameters	7
	Does not follow a standard guideline and reports some, but not all of the test parameters	4
	Does not report any test parameters	2

[a] In the derivation of the reported ESVs, scoring of wildlife studies was not conducted using the criteria in this table given the study reviews separately conducted by the USAPHC in their development of TRVs for several PFAS, which were adopted, and due to the limited number of studies available for the remaining PFAS.

Source: EPA (2005).

2.4.3 Aquatic Life and Aquatic-Dependent Wildlife

2.4.3.1 Aquatic Life

We will adapt appropriately the criteria in Table 2-7, developed for wildlife TRVs (EPA 2005) to evaluate studies on aquatic life. The criteria in Table 2-7 represent good toxicological practice, independent of exposure media or receptors. Criteria for dose quantification and dose route will be adapted to aquatic exposures. We will apply the same binning process described above to categorize study quality. We will also consider the following guidelines on the collection of data from the Guidance (Stephens et al. 1985):

- Collect all available data on the material concerning (a) toxicity to, and bioaccumulation by, aquatic animals and plants; (b) FDA action levels 12; and (c) chronic feeding studies and long-term field studies with wildlife species that regularly consume aquatic organisms.
- All data that are used should be available in typed, dated, and signed hard copy (publication, manuscript, letter, memorandum, etc.) with enough supporting information to indicate that acceptable test procedures were used and that the results are probably reliable.
- Questionable data, whether published or unpublished, should not be used. For example, data should usually be rejected if they are from tests that did not contain a control treatment, tests in which too many organisms in the control treatment died or showed signs of stress or disease, and tests in which distilled or deionized water was used as the dilution water without addition of appropriate salts.
- Data on technical grade materials may be used if appropriate, but data on formulated mixtures and emulsifiable concentrates of the material of concern should not be used.
- For some highly volatile, hydrolyzable, or degradable materials it is probably appropriate to use only results of flow-through tests in which the concentrations of test material in the test solutions were measured often enough using acceptable analytical methods.
- Data should be rejected if they were obtained using:
    - Brine shrimp, because they usually only occur naturally in water with salinity greater than 35 g/kg.
    - Species that do not have reproducing wild populations in North America.
    - Organisms that were previously exposed to substantial concentrations of the test material or other contaminants.
- Questionable data, data on formulated mixtures and emulsifiable concentrates, and data obtained with non-resident species in North America or previously exposed organisms may be used to provide auxiliary information but should not be used in the derivation of criteria.

2.4.3.2 Wildlife Exposures through Aquatic Pathways

To derive a Tier I wildlife ESVs for aquatic pathways, sufficient toxicity data are needed so that sub-chronic or chronic dose-response curves can be developed for each of the representative mammalian and avian species. The preferred study types used to develop dose-response curves are shown in Table 2-8.

Table 2-8 Criteria for Selecting/Rejecting Data for use in Developing Aquatic ESVs for the Protection of Wildlife

1. Data from peer-reviewed field studies of wildlife species takes precedence over other types of studies.
2. An acceptable field study must be of sub-chronic or chronic duration, provide a defensible, chemical-specific dose-response curve in which cause and effect are clearly established, and assess acceptable endpoints (reproduction, growth, and mortality).
3. If acceptable wildlife field studies are not available, the necessary toxicity information may come from peer-reviewed laboratory studies
4. To reduce uncertainties in making interspecies extrapolations, when laboratory studies are used preference will be given to laboratory studies with wildlife species rather than traditional laboratory animals.
5. All available laboratory data and field studies will be reviewed to assess the reasonableness of the toxicity value used, and the appropriateness of any uncertainty factors (UFs) that were used in the studies.
6. The mammalian data must come from at least one well-conducted study of 90 days or greater and designed to observe sub-chronic or chronic effects as defined in this document
7. The avian data must come from at least one well-conducted study of 70 days or greater and designed to observe sub-chronic or chronic effects as defined in this document
8. Studies involving exposure routes other than oral will be considered but only if an equivalent oral daily dose can be estimated and technically justified
9. Preference will be given to studies assessing effects on developmental or reproductive endpoints.

Source: EPA (1995a)

The Technical Support Document for developing wildlife criteria for the Great Lakes (EPA 1995b) provides additional discussion on the selection of appropriate toxicity studies.

2.5 References

Deck, A.T., and M.S. Johnson. 2015. “Methods for Derivation of Wildlife Toxicity Values for Use in Ecological Risk Assessments,” Chapter 2 in: *Wildlife Toxicity Assessments for Chemicals of Military Concern* (M. Williams et al., eds.). Elsevier, Waltham, MA.

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EPA. 2005. *Guidance for Developing Ecological Soil Screening Levels*. Washington, DC: U.S. Environmental Protection Agency. OSWER Directive 9285.7-55.

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Stephen, C.E., D.I. Mound, D.J. Hansen, J.R. Gentile, G.A. Chapman, and W.A. Brungs. 1985. *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses*. PB85-227049. Prepared by U.S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratories, Duluth, MN.

3 DERIVATION OF SOIL ESVs FOR TERRESTRIAL PLANTS AND SOIL INVERTEBRATES

3.1 Data Extraction and Scoring

Section 2 of this report describes the process and acceptance criteria that will be used to identify potentially acceptable studies for developing screening levels. For toxicology studies that meet our ESV acceptance criteria (Table 2-5), we will extract and score toxicity data for both plants and soil invertebrates following the process outlined in Section 2.4.1, which is based on EPA's Eco-SSL guidance (EPA 2005). Soil concentrations will be converted, if necessary, to a dry weight using reported soil moisture content; PFAS concentrations will be based on the molecular weight of the PFAS acids, not on that of a salt, if used in studies.

3.2 Derivation of ESVs

We will compute ESVs for both plants and soil invertebrates as the geometric mean of the toxicity values selected from qualifying studies, a calculation which requires a minimum of three values. We will give preference to studies in natural soil with the highest bioavailability for PFAS. If only one or two qualifying studies are available, we will use the single value or arithmetic mean, respectively.

We will evaluate bioavailability of PFAS in soils based loosely on Eco-SSL Guidance, Attachment 3-2 (EPA 2005), which accounts for soil pH and sorbate (PFAS) sorption constants (Log Koc). The derivation will use the preferred toxicity values: EC_{20}, MACT (bounded LOAEL/NOAEL), and EC_{10} (Section 2.4.1.2).

3.3 References

EPA (U.S. Environmental Protection Agency). 2005. *Guidance for Developing Ecological Soil Screening Levels*. Washington DC: U.S. Environmental Protection Agency. OSWER Directive 9285.7-55.

4 DERIVATION OF SOIL ESVs FOR WILDLIFE

Methods for deriving soil based PFAS ESVs for wildlife generally follow EPA guidance for developing ecological soil screening levels (EPA 2005). This section describes methods and assumptions that will be used to develop soil based PFAS ESVs for wildlife including:

1. Wildlife ingestion models for estimating exposure to wildlife from PFAS compounds in soil (Section 4.1);
2. Derivation of wildlife TRVs for PFAS compounds (Section 4.2); and
3. Identification of soil based PFAS ESVs for wildlife (Section 4.3)

Section 2 of this report describes our process and acceptance criteria for identifying potentially acceptable studies for developing the soil ESVs for wildlife.

4.1 Wildlife Ingestion Exposure Modeling

Modeling to estimate wildlife exposure doses will be consistent with methods described in EPA's guidance for developing ecological soil screening values for wildlife (EPA 2005).

4.1.1 Calculation of Ingestion Exposures

The general equation that will be used for estimating soil-based contaminant exposure to wildlife through ingestion of food items and incidental soil ingestion is:

$$\mathrm{ED}_j = \left(\left[\mathrm{Soil}_j * P_s * \mathrm{FIR} * \mathrm{AF}_{js}\right] + \sum_{i=1}^{N}\left[B_{ij} * P_i * \mathrm{FIR} * \mathrm{AF}_{ij}\right]\right) * \mathrm{AUF} \qquad \text{(Equation 4-1)}$$

where:

ED_j = Ingestion dose for contaminant (*j*) (milligram contaminant per kilogram organism bodyweight per day),
Soil_j = Concentration of contaminant (*j*) in soil (mg/kg dry weight),
N = Number of different biota types in diet (see Table 4-1),
B_{ij} = Concentration of contaminant (*j*) in biota type (*i*) (mg/kg dry weight) (see Section 4.1.3),
Pi = Proportion of biota type (*i*) in diet (value from 0 to 1) (see Table 4-1),
FIR = Food ingestion rate (kilogram food [dry weight] per kilogram organism bodyweight [wet weight] per day) (see Table 4-1),
AF_{ij} = Absorbed fraction of contaminant (*j*) from biota type (*i*) (for screening purposes set equal to 1),
AF_{js} = Absorbed fraction of contaminant (*j*) from soil (*s*) (for screening purposes set equal to 1),
P_s = Soil ingestion as proportion of diet (see Table 4-1),
AUF = Area use factor (for screening purposes set equal to 1).

Using this equation, exposure from incidental soil ingestion is added to the total dietary (food-based) exposure, resulting in a total oral exposure greater than 100%. This equation includes terms for the absorbed fraction (AF) of the contaminant from soil and the diet as well as an area use factor (AUF) that represents the fraction of time an animal would be exposed); for calculation of PFAS ESVs, which are intended to be conservative screening values, AF and AUF are set equal to 1. Although some ecological risk assessments consider seasonal changes in proportions of food items in the diet by applying seasonal use factors (SUFs), this will not be considered in development of PFAS wildlife screening values (i.e., SUF would be equal to 1 for all diet items).

The concentration of contaminants in specific types of biota eaten in the diet will be estimated as described in Section 4.1.3.

4.1.2 Selection of Surrogate Wildlife Receptors

Consistent with EPA Eco-SSL Guidance for developing ecological soil screening values (EPA 2005), surrogate species will be used to derive the soil based PFAS wildlife ESVs. These surrogate species are considered to be representative of other species within the same class (mammalian or avian) that have similar diets.

The purpose of focusing on representative species within generic trophic groups is to develop a set of generic screening values that would be protective of the great majority of species present at any site, regardless of the presence or absence of a particular species. The trophic groups for which screening levels will be developed are expected to be present or potentially present at most sites where PFAS ESVs will be applied. Applying this approach will provide results useful for comparing risks associated with different exposure routes (e.g., ingestion of food versus ingestion of soil) and different contaminant transport pathways (e.g., soil to herbivore, soil to ground insectivore, soil to soil invertebrate, and soil to plant). In addition, the use of surrogate receptors is consistent with *Ecological Risk Assessment Guidance for Superfund* (ERAGS), which states: “for the screening-level ERA, assessment endpoints are any adverse effects on ecological receptors, where receptors are plant and animal populations and communities, habitats, and sensitive environments” (EPA 1997).

Consistent with the Eco-SSL guidance (EPA 2005), herbivore, ground insectivore, and carnivore trophic groups for both mammals and birds will be used for the PFAS ESV wildlife exposure models. Within each of these trophic groups, uptake for a surrogate species will be modeled in order to provide a conservative representation for their respective trophic groups. These species (Table 4-1) are generally small in size relative to other species within their respective trophic groups. Because small size is generally associated with higher metabolic rates and smaller home ranges, exposure for small receptors on a bodyweight basis is assumed to be high and ESVs based on these species are likely to be protective of larger species of mammals and birds in the same trophic groups (EPA 2005).

Table 4-1 Surrogate Wildlife Receptors and Exposure Model Parameters for Developing Soil-Based PFAS ESVs[a]

Receptor Group (Surrogate Species)	Assumed Diet	Food Ingestion Rate[b] (FIR, kg dw/kg bw/ day)	Soil Ingestion[c] (P_s)
Mammalian Herbivore (Meadow Vole)	100% foliage	0.0875	0.032
Mammalian Ground Invertivore[d] (Short-tailed shrew)	100% earthworms	0.209	0.030
Mammalian Carnivore (Long-tailed weasel)	100% small mammals	0.130	0.043
Avian Granivore (Mourning dove)	100% seeds	0.190	0.139
Avian Ground Invertivore (American woodcock)	100% earthworms	0.214	0.164
Avian Carnivore (Red-tailed hawk)	100% small mammals that consume 100% earthworms	0.0353	0.057

[a] Source: EPA (2005).
[b] High end point estimate based on measured data (see EPA 2005, Attachment 4-1, for derivation).
[c] Soil ingestion as proportion of diet (see EPA 2005, Attachment 4-1, for derivation); dw = dry weight.
[d] Uptake for insectivores will be estimated in the models by assuming earthworm prey.

Table 4-1 presents the surrogate species upon which soil-based PFAS ESVs for wildlife will be based, along with the assumed diets and food and soil ingestion rates for parameterizing the associated wildlife exposure models. Included are three mammalian and three avian species that are intended to represent highly exposed species. It is assumed that identification of ESVs for these six species will also be protective of other species of herbivores, ground invertivores, and carnivores (EPA 2005). FIRs for modeling contaminant uptake by surrogate wildlife receptors, as identified in Table 4-1, are values identified in the Eco-SSL Guidance (EPA 2005); those values were based on typical and high-end food intake rates for each of the surrogate species and were compiled from the Wildlife Exposure Factors Handbook (EPA 1993) and from other available sources.

4.1.3 Estimating Contaminant Concentrations in Dietary Items

Concentrations of PFAS compounds in biota serving as food items (B_{ij}; Equation 4-1) in wildlife diets (plants, earthworms, or small mammals as indicated in Table 4-1) will be estimated by assuming that the concentration of compound *j* in food type *i* can be predicted from the concentration of the contaminant in the soil (Soil_j; Equation 4-1). However, the nature of the relationship between soil concentrations and the resulting tissue concentrations in organisms is not always proportional to soil concentrations (see, e.g., Sample et al. 2014) and can take a variety of forms, including constant, log-linear, or linear (EPA 2005).

Recognizing this, the estimation of the concentration of PFAS compounds in tissues of prey organisms will be estimated using a hierarchical decision process described in the Eco-SSL Guidance (EPA 2005). Thus, in order of preference, the tissue concentration values in prey items will be derived using:

1. Existing regression equations identified from the literature;
2. New regression equations developed using paired data pertaining to contaminant concentrations in tissues relative to (a) concentrations in soil (for invertebrate and plant food items) or (b) relative to concentrations in food eaten by small mammals that are then prey for mammalian or avian receptors);
3. Ratios of contaminant in soil to contaminant in food items (i.e., bioaccumulation factors, BAFs) from the literature or from paired data identified during attempts to develop new regressions (item 2, above); or
4. Other assumptions about bioaccumulation of contaminants from soil into tissues of food items.

4.2 Derivation of Wildlife TRVs

For the development of ecological soil screening values, the EPA (2005) defines a wildlife TRV as follows:

> *Dose above which ecologically relevant effects might occur to wildlife species following chronic dietary exposure and below which it is reasonably expected that such effects will not occur.*

Thus, wildlife TRVs are derived estimates of threshold levels above which chemical doses or concentrations result in adverse effects on wildlife species (Allard et al. 2010). In practice, TRVs are compared to calculated or measured chemical exposure estimates for specific sites to determine whether wildlife species may be adversely affected. In most cases, chemical-specific TRVs for avian and mammalian wildlife are derived from, and compared to, oral exposure estimates in order to predict the potential for adverse effects on avian and mammalian wildlife (Allard et al. 2010).

Derivation of PFAS TRVs for wildlife will follow technical guidance developed by U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM 2000), as informed by EPA's GLI guidance on selecting uncertainty factors (see Sec 6.2.2). USAPHC is currently in the process of developing draft wildlife TRVs for some PFAS compounds following this process and, unless there is a clear need to update these values, wildlife TRVs for PFAS compounds developed by the USAPHC will be adopted directly in the derivation of soil ESVs.

Three principal approaches are used to develop TRVs for wildlife, in descending order of preference: (1) the benchmark dose approach, (2) the NOAEL/LOAEL approach, and (3) the approximation approach (Williams et al. 2015; USACHPPM 2000). For the derivation of PFAS TRVs for wildlife, the benchmark dose approach will be preferred as long as adequate information is available to apply this method, which is the most data intensive of the three. In cases where insufficient data are available for developing benchmark doses, the NOAEL/LOAEL approach, followed by the approximation dose approach will be applied, according to data availability. For some PFAS compounds, there may be insufficient or inadequate data for development of TRVs using any of these methods. Sections 4.2.1 through 4.2.3 describe methods and assumptions for identifying PFAS wildlife TRVs using these three approaches.

Under all three approaches, low and high TRV values will be identified to bracket the range between exposure levels at which no observed adverse effects are expected to occur and levels at which adverse effects are expected to begin to occur.

4.2.1 Benchmark Dose Approach

The benchmark dose approach refers to the use of dose–response relationships to identify specific benchmarks or thresholds of effects to be used as the basis for developing TRVs (Mayfield and Skall 2018; Williams et al. 2015; USACHPPM 2000; EPA 2012).

The benchmark dose approach fits curves to dose-response data from the available relevant toxicity data and endpoints and takes variation in the measurement of endpoints into account (EPA 2012; Mayfield and Skall 2018). Preferred endpoints will be those that are considered relevant to population level effects (USACHPPM 2000) and biologically significant (Mayfield and Skall 2018). Endpoint variation is captured by identifying low and high TRV estimates for each representative wildlife receptor-toxicant combination. When possible, the low-value TRV will be based on the lower 95% confidence interval for a 10% effect level (i.e., a dose about which there is 95% confidence that 10% or fewer animals are expected to exhibit an adverse effect) as described in USACHPPM (2000). Alternatively, low-TRV values can be based on the lower 95% confidence level based on one standard deviation from the control mean if suitable ranges of values are not available for a particular test species (Mayfield and Skall 2018). Depending on the available data derived from suitable studies, the high-value TRVs for avian and mammalian wildlife species will be calculated as either (1) the dose that corresponds to the estimated 10% population effect level or (2) as the value on the best-fit dose-response curve that represents the threshold level where adverse effects would be expected. TRVs that specifically consider assessment endpoints related to mortality, reproduction, or growth for avian and mammalian wildlife will be developed.

Use of the benchmark dose approach is preferred because it considers all the suitable data available for a specific endpoint from relevant studies and plots a best-fit dose-response function that can most reliably identify a concentration that results in a threshold-level of unacceptable effects. However, development of wildlife TRVs using dose–response relationships can be challenging because datasets available for examining a variety of exposure levels and species are limited (Mayfield and Skall 2018), especially for emerging contaminants such as PFAS.

As described in the following sections, the principal steps for identifying a benchmark dose include:

1. Data evaluation, which includes the selection of studies and endpoints for developing benchmark dose calculations;
2. Identification of a benchmark response (BMR) value; and
3. Selecting, assessing, and running the appropriate model(s) to compute the benchmark dose and associated confidence limits.

4.2.1.1 Evaluation of Data

The EPA has not developed specific guidance for use of the benchmark dose modeling for derivation of TRVs for wildlife. However, the process of developing benchmark doses for wildlife TRVs can be informed by technical guidance developed for application to human health risk assessments (EPA 2012), as well as frameworks specific to developing wildlife TRVs (e.g., Mayfield and Skall 2018; Mayfield et al. 2014). The first step is to evaluate whether the available data are adequate for developing benchmark doses for the PFAS compounds of concern, appropriate wildlife species, and ecologically relevant endpoints related to mortality, reproduction, or growth for relevant wildlife species. Steps followed to evaluate the feasibility of conducting benchmark dose modeling for PFAS effects on wildlife will be consistent with recommendations provided by EPA (2012), as shown in Figure 4-1.

Studies involving multiple dose groups and exhibiting a graded monotonic response with dose will generally be most useful for benchmark dose analysis. Studies that identify only a single dose level that elicits a response compared to controls will generally not support benchmark dose analysis, although there may be exceptions (EPA 2012). Studies with one or multiple doses near the BMR level are preferable for estimating benchmark doses.

Selection of studies for benchmark dose analysis will be based on the quality of the studies, the adequacy of the results and data reported in the study, and the ecological relevance of the endpoints examined in the study. The process of selecting and scoring studies will ultimately determine whether sufficient high-quality data are available for benchmark dose analysis for wildlife species for specific PFAS compounds. All the suitable relevant studies will be considered for dose-response modeling. Combining several datasets may be an option when the datasets are determined to be statistically and biologically compatible (see EPA 2012 for additional information).

Ecologically relevant endpoints related to mortality, reproduction, or growth from studies judged to provide suitable datasets will be considered for modeling. This will help ensure that no sensitive endpoints are excluded from the analysis. The EPA (2012) recommends that, at a minimum, datasets used for benchmark dose modeling should: (1) establish statistically

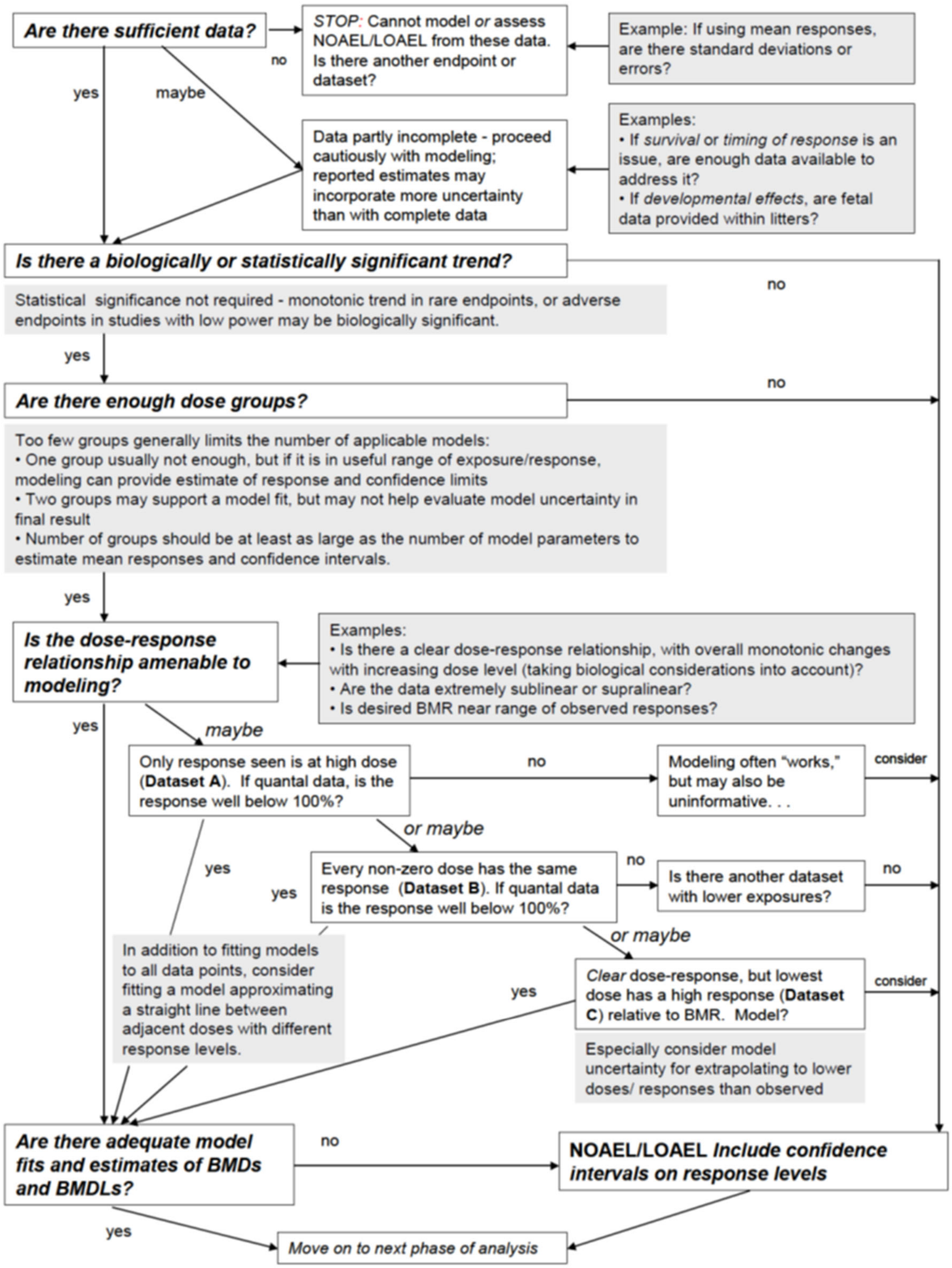

Figure 4-1 Steps for Evaluating Data Suitability and Feasibility of Benchmark Dose Modeling (source: EPA 2012). Datasets A, B, or C refer to examples illustrated in EPA (2012), Figure 2B.

or biologically significant dose-related trends for the selected endpoints and (2) contain information about the dose-response relationship that fall between the control level and the maximal response level.

4.2.1.2 Identification of a BMR Value

The BMR value is defined as a predetermined change in the response rate of an adverse effect relative to the background response rate of the effect. The BMR value identifies the level of change from the background response that represents an adverse effect when calculating benchmark doses and when calculating lower and upper confidence limits (BMDLs and BMDUs, respectively) for the calculated benchmark doses. For the purposes of identifying benchmark doses for PFAS TRVs for use in developing soil ESVs, a default response level of 10% will be selected for each of the assessment endpoints (mortality, reproduction, or growth) for the wildlife species, especially birds and mammals. This would result in identification of a TRV range that extends from an ED_{10} at the upper bound to the lower 95% confidence limit of the ED_{10} as the lower bound. Under these benchmarks, it would be anticipated that 90% of individuals in an exposed population will not experience adverse effects at exposures at the estimated benchmark dose level (USACHPPM 2000). Specific statistical approaches may be adopted during analysis based on further discussions with the interagency work group.

4.2.1.3 Modeling the Benchmark Dose

Determining a benchmark dose involves fitting a mathematical model to dose-response data in a manner that most adequately describes the dataset, especially at the lower end of the observable dose-response range. Such mathematical fitting of the dose-response relationships allows estimates of uncertainty associated with doses corresponding to the identified BMR (Section 4.2.1.2). In practice, this procedure involves selecting a family (or families) of models for consideration, based on characteristics of the data and experimental design, and fitting the models using one of a few established methods. Various considerations for model selection, model fitting, assessing how well the calculated models describe the data, improving model fit, comparing models, and calculating confidence limits to obtain a BDML are presented in EPA (2012) and Mayfield and Skall (2018).

The EPA's Benchmark Dose Software (BMDS; EPA 2018) may be used to conduct benchmark dose modeling for identifying PFAS wildlife TRVs. EPA developed the BMDS (currently BMDS version 3.0; EPA 2018) as a tool to facilitate the application of benchmark dose methods to hazardous pollutant risk assessments; BMDS is consistent with the EPA's Benchmark Dose Technical Guidance Document (EPA 2012, 2018). BMDLs and benchmark doses derived using the benchmark dose approach will be used as the preferred low- and high-range TRVs (functionally equivalent to NOAELs and LOAELs, respectively) for the development of PFAS soil ESVs as described in Section 4.4.

4.2.2 NOAEL/LOAEL Approach

The NOAEL/LOAEL approach uses NOAEL and LOAEL values from relevant studies pertaining to ecologically relevant endpoints for the wildlife groups of interest to determine the TRV values for each chemical of concern (USACHPPM 2000).

As described in the following sections, the principal steps for identifying TRVs from NOAEL/LOAEL information include:

1. Identify studies that contain adequate data for applying the NOAEL/LOAEL approach for the contaminants, endpoints, and wildlife groups of interest;
2. Extract NOAEL and LOAEL values from the relevant studies and segregate and plot the values according to contaminants, endpoints, and wildlife groups; and
3. Derive LOAEL-based and NOAEL-based TRVs from extracted or plotted data.

4.2.2.1 Evaluation of Data

The toxicological literature identified from the literature search as described in Section 2 will be reviewed for applicability to establishing wildlife TRVs for PFAS compounds. As with the benchmark dose approach, the NOAEL/LOAEL approach will use chronic studies, not acute or subacute toxicity studies (i.e., studies with exposures of 3 days or less in duration). By excluding acute toxicity data, the developed TRVs will identify doses protective of most species from adverse effects associated with long-term exposures and sublethal reproductive and growth effects (EPA 2005). Chronic studies include exposure durations of sufficient length to reveal most adverse effects that will occur, or would be expected to occur, over the lifetime of an exposed organism (EPA 1985).

TRVs will be developed using all the relevant toxicological data from appropriate studies; use of a single study will be avoided. In addition, wildlife TRVs will only be derived from oral dose response data because such data are more relevant to establishing soil screening levels that will be protective of potential exposures from ingestion of soil or food. Following Eco-SSL Guidance (EPA 2005), the required dataset will consist of at least three NOAEL or LOAEL results for at least two test species for either growth, reproduction or mortality effects.

Attachment 4-4 of the Eco-SSL Guidance (EPA 2005) provides a data evaluation scoring system based on 10 attributes of evaluated toxicological studies. This scoring system will be adopted for the development of PFAS soil ESVs. Any study endpoints receiving a total data evaluation score of 65 or less of a possible 100 will not be used to derive TRVs.

4.2.2.2 Sorting and Plotting Toxicological Data

NOAEL and LOAEL data extracted from relevant studies will be depicted in summary plots for each of the target PFAS compounds sorted by endpoints relevant to mortality, reproduction, and growth; mammalian and avian toxicological data will be presented on separate plots. Attachment 4-5 of the Eco-SSL Guidance (EPA 2005) provides examples of summary plots.

Such plots allow comparisons of the relative results for different species, as well as results from the same study.

4.2.2.3 Deriving TRVs

Following the USAPHC guidance (USACHPPM 2000), the minimum dataset for deriving a wildlife TRV using the NOAEL/LOAEL approach consists of (1) three studies of sufficient quality addressing relevant endpoints (Table 2-2), which collectively provide data for three or more species within a taxonomic class; (2) data for at least two different taxonomic orders; and (3) at least two chronic LOAELs and at least one chronic NOAEL. Relevant effects relate to population sustainability and include mortality, reproduction, development, and growth. If these minimum dataset requirements are met for the wildlife group of interest, then the PFAS-specific wildlife TRVs will be selected from the relevant studies using the NOAEL/LOAEL TRV derivation process identified in the same guidance (USACHPPM 2000). The LOAEL-based TRV will be the lowest documented LOAEL from the chronic mortality, reproduction, or growth endpoints. The NOAEL-based TRV will be selected from the highest NOAEL that is lower than the selected LOAEL within the same endpoint group as the selected LOAEL. If a NOAEL from the same endpoint is unavailable, then the highest NOAEL that is less than the selected LOAEL within all relevant endpoints will be selected as the NOAEL-based TRV.

4.2.3 Approximation Approach

The approximation approach will be used if the minimum data requirements for either the benchmark dose or NOAEL/LOAEL are not met (USACHPPM 2000). When the requirements are not satisfied, the available toxicity data are insufficient to characterize toxicity for a class of animals (i.e., mammals or birds) with an appropriate degree of certainty. In such cases, uncertainty factors will be applied to develop TRVs until more toxicity data are available.

The most relevant and reliable study in terms of quality and applicability will be used to approximate TRVs from the NOAEL and LOAEL for a given PFAS. These TRVs will be derived by dividing the NOAEL and LOAEL of interest by an appropriate uncertainty factor. When multiple uncertainty factors are required, the NOAEL and LOAEL will be divided by the product of the uncertainty factors. Extrapolation from a single study or from data that may be unreliable given an understanding of the study design (e.g., power of the statistical comparisons) may not be appropriate. Professional judgment will determine whether development of TRV approximations from limited data is justified.

The uncertainty factors that are applied to develop TRVs using this approach account for potential differences in responses due to (1) species-specific differences, (2) differences in exposure duration (e.g., acute versus chronic exposures), and (3) differences in endpoints (e.g., lethality versus non-lethal effects). A general uncertainty factor of 10 will be used to account for potential interspecies differences for the development of TRVs for wildlife. Table 4-2 presents additional uncertainty factors compiled by USAPHC (USACHPPM 2000) to account for differences in test exposure duration and endpoint, which will be applied as appropriate.

Table 4-2 TRV Uncertainty Factors to Account for Differences in Response Due to Exposure Duration and Endpoint

	Uncertainty Factor Used to Develop TRV	
Type of Data Available	**NOAEL-based TRV**	**LOAEL-based TRV**
Chronic NOAEL	1	NA[a]
Chronic LOAEL	10	1
Subchronic LOAEL	10	NA
Subchronic LOAEL	20	4
Acute NOAEL	30	NA
Acute LOAEL	50	10
LD_{50}	100	20

[a] NA = not appropriate.

Source: USACHPPM (2000).

4.3 Derivation of Wildlife ESVs

The basic equation for estimating potential risks to wildlife from contaminant exposure is:

$$Hazard\ Quotient\ (HQ) = \frac{Exposure\ Dose\ (\frac{mg}{kg\ bw}/day)}{TRV\ (\frac{mg}{kg\ bw}/day)} \qquad \text{(Equation 4-2)}$$

where both the calculated exposure dose (see Section 4.1) and the TRV (Section 4.2) are expressed in the same units (i.e., milligrams of contaminant per kilogram of organism bodyweight per day). Using this relationship, the soil-based wildlife ESVs for PFAS compounds will be calculated as the soil concentration that results in a HQ = 1 (i.e., when the contaminant-specific TRV and exposure dose are equal). After setting the parameters for AF_{ij}, AF_{sj}, and AUF in the exposure dose equation (Equation 4-1) to 1, this relationship can be expressed as:

$$\mathrm{HQ}_j = \frac{[(\mathrm{Soil}_j * P_s * \mathrm{FIR}) + \sum_{i=1}^{N}[B_{ij} * P_i * \mathrm{FIR}]]}{\mathrm{TRV}_j} \qquad \text{(Equation 4-3)}$$

Where:

HQ_j = Hazard quotient for contaminant (*j*) in soil;

FIR = Food ingestion rate (kilogram food [dry weight] per kilogram organism bodyweight [wet weight] per day);

Soil_j = Concentration of contaminant (*j*) in soil (mg/kg dry weight);

P_s = Soil ingestion as proportion of diet;

Pi = Proportion of biota type (*i*) in diet;

B_{ij} = Concentration of contaminant (*j*) in biota type (*i*) (mg/kg dry weight); and

TRV_j = TRV for contaminant (*j*) (mg [dry weight]/kg bodyweight [wet weight]/day).

In addition, note that summation of the contribution of multiple diet items to ingestion exposure that is indicated in Equation 4-3 will not be necessary when the assumed diets of the modeled surrogate wildlife receptors consist of single types of food items as identified in Table 4-1 (and P_i in Equation 4-3 = 1). The general procedure for calculating the wildlife ESV for a contaminant (j) will be to solve Equation 4-3 to determine the concentration in soil ($Soil_j$) that results in an HQ_j equal to 1; that soil concentration will be identified as the soil ESV for wildlife. This process will be used to identify ESV values for each of the target PFAS compounds for each mammalian and avian wildlife receptor identified in Table 4-1. The final wildlife ESV for a specific PFAS compound, which is intended to be protective of all mammal and bird species, will be identified using the lowest of the species-specific ESVs for the PFAS compound.

4.4 References

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5 DERIVATION OF AQUATIC ESVs

The derivation of aquatic PFAS ESVs for the protection of aquatic biota and wildlife involves evaluation of available data for data quality and applicability, then using the applicable data to develop screening values. The methods to be used to develop the PFASs ESVs are based on in part, and consistent with, EPA methods for deriving numerical water concentrations for the protection of aquatic biota (Stephen et al. 1985; EPA 1995a). Similar approaches have been used by others to identify aquatic PFAS ecological screening values (e.g., Giesy et al. 2010; Salice et al. 2018).

A two-tiered (Tiers I and II) methodology will be employed to derive acute and chronic freshwater and marine ESVs, using data from multiple taxonomic groupings. This methodology is based on the 1995 Great Lakes Initiative methodology for aquatic life criteria (EPA 1995a), which itself is based on the EPA methodology for deriving national water quality criteria (Stephen et al. 1985). The Tier I methodology is based in part on the methodology for deriving national water quality criteria and requires a specific level and type of data. If sufficient data are not available, a Tier II methodology will be used to derive the screening levels. As the Tier II approach includes greater levels of uncertainty (due to reduced data availability), it will likely result in more stringent screening level.

Depending on data availability, two types of PFAS-specific ESVs may be developed under each tier: a maximum screening level (for acute exposure) and a continuous screening level (for chronic exposure). During a screening risk assessment, a surface water PFAS concentration can be compared to the ESV for that specific PFAS, and further evaluation (i.e., a baseline risk assessment) or site management would be indicated if the ESV is exceeded. Both methodologies are described below.

5.1 Development of a Tier I PFAS ESV

In the Tier I approach, PFAS-specific final acute and chronic toxicity values are developed, and these are then used to derive ESVs that represent maximum and continuous screening levels for the target PFAS compound (Figure 5-1). The Tier I methodology uses:

1. Acute and, if available, chronic toxicity tests meeting data requirements addressing eight or more families of aquatic animals;
2. Acute–chronic ratios for the different families and species, if sufficient chronic data are not available, and
3. At least one acceptable test with an algae or vascular plant.

The toxicity tests will target endpoints corresponding to severe adverse impacts to the exposed test organisms related to survival, growth, and reproduction. The acute toxicity test endpoints related to survival, loss of equilibrium, or immobilization (Stephen et al. 1985; EPA 1995a), while endpoints for the chronic tests will target survival, growth, and reproduction.

Specific data needs for deriving freshwater and marine ESVs are listed in Table 5-1. If available, these PFAS-specific data will be used to derive final acute and chronic values (FAV and FCV, respectively) which, in turn, will serve as the basis for deriving the ESV values (Figure 5-1).

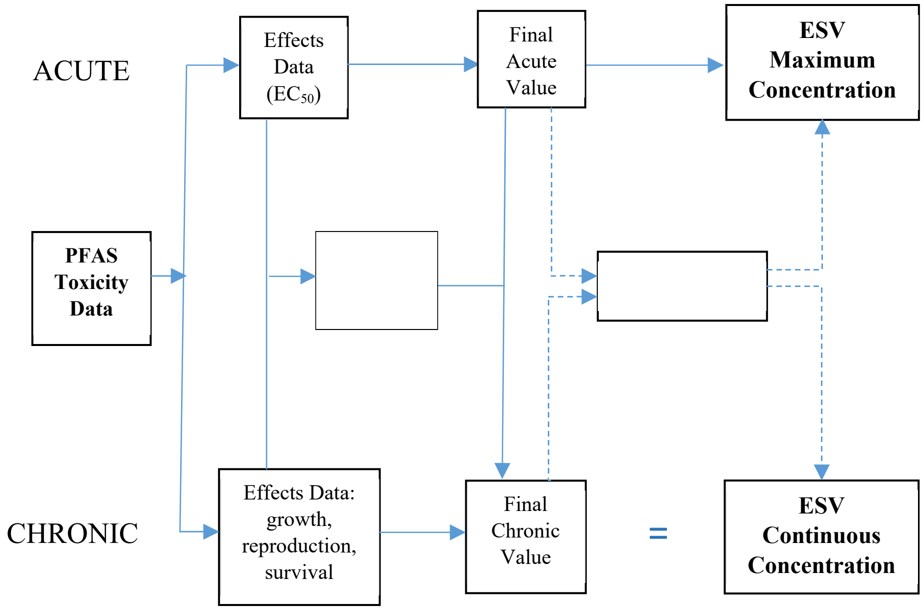

Figure 5-1 Process for Developing PFAS-specific ESVs for Aquatic Biota. (modified from EPA 2015).

Table 5-1 Data Requirements for Development of PFAS-specific ESVs[a]

Data Need	Freshwater ESV	Marine ESV
Acceptable acute and if available chronic toxicity test for the target biota	Minimum of one species in at least eight different families, such that all of the following are included: • The family Salmonidae; • Another family in the class Osteichthyes; • A family in the phylum Chordata; • A planktonic crustacean; • A benthic crustacean; • An insect; • A family in a phylum other than Arthropoda or Chordata; and • A family in any order of insect or any phylum not already represented	Minimum of one species in at least eight different families, such that all of the following are included: • Two families in the phylum Chordata; • A family other than Arthropoda or Chordata; • Either the Mysidae or Penaeidae family; • Three other families not in Chordata (may include Mysidae or Penaeidae, whichever has not yet been used; and • Any other family.
Acute–chronic ratio if sufficient	For species in at least three different families, provided that one of the three species are:	For species in at least three different families, such that the three species are:

Table 5-1 Data Requirements for Development of PFAS-specific ESVs[a]

Data Need	Freshwater ESV	Marine ESV
chronic data are not available	• At least one fish; • At least one invertebrate; and • At least one is an acutely sensitive freshwater species[b]	• At least one is a fish; • At least one is an invertebrate; and • At least one is a sensitive species[c]
Acceptable algae or plant acute test	With a freshwater alga or vascular plant. • If the plant is among the most sensitive test organisms, a plant from another phylum should be used.	With a saltwater alga or vascular plant. • If the plant is among the most sensitive test organisms, a plant from another phylum should be used.

[a] Based, in part, on methods in Stephen et al. (1985) and EPA (1995a).
[b] The other two may be saltwater species.
[c] The other two may be freshwater species.
[d] If a maximum permissible tissue concentration is available.

5.1.1 Developing a Final Acute Value

The PFAS-specific final acute value (FAV) is the estimated short-term PFAS exposure concentration deemed protective of approximately 95% of the tested genera and is used to derive the PFAS-specific ESV acute exposure level. Calculation of the FAV requires acute toxicity data for one or more species meeting data requirements for at least eight families of fish and aquatic invertebrates (Table 5-1). The FAV is calculated as the genus mean acute values (GMAVs) for all genera with suitable toxicity data.

The GMAV is calculated using the species mean acute value (SMAV) for all the species evaluated in a particular genus. The SMAV will be calculated in one of two ways:

- As the geometric mean[1] of the results of all acceptable flow-through acute toxicity tests using the most sensitive life stage of the tested species and in which the PFAS concentrations were measured; or
- If such toxicity data are not available, the SMAV will be calculated as the geometric mean of all acceptable acute toxicity tests with the most sensitive tested life stage.

Once the SMAVs are calculated, the GMAV of a particular genus is calculated as the geometric mean of all the SMAVs derived for each species within that genus.

To calculate the FAV, the GMAVs developed for all the genera will be ordered from low to high and assigned a rank, *R*, from lowest to highest. If two or more GMAVs are identical, they will be

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[1] The geometric mean of *N* numbers is the *N*th root of the product of the *N* numbers. Alternatively, the geometric mean can be calculated by adding the logarithms of the *N* numbers, dividing the sum by N, and taking the antilog of the quotient. The geometric mean of two numbers is the square root of the product of the two numbers, and the geometric mean of one number is that number.

assigned successive ranks. Next, each GMAV will be assigned a cumulative probability score (*P*), calculated as:

$$P = \frac{R}{(N+1)} \qquad \text{(Equation 5-1)}$$

Where:

P = cumulative probability score of the GMAV;

R = the GMAV rank (from 1 to N); and

N = number of GMAVs in the ranked dataset.

Next, the four GMAVs with cumulative probabilities closest to 0.05 (typically the four lowest GMAVs if fewer than 59 GMAVs are available) will be selected, and together with their probabilities will be used to calculate the PFAS-specific FAV, as follows:

$$S^2 = \frac{(\sum(\ln \mathrm{GMAV})^2) - \frac{(\sum \ln \mathrm{GMAV})^2}{4}}{\sum(P) - \frac{(\sum(\sqrt{P}))^2}{4}} \qquad \text{(Equation 5-2)}$$

$$L = \frac{\sum(\ln \mathrm{GMAV}) - S(\sum(\sqrt{P}))}{4} \qquad \text{(Equation 5-3)}$$

$$A = S\left(\sqrt{0.05}\right) + L \qquad \text{(Equation 5-4)}$$

$$\mathrm{FAV} = e^{A} \qquad \text{(Equation 5-5)}$$

This FAV represents the 5% acute hazardous PFAS water concentration (HC5) that theoretically is protective of 95% of aquatic genera acutely exposed to that concentration. Dividing the FAV by 2 provides a more effective low effect level value (EPA 2015). The HC5 may alternatively be derived by performing a least squares regression of the four GMAV log values (if fewer than 59 values are available) on the percentile ranks.

5.1.2 Developing a Final Chronic Value

The PFAS-specific final chronic value (FCV) is the estimated chronic exposure level deemed protective of approximately 95% of the tested genera exposed to that concentration and will be used to develop the chronic ESV. The FCV will be calculated in one of two ways: (1) using the same approach employed to develop the FAV, or (2) by dividing the FAV by a final acute–chronic ratio (FACR).

5.1.2.1 FAV-based Approach

To develop a FCV using the FAV procedure (see Section 5.1.1), chronic toxicity values will be needed for species meeting eight data requirements (Table 5-1). If appropriate data are available, the FCV can be derived either by:

1. Calculating the geometric mean of effects concentrations from chronic tests; or
2. Analyzing the chronic data using regression analysis.

If available, values from the chronic toxicity tests may be used to develop a species-specific mean chronic value (SMCV) for each species in the dataset. The SMCV will be calculated as the geometric mean of the results of all acceptable lifecycle and partial lifecycle toxicity tests for the species. For fish species in the dataset, if no such lifecycle test results are available then the SMCV will be calculated as the geometric mean of all acceptable early life-stage tests for that species.

Next, a genus mean chronic value (GMCV) will be developed for each genus in the dataset. This GMCV will be calculated as the geometric mean of all SMCVs for each genus in the dataset. Next, all the GMCVs developed for the genera in the dataset will be ordered and assigned a rank, *R*, from lowest to highest. The FCV will then be developed using the four lowest-ranked GMCVs and applying Equations (5-1) through (5-5) but substituting SMCV for SMAV and GMCV for GMAV. Similar to the FAV/2, this FCV is the HC5 that represents the PFAS water concentration that theoretically is protective of 95% of aquatic species exposed to that concentration. Alternatively, the HC5 may be derived by performing a least squares regression of the four GMCV values (log values) on the percentile ranks.

5.1.2.2 Acute-to-Chronic Ratio Approach

If chronic values are not available to meet the eight data requirements for taxonomic families (Table 5-1), a FCV cannot be derived as described in Section 5.1.2.1. In such cases, an FCV will be developed using an acute-to-chronic ratio (ACR) derived using results from acute and chronic tests on the same species (Stephen et al. 1985; EPA 1995a). An ACR is derived by dividing a species-specific chronic toxicity value from an acceptable chronic test by an acute toxicity value from an acute test on the same species (Stephen et al. 1985; EPA 1995a). To be suitable for ACR derivation, the acute and chronic toxicity data must meet one of the following specific requirements:

- The acute and chronic toxicity tests were conducted as part of the same study, by the same laboratory, using the same species and dilution water;
- The acute toxicity test was conducted in a separate study, but by the same laboratory, using the same species and dilution water; or
- The acute toxicity test was conducted in a separate study by a different laboratory, but using the same species and same dilution water.

If necessary, acute and chronic data from the same species, regardless of test conditions, may be used. If no such acute toxicity test data are available, ACR development will not be possible.

If suitable data are available, an ACR will be calculated for each species as:

$$SMACR = \frac{SMAV}{SMCV} \qquad \text{(Equation 5-6)}$$

where:

SMACR = Species Mean Acute-Chronic Ratio;

SMAV = Species Mean Acute Value; and

SMCV = Species Mean Chronic Value.

The SMAV is the geometric mean of the results of all acceptable acute tests and the SMCV is the geometric mean of the results of all acceptable chronic tests. Next, a species mean acute-chronic ratio (SMACR) for a given species will be calculated as the geometric mean of all the SACRs for that species. If the minimum ACR data requirements described earlier are not met with freshwater data alone, saltwater data may be used along with the freshwater data to provide a sufficient dataset (Stephen et al. 1985; EPA 1995a).

The 1995 GLI guidance identifies derivation of a final ACR (FACR) in one of the three following ways:

1. If the SMACR appears to increase or decrease as the SMAVs increase, the FACR will be calculated as the geometric mean of the SMACRs for species in the dataset whose SMAVs are close to the FAV;
2. If no major trend is apparent and the SMACRs for all species in the dataset are within a factor of 10, the FACR will be calculated as the geometric mean of all the SMACRs; or
3. If the most appropriate SMACRs are less than 2.0, and especially if less than 1.0, the FACR will be assumed to be 2.[2]

If the available PFAS-specific SMACRs do not allow use of any of these three approaches, it will not be possible to derive a useable FACR, and neither a PFAS-specific FCV nor a Tier I ESV for chronic exposure can be calculated.

Sufficient data were available for Tier I FACR derivation for only PFOA and PFAS. Following discussions with the EPA Interagency Team, the PFOA FACR was the highest SMACR calculated from the available PFOA data. For PFOS, the FACR was calculated as the 90th percentile value of the SMACRs.

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[2] In such cases, acclimation is assumed to have occurred during the chronic test, and thus continuous exposure and acclimation cannot be assured to provide adequate protection in field situations (EPA 1995a).

For PFOA and PFOS, the FCV can be calculated as:

$$FCV = \frac{FAV}{FACR} \qquad \text{(Equation 5-7)}$$

where:

FCV = final chronic value;
FAV = final acute value; and
FACR = final acute–chronic ratio.

5.1.3 Final Aquatic Plant Value

Pending data availability, the derivation of a Tier I PFAS ESV includes consideration of aquatic plant toxicity data to derive a final plant value (FPV). The FPV is the lowest plant toxicity value for an important aquatic plant species in an acceptable toxicity test for which a PFAS concentration was measured and the adverse effect was biologically important. The FPV will be based on 96-hour tests conducted with algae, or chronic tests conducted with an aquatic vascular plant (Stephen et al. 1985; EPA 1995a). The FPV will then be lowest result among the acute and chronic tests.

5.1.4 Tier I PFAS ESV Derivation

Depending on data availability, two Tier I PFAS ESVs will be developed:

- Maximum ESV (acute exposure ESV), and
- Continuous ESV (chronic exposure ESV).

For a specific PFAS, the acute exposure ESV will be calculated as one-half the PFAS-specific FAV and represents the highest concentration of the specific PFAS in the water column to which an aquatic community can be briefly exposed without resulting in an unacceptable effect.

The chronic exposure ESV will be the lowest of the FCV or the FPV (if available) and represents the highest concentration of the specific PFAS in the water column to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect.

5.2 Development of a Tier II ESV

If insufficient data are available to develop Tier I ESVs, a Tier II ESV will be developed following the methodology presented in the Great Lakes Water Quality Initiative guidance (EPA 1995a). The Tier II methodology uses available aquatic toxicity test data to calculate secondary acute and chronic values, and secondary acute-chronic ratios. These values in turn are used develop secondary maximum and continuous water concentrations for the protection of aquatic biota.

5.2.1 Derivation of Secondary Acute Values

If species-specific toxicity test data are available meeting only some of the eight data requirements for taxonomic families used to derive a Tier I FAV (Table 5-1), a secondary acute value (SAV) will be calculated as follows. A SMAV will be calculated for each species with available toxicity test data. For a freshwater ESV, the dataset at a minimum must include data for one of the following three genera in the family Daphnidae: *Ceriodaphnia*, *Daphnia*, or *Simocephalus*. For marine ESVs, the dataset should include data from one of the following families: Mysidae or Penaeidae. Next, a GMAV will be calculated as the geometric mean of the SMAVs for all species in that genus. The resultant GMAVs will then be ranked from lowest to highest, and a SAV will be calculated by dividing the lowest GMAV by a secondary acute factor (SAF) (Table 5-2) from the GLI methodology (EPA 1995a):

$$SAV = \frac{GMAV_L}{SAF} \qquad \text{(Equation 5-8)}$$

where:

SAV = secondary acute value;

$GMAV_L$ = lowest GMAV from the available toxicity test data; and

SAF = secondary acute factor, based on number of required Tier I taxa

Table 5-2 Secondary Acute Factors (EPA 1995a)

Number of Tier I Taxonomic Families in the Tier II Dataset	Adjustment Factor
1	21.9
2	13.0
3	8.0
4	7.0
5	6.1
6	5.2
7	4.3

The SAF corresponds to the number of the Tier I taxonomic families in the dataset (Table 5-1). For example, if acute toxicity test data are available for species from only three of the eight Tier I families, the SAV would be calculated as the lowest GMAV divided by an SAF of 8.0.

5.2.2 Derivation of Secondary Final Acute-Chronic Ratios

If three or more suitable experimentally determined ACRs (EPA 1995a) are available, a FACR can be developed using the Tier I procedure described in Section 5.1.2.2. However, if fewer than three ACRs are available, it will not be possible to develop an FACR following the Tier I methodology. In such cases, the GLI guidance (EPA 1995a) uses the following approach to derive a secondary FACR. If fewer than three ACRs are available, one or two ACRs—each with a default value of 18—will be used so that there are three ACRs (Table 5-3). The secondary FACR (SFACR) will then be calculated as the geometric mean of the three ACRs. If no experimentally determined ACRs are available, the SFACR will be assigned a value of 18 (EPA 1995a).

Table 5-3 Hypothetical Example of Employing Assumed ACR Values for Use in Developing a SFACR Following EPA Methodology Guidance (EPA 1995a)

Case 1: Three ACRs Available	Case 2: Two ACRs Available	Case 1: One ACR Available
4.5	4.5	4.5
6.9	6.9	18
1.4	18	18
FACR[a] = 3.5	SFACR = 8.2	SFACR = 11.3

[a] FACR and SFACR are calculated as the geometric mean of the three ACRs.

Because the default value of 18 was considerably below the ACRs that were derived with the available data for PFOA and PFOS, this default value was not considered appropriate for use in developing SFACRs. For the perfluorocarboxylic acids other than PFOA, the 90th percentile of the individual PFOA ACRs (instead of 18) was used as the default SACR. For the perfluorosulfonic acids other than PFOS, the 90th percentile of the individual PFOS ACRs was used as the default SFACR.

5.2.3 Secondary Chronic Value

Once the SAV and SACR (or FACR) values are developed for a specific PFAS, the PFAS-specific secondary chronic value (SCV) will be calculated using one of the following:

$$\mathrm{SCV} = \frac{FAV}{SACR} \qquad \text{(Equation 5-9)}$$

$$\mathrm{SCV} = \frac{SAV}{FACR} \qquad \text{(Equation 5-10)}$$

$$\mathrm{SCV} = \frac{SAV}{SACR} \qquad \text{(Equation 5-11)}$$

where:

SCV = secondary chronic value;
FAV = final acute value (from Tier 1 evaluation);
SACR = secondary acute–chronic ratio;
SAV = secondary acute value; and
FACR = final acute–chronic ratio.

5.2.4 Tier II ESV Derivation

Under the Tier II ESV methodology, two PFAS-specific ESVs will be derived:

- Secondary acute exposure ESV, and
- Secondary chronic exposure ESV.

Similar to the Tier I ESV values, the secondary acute exposure ESV will be calculated as one-half the PFAS-specific SAV (EPA 1995a).

$$\text{secondary acute exposure ESV}=\frac{SAV}{2} \qquad \text{(Equation 5-12)}$$

This value represents the highest concentration of the specific PFAS in the water column to which an aquatic community can be briefly exposed without resulting in an unacceptable effect.

The Tier II secondary chronic exposure ESV will be the lowest of the SCV or, if available, a FPV as determined in the Tier I methodology (see Section 5.1.3). The secondary chronic exposure ESV value represents the highest concentration of a specific PFAS in the water column to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect.

5.3 References

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6 DERIVATION OF AQUATIC ESVS FOR WILDLIFE

As with the development of PFAS ESVs for the protection of aquatic biota (Section 5), a two-tiered methodology will also be used to develop aquatic screening levels for the protection of wildlife. These ESVs represent the PFAS concentration at or below which exposure to birds or mammals is not expected to result in unacceptable adverse impacts to growth, reproduction, or survival. This methodology is based in large part on the 1995 GLI Tier I and Tier II methods for deriving water quality criteria to protect wildlife (EPA 1995b, c). The aquatic ESVs for wildlife will support screening ecological risk assessments of surface waters.

6.1 Representative Species for ESV Development

Piscivorous species are the focus of concern for development of the wildlife aquatic PFAS ESVs. Based on the analysis of known or estimated exposure factors for avian and mammalian wildlife species presented in the GLI guidance and technical support documents for developing wildlife criteria (EPA 1995b, c), three avian species and two mammalian species have been selected as representative species for use in developing the wildlife aquatic PFAS ESV (Table 6-1).

Table 6-1 Representative Species for Use in Developing Tier I and Tier II PFAS ESVs

Avian Species	Mammalian Species
Belted Kingfisher	River Otter
Herring Gull	Mink
Osprey	

As discussed in the GLI guidance (EPA 1995b, c), these species are considered representative of avian and mammalian species that are likely to have the highest potential for PFAS exposure through the aquatic food web. Each of the avian species may be found throughout the United States, with the belted kingfisher largely restricted to foraging in freshwater habitats, while the herring gull and osprey may forage in freshwater and also marine coastal habitats. Besides these piscivorous species, other non-piscivorous species (such as shorebirds and some waterfowl) may be exposed through the ingestion of contaminated media while foraging or through the food chain while consuming aquatic and semi-aquatic biota. The two mammalian species also forage in freshwater and marine coastal habitats. Other wildlife species may be selected, following review of the available toxicity data and discussions with the Interagency Team.

6.2 Derivation of Avian and Mammalian Wildlife Values

Development of the wildlife aquatic ESVs first requires first deriving a wildlife value (WV) for each of the representative bird and mammalian species using the following equation:

$$\mathrm{WV}_{\mathrm{PFAS}} = \frac{\left(\frac{\mathrm{TD}}{UF_A \times UF_S \times UF_L}\right) \times W_t}{W + \sum(F_{TLi} \times BAF_{TLi}^{Wt})} \qquad \text{(Equation 6-1)}$$

Where:

WV_{PFAS} = Wildlife value (mg PFAS/L);
TD = Test dose (mg PFAS/kg bodyweight/day) for test species that represents a NOAEL or LOAEL dose;
UF_A = Uncertainty factor (UF) for extrapolating toxicity data across species (unitless);
UF_S = UF for extrapolating from subchronic to chronic exposures (unitless);
UF_L = UF for LOAEL to NOAEL extrapolations (unitless);
W_t = Average weight (kg) for the representative species;
W = Average daily water consumption (L/day) by the representative species;
F_{TLi} = Average daily food consumption rate (kg/day) from trophic level i by the representative species; and
BAF_{LTi}^{WL} = Bioaccumulation factor for wildlife food in trophic level i (L/kg).

The final avian WV will be the geometric mean of the WVs of the representative avian species, and the final mammalian WV will be the geometric mean of the WVs for the representative mammalian species[3] (Table 6-1).

6.2.1 Test Dose Selection and Conversion

For a representative species, multiple test doses may be available from various studies. If multiple values are available, selection of which test dose to use in WV derivation will be based on the following considerations (from EPA 1995b):

1. If, based on different toxicity endpoints, more than one test dose is available within a taxonomic class (e.g., for multiple avian species), the dose from the most sensitive species and which best reflects potential impacts to wildlife populations due to changes in mortality, growth, or reproduction will be selected.
2. If more than one test dose is available within a taxonomic class and all are based on the same endpoint, the dose will be selected from the most sensitive species.
3. If multiple test doses are available from various studies for a given species and are based on the same toxicity endpoint, the test dose used for that species will be the geometric mean of those test doses.

Whatever test dose is selected, it must be in appropriate units: milligram of PFAS per kilogram of bodyweight per day (mg/kg/day, wet weight). If the dose is in other units, the following procedures will be used to convert the test dose to the units needed to calculate a WV:

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[3] The geometric mean of two numbers is the square root of the product of the two numbers

- If the test dose is given in milligrams of PFAS per liter of water consumed (mg/L), the dose will be multiplied by the daily average volume of water consumed by the test animals (L/day) and divided by the average weight (kg) of the test animals; or
- If the test dose is given in milligrams of PFAS per kilogram of food consumed (mg/kg), the dose will be multiplied by the average amount of food consumed daily (kg/day) and divided by the average weight of the test animals in kilograms (kg) (EPA 1995b).

For these conversions, the drinking and feeding rates, as well as bodyweight, will be those reported in the associated study. If the study does not provide the exposure information for the test species, this information will be derived using the exposure estimation methods presented in Chapter 4 of the *Wildlife Exposure Factors Handbook* (EPA, 1993) together with the methods and recommendations presented in the GLI *Technical Support Document for Wildlife Criteria* (EPA 1995c).

6.2.2 Uncertainty Factors

6.2.2.1 LOAEL to NOAEL Extrapolations Using Uncertainty Factors (UF_L)

In calculating a species-specific WV (Equation 6-1), the preferred test dose is a NOAEL dose for the target species and based on a chronic toxicity test. If the test dose is available only as a LOAEL, the NOAEL will be estimated by dividing the LOAEL by an uncertainty factor[4] (UF_L in Equation 6-1) ranging from 1 and 10, depending on the dose-response curve and any other available data. Selection of an appropriate UF_L will follow the procedures and recommendations presented in GLI technical support documents for wildlife and human health criteria development (EPA 1995c, e), as well as discussion with and input from the Interagency Team.

6.2.2.2 Sub-chronic to Chronic Extrapolations (UF_S)

When only sub-chronic data are available, the test dose will be derived by extrapolating from sub-chronic to chronic levels. This will be done by dividing the sub-chronic value by an appropriate UF (UF_S in Equation 6-1) ranging from 1 to 10. Selection of an appropriate UFs will follow the guidance presented in GLI wildlife criteria technical support document (EPA 1995c), as well as discussion with and input from the Interagency Team.

6.2.2.3 Interspecies Extrapolations (UF_A)

If a test dose is not available for the target representative species (Table 6-1), available dose values from other species (within the same class) will be extrapolated to the target representative species. For this extrapolation (which will follow a taxonomic hierarchy from genus to higher-level taxonomic groupings), the non-target-species test dose will be divided by an UF (UF_A in Equation 6-1) ranging from 1 to 100 depending on the species. Selection of the appropriate UF_A

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[4] Uncertainty factors referred to here and in Equation 6-1 account for uncertainty when applying a dose response in one species to another species, for converting from sub-chronic to chronic exposures, and for estimating a NOAEL from a LOAEL. In the latter two cases, the uncertainty factors incorporate a factor that accounts for a change in magnitude in the converted values.

will follow the guidance presented in the GLI wildlife criteria technical support document (EPA 1995c), as well as considerations of discussions with, and input from, the Interagency Team. The application of a UF_A will only apply to extrapolation across species within a taxonomic class, and not for interclass extrapolations.

6.2.3 Bioaccumulation Factors

In the GLI methodology (EPA 1995c), the calculation of a WV may incorporate a BAF[5] for wildlife food from different trophic levels (see Equation 6-1), with the BAF obtained from published studies (of acceptable quality [see Section 2]). The GLI guidance (EPA 1995b) discusses deriving BAFs when evaluating food chain uptake via the consumption of piscivorous birds by other birds (e.g., herring gull by eagles). The GLI guidance also calls for the BAF to be derived by multiplying the trophic level 3 BAF for fish by a biomagnification factor to account for the biomagnification from fish to the consumed birds. Although this is appropriate for many organic compounds, it may be less appropriate for PFAS compounds.

In general, the more lipophilic a compound (as measured by its octanol-water partition coefficient, K_{OW}), the higher the tendency for that compound to bioaccumulate. However, PFAS molecules are partly lipophilic and partly hydrophilic, and thus the K_{OW} becomes less of an indicator of possible bioaccumulation. Rather, the length of each PFASs fluorinated chain length appears to be a better indicator of bioconcentration and bioaccumulation potential. For example, perfluorinated sulfonates appear to be more bioaccumulative than perfluorinated carboxylates of the same fluorinated carbon number, while perfluorinated carboxylates with seven or fewer fluorinated carbons appear to have low bioaccumulation and biomagnification potential in food webs (Conder et al. 2008).

A determination will be made of the availability of PFS-specific BAFs, and if available the BAFs will be used. The trophic level to which a PFAS-specific BAF will be applied will be the same as the trophic level of the organisms used in the determination of the BAF. If more than one BAF is available for a given species and trophic level, a species mean BAF will be calculated as the geometric mean of the BAFs. If a BAF is available for either trophic level 3 or 4, but not both, a baseline BAF for the other trophic level will be calculated following the procedures described in GLI Methodology for Deriving Bioaccumulation Factors (EPA 1995d). Acceptability of reported field-measured BAFs or reported derived BAFs will be evaluated using the criteria and procedures identified in the GLI BAF methodology (EPA 1995d).

6.3 Derivation of the Tier I and II Aquatic ESVs for the Protection of Wildlife

Under the Tier I methodology two WVs are calculated (using Equation 6-1), one for birds and one for mammals. The lowest of these is selected as the wildlife PFAS aquatic ESV:

Tier I Aquatic ESV for Wildlife = lowest of the Avian and Mammalian WVs

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[5] The BAF is the ratio (in L/kg) of a substance's concentration in tissue of an aquatic organism to its concentration in the ambient water, in situations where both the organism and its food are exposed to the ambient water concentrations, and the ratio does not change substantially over time.

If insufficient data are available to develop both avian and mammalian WVs, then a Tier II ESV will be developed as follows. A single, class-specific (Aves or Mammalia, whichever has the appropriate data) WV is developed using the same methodology as described for Tier I (using Equation 6-1). This class-specific WV then becomes the Tier II ESV:

$$\text{Tier II Aquatic ESV for Wildlife} = \text{Class-specific WV}$$

This Tier II ESV will be applicable only to biota from the specific class for which it was developed.

6.4 References

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APPENDIX B: TERRESTRIAL PLANTS AND INVERTEBRATES

B.1 TERRESTRIAL PLANTS

Table B.1-1 ESV for PFOA for Terrestrial Plants in Soil (mg/kg)

Author, Year	ECOTOX Reference Number	Species Scientific Name	Species Common Name	Effect	EC20	EC10	MATC	Value for ESV Calc[a]
Gonzalez-Naranjo and Boltes, 2014	176911	*Sorghum bicolor*	Broomcorn	Growth	19.21			19.21
Zhao, et al., 2011	175188	*Brassica chinensis*	Pak-choi	Growth		177		177
Zhao, et al, 2011	175188	*Brassica chinensis*	Pak-choi	Growth		98		98
Zhao, et al., 2011	175188	*Brassica chinensis*	Pak-choi	Growth		48		48
Zhao, et al., 2011	175188	*Brassica chinensis*	Pak-choi	Growth		103		103
Zhao, et al., 2011	175188	*Brassica chinensis*	Pak-choi	Growth		96		96
Zhao, et al., 2011	175188	*Brassica chinensis*	Pak-choi	Growth		120		120
Zhou, et al., 2016	175702	*Triticum aestivum*	Bread wheat	Growth		83.8		83.8
Kwak, et al., 2020	181724	*Oryza sativa*	Rice	Growth			245	245
Kwak, et al., 2020	181724	*Vigna radiata*	Mung bean	Growth		274		274
					ESV (mg/kg)			**101**

[a] ESV calculated as the geometric mean of identified endpoints.

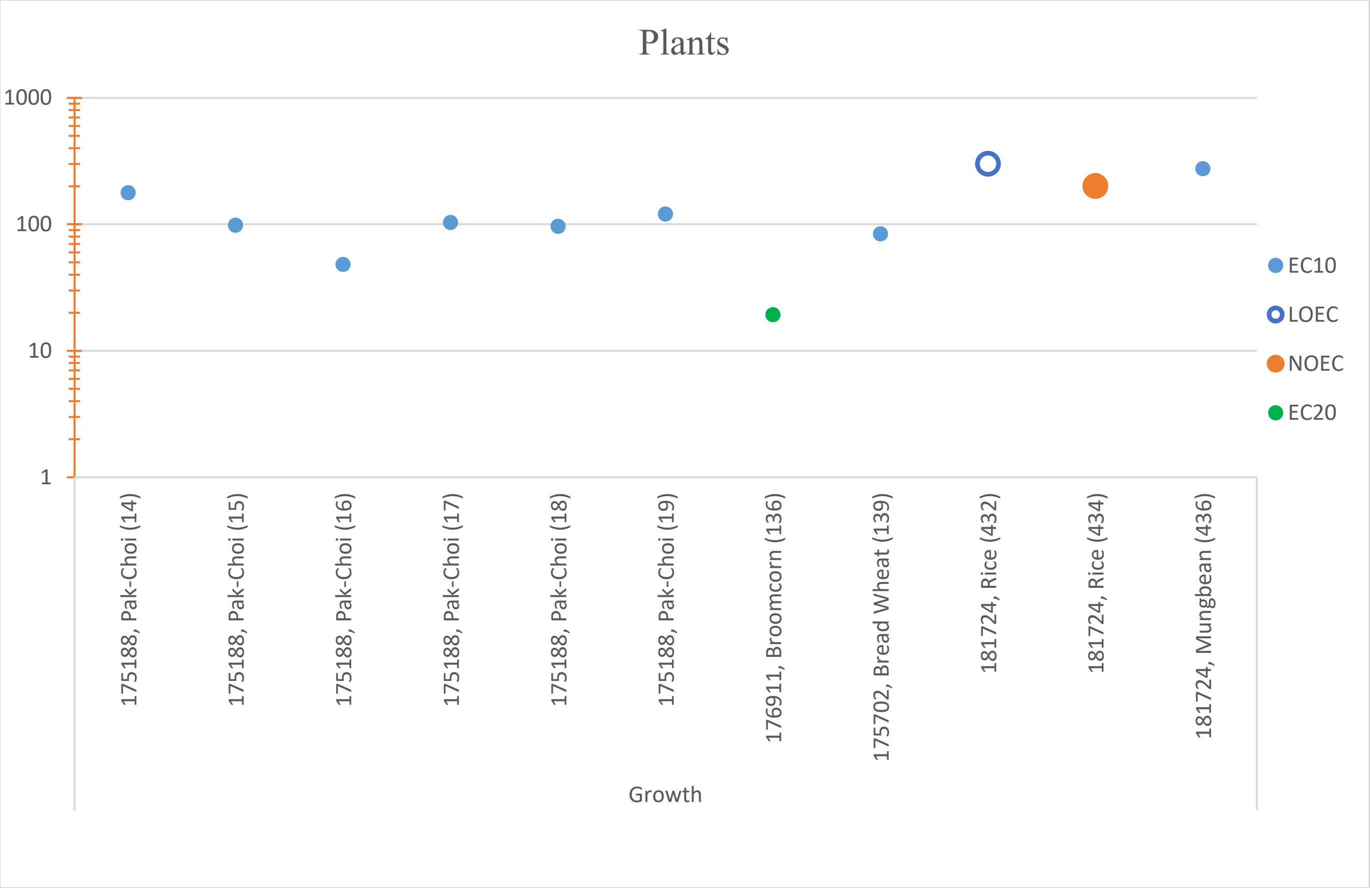

Figure B.1-1 PFOA Toxicity Values for Direct Exposure of Plants in Soil (mg/kg)

Table B.1-2 ESV for PFOS for Terrestrial Plants in Soil (mg/kg)

Author, Year	ECOTOX Reference Number	Species Scientific Name	Species Common Name	Effect	EC25	EC10	MATC[a]	Value for ESV Calc[b]
Brignole, et al., 2003	175361	*Medicago sativa*	Alfalfa	Growth	53.3			53.3
Brignole, et al., 2003	175361	*Linum usitatissimum*	Flax	Growth	81.6			81.6
Brignole, et al., 2003	175361	*Allium cepa*	Common onion	Growth	12.9			12.9
Brignole, et al., 2003	175361	*Lactuca sativa*	Lettuce	Growth	6.79			6.79
Brignole, et al., 2003	175361	*Lolium perenne*	Perennial ryegrass	Growth	7.51			7.51
Brignole, et al., 2003	175361	*Glycine max*	Soybean	Growth	160			160
Brignole, et al., 2003	175361	*Solanum lycopersicum*	Tomato	Growth	11.7			11.7
Zhao, et al., 2011	175188	*Brassica chinensis*	Pak-choi	Growth		115		115
Zhao, et al., 2011	175188	*Brassica chinensis*	Pak-choi	Growth		58		58
Zhao, et al., 2011	175188	*Brassica chinensis*	Pak-choi	Growth		40		40
Zhao, et al., 2011	175188	*Brassica chinensis*	Pak-choi	Growth		72		72
Zhao, et al., 2011	175188	*Brassica chinensis*	Pak-choi	Growth		83		83
Zhao, et al., 2011	175188	*Brassica chinensis*	Pak-choi	Growth		90		90
Yu, et al., 2018	182588	*Lactuca sativa*	Head lettuce	Growth			0.43	0.43
Yu, et al., 2018	182588	*Lactuca sativa var. crispa*	Leaf lettuce	Growth			0.43	0.43
Yu, et al., 2018	182588	*Lactuca sativa var. longifolia*	Romaine lettuce	Growth			0.43	0.43
								ESV (mg/kg) = 17.27

[a] MATC was calculated here as the geometric mean of the associated LOAEL and NOAEL values in the study.

[b] ESV calculated as the geometric mean of identified endpoints.

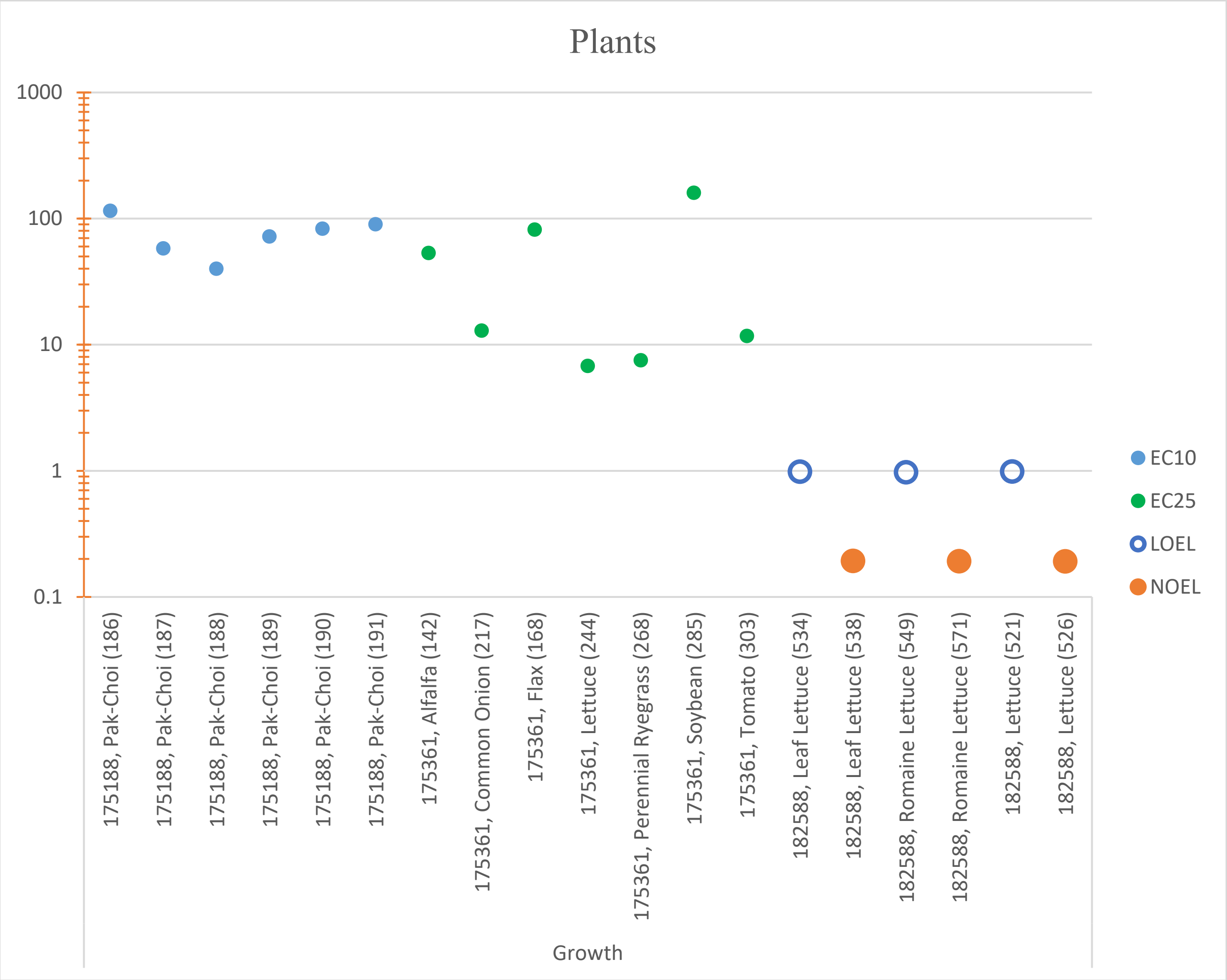

Figure B.1-2 PFOS Toxicity Values for Direct Exposure of Plants in Soil (mg/kg)

B.2 SOIL INVERTEBRATES

Table B.2-1 ESV for PFOA for Terrestrial Invertebrates in Soil (mg/kg)

Author, Year	ECOTOX Reference Number	Species Scientific Name	Species Common Name	Effect	LOAEL	NOAEL	MATC[a]	Value for ESV calc[b]
Zareitalabad, et al., 2013	175666	*Aporrectodea caliginosa*	Worm	Mortality	100	1	10	10
Zheng, et al., 2016	176944	*Eisenia fetida*	Earthworm	Growth	50			50
Joung, et al., 2010	184060	*Eisenia fetida*	Earthworm	Mortality	750	500	612	612
Kwak, et al., 2020	181724	*Eisenia andrei*	Earthworm	Mortality	600	500	548	548
Kwak, et al., 2020	181724	*Lobella sokamensis*	Springtail	Mortality	600	420	502	502
Kwak, et al., 2020	181724	*Folsomia candida*	Springtail	Reproduction	100	50	70.7	70.7
Kwak, et al., 2020	181724	*Caenorhabditis elegans*	Nematode	Reproduction	300	100	173	173
Wang, et al., 2021	188516	*Eisenia fetida*	Earthworm	Growth	10			10
Wang, et al., 2022	188202	*Eisenia fetida*	Earthworm	Growth	10.15			10.15
							ESV (mg/kg)	**77.8**

[a] Maximum acceptable threshold concentration (MATC) was calculated as the geometric mean of the associated LOAEL and NOAEL.

[b] ESV calculated as the geometric mean of identified endpoints.

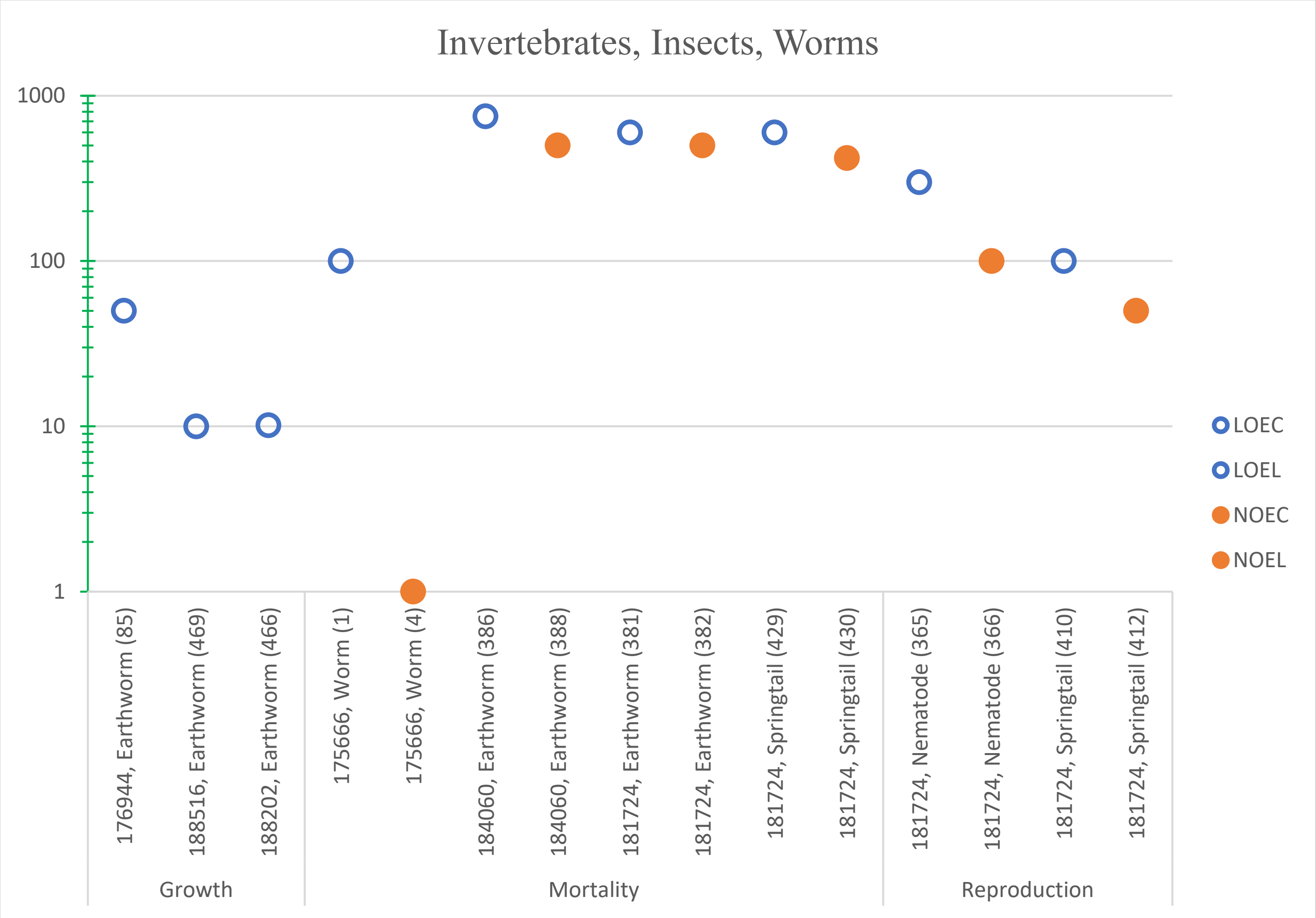

Figure B.2-1 PFOA Toxicity Values for Direct Exposure of Invertebrates in Soil (mg/kg)

Table B.2-2 ESV for PFNA for Terrestrial Invertebrates in Soil (mg/kg)

Author, Year	ECOTOX Reference Number	Species Scientific Name	Species Common Name	Effect	LOAEL	NOAEL	MATC[b]
Karnjanapiboonwong, et al., 2018	177143	*Eisenia fetida*	Earthworm	Growth	100		
Karnjanapiboonwong, et al., 2018	177143	*Eisenia fetida*	Earthworm	Growth		1	10
Karnjanapiboonwong, et al., 2018	177143	*Eisenia fetida*	Earthworm	Mortality	100		
Karnjanapiboonwong, et al, 2018	177143	*Eisenia fetida*	Earthworm	Mortality		1	10
						ESV (mg/kg)[a]	**10**

[a] ESV based on MATC for mortality, following the selection preference within a given study of Reproduction > Mortality > Growth.

[b] MATC was calculated as the geometric mean of associated LOAEL and NOAEL.

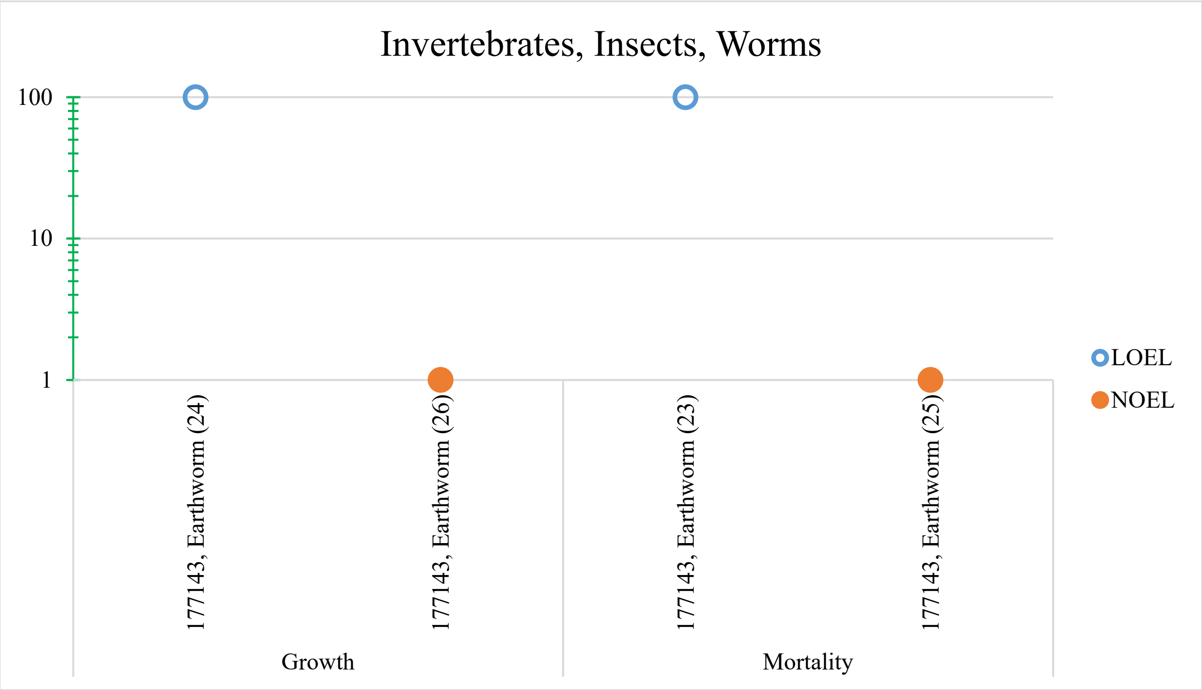

Figure B.2-2 PFNA Toxicity Values for Direct Exposure of Invertebrates in Soil (mg/kg)

Table B.2-3 ESV for PFBS for Terrestrial Invertebrates in Soil (mg/kg)

Author, Year	ECOTOX Reference Number	Species Scientific Name	Species Common Name	Effect	NOAEL
Karnjanapiboonwong, et al., 2018	177143	*Eisenia fetida*	Earthworm	Growth	100
Karnjanapiboonwong, et al., 2018	177143	*Eisenia fetida*	Earthworm	Mortality	100
				ESV (mg/kg)[a]	**100**

[a] ESV is conservatively based on the NOAEL for mortality, in the absence of other toxicity data.

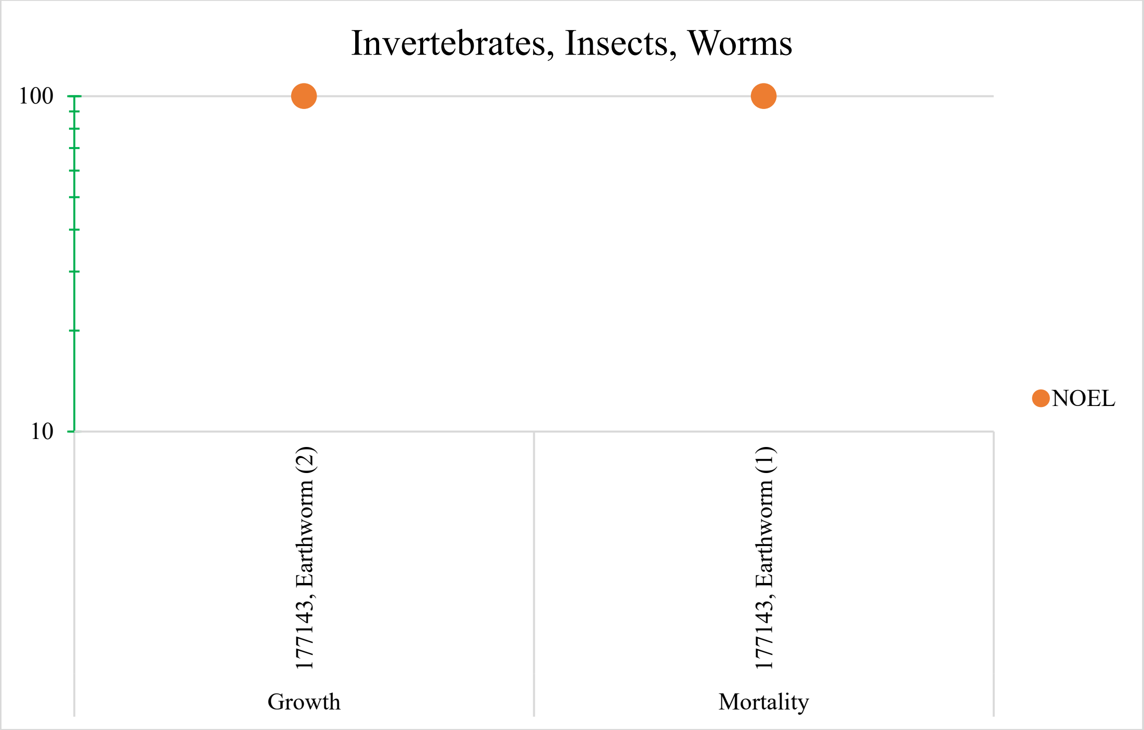

Figure B.2-3 PFBS Toxicity Values for Direct Exposure of Invertebrates in Soil (mg/kg)

Table B.2-4 ESV for PFHxS for Terrestrial Invertebrates in Soil (mg/kg)

Author, Year	ECOTOX Reference Number	Species Scientific Name	Species Common Name	Effect	NOAEL	LOAEL	MATC[b]
Karnjanapiboonwong, et al., 2018	177143	*Eisenia fetida*	Earthworm	Growth	100		
Karnjanapiboonwong, et al., 2018	177143	*Eisenia fetida*	Earthworm	Mortality	1	100	10
						ESV (mg/kg)[a]	**10**

[a] ESV is based on the MATC for mortality.
[b] MATC was calculated as the geometric mean of the associated LOAEL and NOAEL values in the study.

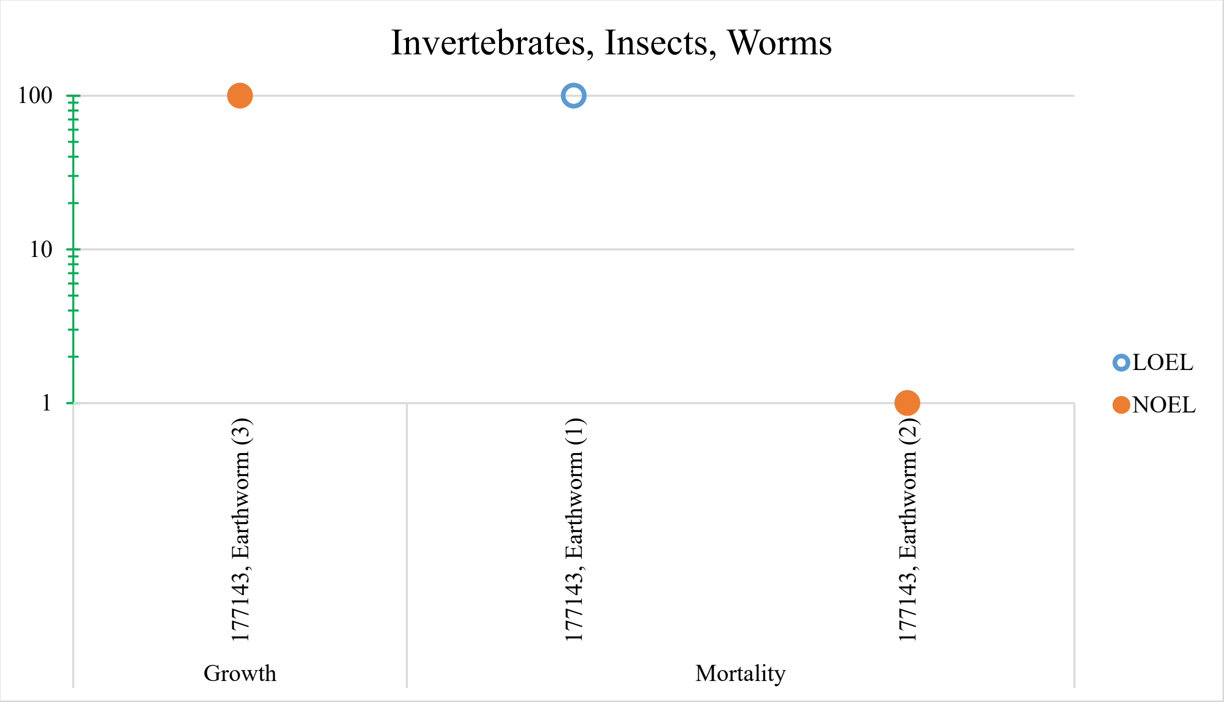

Figure B.2-4 PFHxS Toxicity Values for Direct Exposure of Invertebrates in Soil (mg/kg)

Table B.2-5 ESV for PFOS for Terrestrial Invertebrates in Soil (mg/kg)

Author, Year	ECOTOX Reference Number	Species Scientific Name	Species Common Name	Effect	IC25	LOEC	NOEC	LOAEL	NOAEL	MATC[a]	Value for ESV Calc[b]
Princz, et al., 2018	178027	*Oppia nitens*	Mite	Reproduction	13						13
Princz, et al., 2018	178027	*Oppia nitens*	Mite	Reproduction	33						33
Princz, et al., 2018	178027	*Folsomia candida*	Springtail	Reproduction	74						74
Princz, et al., 2018	178027	*Folsomia candida*	Springtail	Reproduction	185						185
Sindermann, et al., 2002	177116	*Eisenia fetida*	Earthworm	Growth		141	77			104.2	104.2
Xu, et al., 2013	166647	*Eisenia fetida*	Earthworm	Growth				120	80	98.0	98.0
Zareitalabad, et al., 2013	175666	*Aporrectodea caliginosa*	Worm	Growth				100	1	10.0	10.0
Joung, et al., 2010	184060	*Eisenia fetida*	Earthworm	Mortality				256	160	202	202
										ESV (mg/kg)	**57.6**

[a] MATC was calculated here as the geometric mean of the associated LOAEL and NOAEL values in the study.

[b] ESV calculated as the geometric mean of identified endpoints.

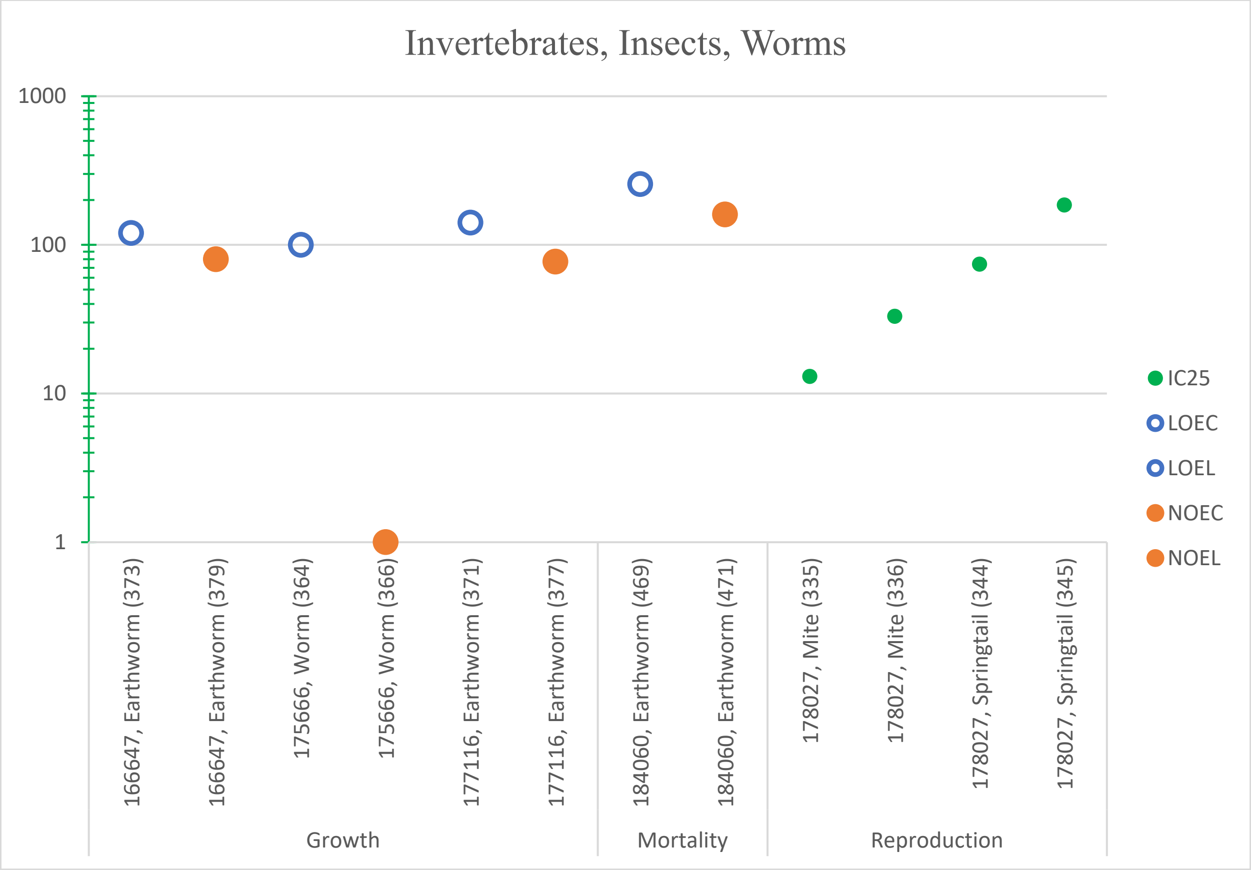

Figure B.2-5 PFOS Toxicity Values for Direct Exposure of Invertebrates in Soil (mg/kg)

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APPENDIX C: TERRESTRIAL BIRDS AND MAMMALS

C.1 EXPOSURE FACTORS FOR TERRESTRIAL WILDLIFE

Exposure factors used as inputs for modeling exposure of representative mammal and bird species to PFAS compounds is presented in Table C-1. The values were determined based on U.S. Environmental Protection Agency (EPA) guidance for developing soil-based ecological screening values (EPA 2005) and the methodology identified in Appendix A.

Table C-1 Input Exposure Factors for Estimating ESVs for Representative Species of Terrestrial Mammals and Birds

Receptor Group (Surrogate Species)[a]	Assumed Diet	Food Ingestion Rate[b] (FIR, kg dw/kg bw day)	Soil Ingestion[c] (P_s)
Mammalian Herbivore (Meadow Vole)	100% foliage	0.0875	0.032
Mammalian Ground Invertivore[d] (Short-tailed shrew)	100% earthworms	0.209	0.030
Mammalian Carnivore (Long-tailed weasel)	100% small mammals	0.130	0.043
Avian Granivore (Mourning dove)	100% seeds	0.190	0.139
Avian Ground Invertivore[d] (American woodcock)	100% earthworms	0.214	0.164
Avian Carnivore (Red-tailed hawk)	100% small mammals that consume 100% earthworms	0.0353	0.057

[a] Source: EPA (2005).

[b] High-end point estimate based on measured data (see EPA 2005, Attachment 4-1 for derivation); dw = dry weight; bw = receptor bodyweight.

[c] Soil ingestion as proportion of diet (See EPA 2005 Attachment 4-1 for derivation).

[d] Uptake for invertivores will be estimated in the models by assuming earthworm prey.

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C.2 BIOACCUMULATION FACTORS (BAFs) FOR ESTIMATING EXPOSURE TO AQUATIC WILDLIFE

Bioaccumulation factors used to estimate concentrations of per- and polyfluorinated alky substances (PFAS) in prey items based upon exposure to soil containing PFAS and used as inputs for modeling exposure of representative mammal and bird species to PFAS are presented in Table C-2.

Table C-2 Bioaccumulation Factors Used for Estimating Food Chain Exposure of Terrestrial Wildlife to PFAS

PFAS	Soil to Invertebrates	Soil to Plants	Soil to Small Mammals
Carboxylic Acids			
PFBA	7[a]	8[a]	NA[c]
PFHxA	1.9[a]	2.2[a]	NA[c]
PFOA	2.15[b]	0.11[a]	NA[c]
PFNA	4.08[b]	1.1[a]	NA[c]
PFDA	5.27[b]	0.7[a]	NA[c]
Sulfonic Acids			
PFBS	3[a]	3.6[a]	NA[c]
PFHxS	23.6[b]	1.5[a]	NA[c]
PFOS	18.0[b]	0.66[a]	11[a]

[a] Based upon estimates provided in Divine et al. (2020).

[b] Rich et al. (2015). Estimate based on 28-day exposure of earthworms to various soil types.

[c] No value identified. A default value of 1.0 was used as an estimate.

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C.3 TOXICITY REFERENCE VALUES FOR TERRESTRIAL MAMMALS AND BIRDS

The toxicity reference values (TRVs; mg PFAS/kg organism bodyweight per day) that were used to calculate ecological screening values (ESVs) for terrestrial wildlife exposed to contaminated soils were either adopted from DCPH published values (Johnson et al. 2021) or derived based upon a review of existing literature as described in Appendix A. Table C-3.1 presents the final TRVs that were used for representative terrestrial mammals and birds. Table C-3.2 presents uncertainty factors (UFs) applied to derive TRVs from laboratory test doses. For TRVs adopted from DCPH, the UFs used in their derivation are listed. UFs applied here followed GLI guidance (EPA 1995a, b), which includes UFs for extrapolating across taxa ($\mathrm{UF_A}$), from sub-chronic-to-chronic exposure durations ($\mathrm{UF_S}$), and from LOAEL-to-NOAEL endpoints ($\mathrm{UF_L}$). For $\mathrm{UF_A}$, a factor of 2 was applied for each taxonomic level the representative species was removed from the test species. For $\mathrm{UF_S}$, a value of 5 was applied for extrapolating from sub-chronic to chronic exposures. No $\mathrm{UF_L}$ values were needed for the TRVs developed in this report.

Table C-3.1 TRVs for Terrestrial Mammals and Birds[a]

Compound	Mammalian Herbivore (Meadow Vole)	Mammalian Ground Invertivore (Short-tailed Shrew)	Mammalian Carnivore (Long-tailed Weasel)	Avian Granivore (Mourning Dove)	Avian Ground Invertivore (American Woodcock)	Avian Carnivore (Red-tailed Hawk)
Carboxylic Acids						
PFBA	4.38[b]	4.38[b]	4.38[b]	NA[c]	NA[c]	NA[c]
PFHxA	2.50[d]	2.50[d]	2.50[d]	NA[c]	NA[c]	NA[c]
PFOA	1.75[e]	1.75[e]	1.75[e]	NA[c]	NA[c]	NA[c]
PFNA	0.021[f]	0.021[f]	0.021[f]	NA[c]	NA[c]	NA[c]
PFDA	0.075[g]	0.075[g]	0.075[g]	NA[c]	NA[c]	NA[c]
Sulfonic Acids						
PFBS	5.3[h]	5.3[h]	5.3[h]	105[i]	105[i]	105[i]
PFHxS	1.43[j]	0.715[j]	0.715[j]	NA[c]	NA[c]	NA[c]
PFOS	0.030[k]	0.015[k]	0.015[k]	0.15[l]	0.15[l]	0.15[l]

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[a] The presented TRVs (mg/kg-day) for the various surrogate species were derived from the test dose identified in the selected study for a corresponding test species after applying suitable values for uncertainty factors for extrapolating across species(UF_a), for extrapolating from

sub-chronic to chronic exposures (UF_S), and for extrapolating from a LOAEL to a NOAEL (UF_L). The presented TRVs were calculated as the test dose for the selected effect and endpoint from the selected study for the test species divided by the product of all three uncertainty factors as they apply.

[b] Das et al. (2008) – PFBA NOAEL of 35 mg/kg-day for reproduction and growth in mice for chronic (294-day) exposures converted to a TRV of 4.38 mg/kg-day after applying UF_A =8.

[c] NA = no suitable TRV value identified.

[d] Iwai and Hoberman (2014). PFHxA NOAEL of 100 mg/kg-day for mice pup development (bodyweight) for sub-chronic (18-day) exposures converted to a TRV of 4.17 mg/kg-day after applying UF_A =8 × UF_S =5 (UF_{tot} = 40).

[e] DeWitt et al. (2008). PFOA benchmark dose low (BMDL) value of 1.75 mg/kg-day for immunomodulation effects in female mice in sub-chronic (15-day) exposures as derived as the TRV by Johnson et al. (2021) citing this study; the use of a sensitive endpoint in a sensitive test species required no further application of uncertainty factors for class Mammalia.

[f] Wolf et al. (2010). PFNA NOAEL of 0.83 mg/kg-day for reproductive effects in mice in sub-chronic (18-day) exposures converted to a TRV of 0.021 mg/kg-day after applying UF_A = 8 × UF_S = 5 (UF_{tot} = 40).

[g] Harris and Birnbaum (1989). PFDA NOAEL of 3 mg/kg-day for development (fetal bodyweight) in mice in sub-chronic (18-day) exposures converted to a TRV of 0.075 mg/kg-day after applying UF_A = 8 × UF_S = 5 (UF_{tot} = 40).

[h] Leider et al. (2009). PFBS NOAEL of 60 mg/kg-day for hematological effects in mice in sub-chronic (90-day) exposures converted to a TRV of 5.3 mg/kg-day by Johnson et al. (2021) citing this study after adjusting for the molecular weight of potassium in the salt form used in the study (60 × 0.8 = 53) and applying UF_{tot} = 10.

[i] Newsted et al. (2008). PFBS LOAEL of 3,160 mg/kg-day for growth (bodyweight) in bobwhite in acute exposures converted to a TRV of 105 mg/kg-day by Johnson et al. (2021) citing this study after applying UF_{tot} = 30.

[j] Narizzano and Bohannon (2021). PFHxS benchmark dose low (BMDL) value of 5.72 mg/kg-day for stillbirths in deer mouse after 28-d chronic exposure converted to a TRV of 0.715 mg/kg-day for short-tailed shrew and long-tailed weasel after applying UF_A = 8 x UF_S = 1 x UF_L = 1 (UF_{tot} = 8), and to a TRV of 1.43 mg/kg-day for meadow vole after applying a UF_A = 4 x UF_S = 1 x UF_L = 1 (UF_{tot} = 4).

[k] Narizzano and Bohannon (2021). PFOS benchmark dose low (BMDL) value of 0.12 mg/kg-day for total litter loss in white-footed mouse after 28-d chronic exposure converted to a TRV of 0.015 mg/kg-day for short-tailed shrew and long-tailed weasel after applying UF_A = 8 x UF_S = 1 x UF_L = 1 (UF_{tot} = 8), and to a TRV of 0.030 mg/kg-day for meadow vole after applying a UF_A = 4 x UF_S = 1 x UF_L = 1 (UF_{tot} = 4).

[l] Newsted et al. (2007); Gallagher et al. (2003a,b). PFOS NOAEL of 1.5 mg/kg-day for reproductive effects in bobwhite and mallard in chronic exposures converted to a TRV of 0.15 mg/kg-day by Johnson et al. (2021) citing these studies after applying UF_{tot} = 10.

Table C-3.2 Summary of Uncertainty Factors[a] and Derivation of TRVs

PFAS	UF_A	UF_S	UF_L	UF_{tot}	Test Dose[b] (mg/kg-d)	Endpoint	TRV (mg/kg-d)
Mammalian (Invertivore)							
PFBA	8	1	1	8	35	NOAEL	4.38
PFHxA	8	5	1	40	100	NOAEL	2.50
PFOA	-[c]	-	-	1	1.75	BMDL	1.75
PFNA	8	5	1	40	0.83	NOAEL	0.021
PFDA	8	5	1	40	3	NOAEL	0.075
PFBS	-	-	-	10	53	NOAEL	5.3
PFHxS	8	1	1	8	5.72	BMDL	0.715
PFOS	8	1	1	8	0.12	BMDL	0.015
Avian							
PFBS	-	-	-	30	3,160	LOAEL	105
PFOS	-	-	-	10	1.5	NOAEL	0.15

[a] Uncertainty Factors for Inter-taxon Extrapolation (UF_A), Extrapolation Across Exposure Durations (UF_S), Extrapolating across Endpoints (UF_L), and total uncertainty (UF_{tot}). See Section 3.6.2 for a discussion of uncertainty factors.

[b] Source studies for test dose and endpoint are identified in Table C-3.1

[c] A dash indicates TRVs derived by Johnson et al. 2021, where only a UF_{tot} was identified.

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C.4 ESVs for Terrestrial Wildlife

The soil-based ESVs derived for terrestrial mammals and birds based on ingestion modeling are presented in Table C-4. Methods for derivation of the ESVs for terrestrial wildlife are described in Appendix A.

Table C-4 Soil-Based Ecological Screening Values (mg PFAS/kg soil) for Representative Terrestrial Mammals and Birds[a]

Compound	Mammalian Herbivore (Meadow Vole)	Mammalian Ground Invertivore (Short-tailed Shrew)	Mammalian Carnivore (Long-tailed Weasel)	Avian Granivore (Mourning Dove)	Avian Ground Invertivore (American Woodcock)	Avian Carnivore (Red-tailed Hawk)
Carboxylic Acids						
PFBA	6.23	**2.98**	32.3	--[b]	--[b]	--[b]
PFHxA	12.8	**6.20**	18.4	--[b]	--[b]	--[b]
PFOA	141	**3.84**	12.9	--[b]	--[b]	--[b]
PFNA	0.209	**0.0242**	0.153	--[b]	--[b]	--[b]
PFDA	1.17	**0.0677**	0.553	--[b]	--[b]	--[b]
Sulfonic Acids						
PFBS	16.7	**0.817**	39.1	148	**15.8**	2,820
PFHxS	10.7	**0.145**	5.27	--[b]	--[b]	--[b]
PFOS	0.495	**0.0040**	0.010	0.988	**0.0386**	0.384

[a] The minimum soil-based ESV for each PFAS for both mammals and birds is identified using bold text.

[b] Insufficient data were available to develop an ESV.

APPENDIX D: AQUATIC LIFE

D.1 FRESHWATER

D.1.1 PFBA

Table D.1.1-1 PFBA Freshwater Acute LC/EC50 Values for Aquatic ESV Derivation

Family	Genus	Species Common Name	Species Scientific Name	Effect Measurement	Endpoint	Conc (mg/L)	Chemical Analysis	Exposure Type	Life Stage	Duration (days)	Author	Year	ECOTOX Ref No.
Brachionidae	*Brachionus*	Rotifer	*Brachionus calyciflorus*	Mortality	LC50	110	Not reported	Static	Neonate	1	Wang, et al.	2014	175717
Chydoridae	*Chydorus*	Daphnid	*Chydorus sphaericus*	Mortality	EC50	462	Unmeasured	Static	Neonate	2	Ding et al.	2012a	a0620
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	>3,000	Unmeasured	Static	Embryo	4	Hagenaars, et al	2011	152104
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Multiple	EC50	2,200	Unmeasured	Static	Embryo	6	Ulhaq, et al.	2013	165818
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	13,795	Unmeasured	Renewal	Gastrula	4	Godfrey, et al.	2017	177139
Daphniidae	*Daphnia*	Water flea	*Daphnia magna*	Mortality	LC50	>1,006	Unmeasured	Static	Not reported	2	Boudreau	2002	175259
Daphniidae	*Daphnia*	Water flea	*Daphnia magna*	Mortality	EC50	182	Unmeasured	Static	Neonate	2	Ding, et al.	2012a	a0620
Daphniidae	*Daphnia*	Water flea	*Daphnia pulicaria*	Mortality	LC50	>1,006	Unmeasured	Static	Not reported	2	Boudreau	2002	175259

Table D.1.1-2 PFBA Genus Geomeans of Acute LC/EC50 Values

Family	Genus	Genus Geomean (µg/L)
Brachionidae	*Brachionus*	110,000
Chydoridae	*Chydorus*	462,000
Cyprinidae	*Danio*	4,498,715
Daphniidae	*Daphnia*	656,087

Table D.1.1-3 PFBA Freshwater ESV Derivation (per EPA 2012 Tier II Methodology)

Lowest GMAV (µg/L)	**110,000**		**Plant Values (IC/EC50, µg/L)**		
Number of Tier I taxa out of 8	4		*Pseudokircheriella*	262,198	Ding, et al. 2012c
Secondary Acute Factor (SAF)	7		*Pseudokircheriella*	620,715	Boudreau 2002
Secondary Acute Value (SAV) (µg/L)	15,714		*Chlorella*	727,735	Boudreau 2002
Secondary Acute Chronic Ratio (SACR)[a]	207.5				
Secondary Chronic Value (SCV) (µg/L)	75.7				
Final Plant Value (FPV) (µg/L)	262,198				
Exposure ESV (µg/L)	**75.7**				

[a] The SACR was taken from the provisional value for PFOA in EPA's draft water quality criteria report for PFOA (EPA 2022a).

D.1.2 PFHxA

Table D.1.2-1 PFHxA Freshwater Acute LC/EC50 Values for Aquatic ESV Derivation

Family	Genus	Species Common Name	Species Scientific Name	Effect Measurement	Endpoint	Conc (mg/L)	Chemical Analysis	Exposure Type	Life Stage	Duration (days)	Author	Year	ECOTOX Ref No.
Brachionidae	*Brachionus*	Rotifer	*Brachionus calyciflorus*	Mortality	LC50	140	Not reported	Static	Neonate	1	Wang, et al.	2014	175717
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	91.1	Unmeasured	Static	Embryo	5	Annunziato, et al.	2019	178562

Table D.1.2-2 PFHxA Genus Geomeans of Acute LC/EC50 Values

Family	Genus	Genus Geomean (µg/L)
Brachionidae	*Brachionus*	140,000
Cyprinidae	*Danio*	91,076

Table D.1.2-3 PFHxA Freshwater ESV Derivation (per EPA 2012 Tier II Methodology)

Lowest GMAV	91,076		Plant Values (EC50, µg/L)		
Number of Tier I taxa out of 8	2		*Skeletonema marinoi*	1,482,340	Latala et al. 2009
Secondary Acute Factor (SAF)	13		*Scenedesmus acutus* var. *acutus*	628,110	Liu et al. 2008
Secondary Acute Value (SAV) (µg/L)	7,006		*Chlorella vulgaris*	4,032,468	Latala et al. 2009
Secondary Acute Chronic Ratio (SACR)[a]	207.5				
Secondary Chronic Value (SCV) (µg/L)	33.8				
Final Plant Value (FPV) (µg/L)	682,110				
Chronic Exposure ESV (µg/L)	**33.8**				

[a] The SACR was taken from the provisional value for PFOA in EPA's draft water quality criteria report for PFOA (EPA 2022a).

D.1.3 PFOA

Table D.1.3-1 PFOA Freshwater Acute LC/EC50 Values for Aquatic ESV Derivation

Family	Genus	Species Common Name	Species Scientific Name	Effect	End-point	Conc (mg/L)	Chemical Analysis	Exposure Type	Life Stage	Dura-tion (days)	Author	Year	ECO-TOX Ref No
Ambystomatidae	*Ambystoma*	Jefferson's salamander	*Ambystoma jeffersonianum*	Mortality	LC50	1070	Unmeasured	Static	Larva	4	Tornabene, et al.	2021	185550
Ambystomatidae	*ambystoma*	Small mouthed salamander	*Ambystoma texanum*	Mortality	LC50	474	Unmeasured	Static	Larva	4	Tornabene, et al.	2021	185550
Ambystomatidae	*ambystoma*	Tiger salamander	*Ambystoma tigrinum*	Mortality	LC50	752	Unmeasured	Static	Larva	4	Tornabene, et al.	2021	185550
Baetidae	*Macrophthalmus*	Mayfly	*Neocloeon triangulifer*	Mortality	LC50	13	Measured	Static	Larva	4	Soucek, et al.	2023	--
Bufonidae	*anaxyrus*	American toad	*Anaxyrus americanus*	Mortality	LC50	711	Unmeasured	Static	Larva	4	Tornabene, et al.	2021	185550
Brachionidae	*Brachionus*	Rotifer	*Brachionus calyciflorus*	Mortality	LC50	150	Reported	Static	Neonate	1	Zhang, et al.	2013	175669
Ranidae	*Bufo*	Asiatic toad	*Bufo gargarizans*	Mortality	LC50	114	Reported	Static	Tadpole	4	Yang, et al.	2014	175260
Cyprinidae	*Carassius*	Goldfish	*Carassius auratus*	Mortality	LC50	606	Reported	Static	Not reported	4	Yang, et al.	2014	175260
Chironomidae	*Chironomus*	Midge	*Chironomus plumosus*	Mortality	LC50	402	Reported	Static	Larva	4	Yang, et al.	2014	175260
Viviparidae	*Cipangopaludina*	Snail	*Cipangopaludina cathayensis*	Mortality	LC50	740	Reported	Static	Not reported	4	Yang, et al.	2014	175260
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	24.6	Unmeasured	Not reported	Embryo	4	Corrales, et al.	2017	177136
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	386	Not Reported	Renewal	Embryo	4	Ding, et al.	2012b	181737
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	386	Unmeasured	Renewal	Egg	4	Ding, et al.	2013	175221
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	82.8	Unmeasured	Static	Embryo	2	Gebreab, et al.	2020	184984
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	473	Unmeasured	Renewal	Gastrula	4	Godfrey, et al.	2017	177139
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Multiple	EC50	206	Unmeasured	Static	Embryo	4	Hagenaars, et al.	2011	152104
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	157	Unmeasured	Static	Embryo	4	Kalasekar, et al.	2015	172976
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	300	Unmeasured	Static	Embryo	2	Pecquet, et al.	2020	184778
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	500	Reported	Static	Embryo	2	Rainieri, et al.	2017	181025
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	33.9	Unmeasured	Static	Embryo	0.8	Satbhai, et al.	2022	189936
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Morphology	EC50	759	Unmeasured	Renewal	Embryo	4	Stengel, et al.	2017	176328
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	759	Unmeasured	Renewal	Embryo	4	Stengel, et al.	2018	188159
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	47.3	Unmeasured	Static	Embryo	1	Weiss-Errico, et al.	2017	181466
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	499	Unmeasured	Renewal	Embryo	4	Ye, et al.	2007	185056

Family	Genus	Species Common Name	Species Scientific Name	Effect	End-point	Conc (mg/L)	Chemical Analysis	Exposure Type	Life Stage	Dura-tion (days)	Author	Year	ECO-TOX Ref No
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	119	Reported	Static		4	Zhao, et al.	2016	188617
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	262	Unmeasured	Not reported	Embryo	0.33	Zheng, et al.	2012	160547
Daphniidae	*Daphnia*	Water flea	*Daphnia magna*	Mortality	LC50	269	Unmeasured	Static	Not reported	2	Boudreau	2002	175259
Daphniidae	*Daphnia*	Water flea	*Daphnia pulicaria*	Mortality	LC50	277	Unmeasured	Static	Not reported	2	Boudreau	2002	175259
Daphniidae	*Daphnia*	Water flea	*Daphnia magna*	Mortality	LC50	139	Unmeasured	Static	Neonate	2	Lu, et al.	2016	184769
Daphniidae	*Daphnia*	Water flea	*Daphnia magna*	Mortality	LC50	121	Unmeasured	Static	Neonate	2	Yang, et al.	2019	182580
Daphniidae	*Daphnia*	Water flea	*Daphnia magna*	Mortality	LC50	202	Reported	Static	Not reported	2	Yang, et al.	2014	175260
Dugesiidae	*Dugesia*	Planaria	*Dugesia japonica*	Mortality	LC50	337	Unmeasured	Not reported	Not reported	4	Li	2009	118450
Dugesiidae	*Dugesia*	Planaria	*Dugesia japonica*	Mortality	LC50	39	Unmeasured	Renewal	Not reported	4	Yuan, et al.	2015	177055
Hylidae	*Hyla*	Grey tree frog	*Hyla versicolor*	Mortality	LC50	191	Unmeasured	Static	Larva	4	Tornabene, et al.	2021	185550
Centrarchidae	*Lepomis*	Bluegill	*Lepomis macrochirus*	Mortality	LC50	634	Unmeasured	Not reported	Not reported	4	Dupont Haskell Laboratory	2000	151364
Tubificidae	*Limnodrilus*	Redworm	*Limnodrilus hoffmeisteri*	Mortality	LC50	568	Reported	Static	Not reported	4	Yang, et al.	2014	175260
Ranidae	*lithobates*	Wood Frog	*Lithobates sylvaticus*	Mortality	LC50	999	Unmeasured	Static	Larva	4	Tornabene, et al.	2021	185550
Ranidae	*Lithobates*	Bronze frog	*Lithobates clamitans*	Mortality	LC50	1070	Unmeasured	Static	Larva	4	Tornabene, et al.	2021	185550
Ranidae	*Lithobates*	Bullfrog	*Rana catesbeiana*	Mortality	LC50	1060	Unmeasured	Static	Larva	4	Tornabene, et al.	2021	185550
Ranidae	*Lithobates (Rana)*	Northern leopard frog	*Lithobates pipiens*	Mortality	LC50	752	Unmeasured	Static	Larva	4	Tornabene, et al.	2021	185550
Palaemonidae	*Macrobrachium*	Oriental river prawn	*Macrobrachium nipponense*	Mortality	LC50	367	Reported	Static	Not reported	4	Yang, et al.	2014	175260
Atyidae	*Neocaridina*	Cherry shrimp	*Neocaridina denticulata*	Mortality	LC50	454	Unmeasured	Not reported	Not reported	4	Li	2009	118450
Salmonidae	*Oncorhynchus*	Rainbow trout	*Oncorhynchus mykiss*	Mortality	LC50	707	Unmeasured	Static	Not reported	4	Colombo, et al.	2008	151611
Salmonidae	*Oncorhynchus*	Rainbow trout	*Oncorhynchus mykiss*	Mortality	LC50	4000	Measured	Static	Not reported	4	Dupont Haskell Laboratory	2000	151364
Physidae	*Physella*	European physa	*Physella acuta*	Mortality	LC50	672	Unmeasured	Not reported	Not reported	4	Li	2009	118450
Cyprinidae	*Pimephales*	Fathead minnow	*Pimephales promelas*	Mortality	LC50	413	Unmeasured	Not reported	Larva	4	Corrales, et al.	2017	177136
Cyprinidae	*Pimephales*	Fathead minnow	*Pimephales promelas*	Mortality	LC50	754	Unmeasured	Static		4	Elnabarawy	1980	188557
Cyprinidae	*Pseudorasbora*	Stone moroco	*Pseudorasbora parva*	Mortality	LC50	365	Reported	Static	Not reported	4	Yang, et al.	2014	175260
Unionidae	*Sinanodonta*	Adventive Swan-mussel	*Sinanodonta woodiana*	Mortality	LC50	192	Unmeasured	Static		2	Xia, et al.	2018	184302

Family	Genus	Species Common Name	Species Scientific Name	Effect	End-point	Conc (mg/L)	Chemical Analysis	Exposure Type	Life Stage	Dura-tion (days)	Author	Year	ECO-TOX Ref No
Pipidae	*Xenopus*	Clawed frog	*Xenopus sp.*	Morphology	EC50	258	Unmeasured	Renewal	Blastula	4	Kim, et al.	2013	170608

Table D.1.3-2 PFOA Genus Geomeans of Acute LC/EC50 Values

Family	Genus	Genus Geomean (ug/L)	Rank
Baetidae	Macrophthalmus	13451	1
Ranidae	Bufo	114740	2
Dugesiidae	Dugesia	115156	3
Brachionidae	Brachionus	150000	4
Hylidae	Hyla	191000	5
Unionidae	Sinanodonta	192083	6
Cyprinidae	Danio	205370	7
Daphniidae	Daphnia	219232	8
Pipidae	Xenopus	257635	9
Cyprinidae	Pseudorasbora	365020	10
Palaemonidae	Macrobrachium	366660	11
Chironomidae	Chironomus	402240	12
Atyidae	Neocaridina	454000	13
Cyprinidae	Pimephales	558169	14
Tubificidae	Limnodrilus	568200	15
Cyprinidae	Carassius	606610	16
Centrarchidae	Lepomis	634000	17
Physidae	Physella	672000	18
Bufonidae	Anaxyrus	711000	19
Ambystomatidae	Ambystoma	725204	20
Viviparidae	Cipangopaludina	740070	21
Ranidae	Lithobates	960767	22
Salmonidae	Oncorhynchus	1681876	23

Table D.1.3-3 PFOA Freshwater ESV Derivation (per EPA 2012 Tier I Methodology)

Number of Tier I taxa out of 8	**8**		**Plant Values (µg/L)**			
Final Acute Value (µg/L) =	22,707		*Clamydomonas*	EC50	51,900	Hu et al. 2014
Final Acute Chronic Ratio[a]	207.5		*Chlorella*	EC50	190,990	Xu et al. 2013
Final Plant Value (µg/L)	44,000		*Pseudokirchinella*	EC50	207,460	Xu et al. 2013
			Scenedesmus	EC50	44,000	Hu et al. 2014
			Scenedesmus	EC50	269,630	Yang et al. 2014
Chronic Exposure ESV (µg/L)	**109.4**		*Lemna*	IC50	46,376	Boudreau 2002

[a] The Final ACR was taken from the provisional value for PFOA in EPA's draft water quality criteria report for PFOA (EPA 2022a).

D.1.4 PFNA

Table D.1.4-1 PFNA Freshwater Acute LC/EC50 Values for Aquatic ESV Derivation

Family	Genus	Species Common Name	Species Scientific Name	Effect	End-point	Conc (mg/L)	Chemical Analysis	Exposure Type	Life Stage	Dura-tion (days)	Author	Year	ECOTOX Ref No
Chydoridae	*Chydorus*	Daphnid	*Chydorus sphaericus*	Mortality	EC50	28.0	Unmeasured	Static	Neonate	2	Ding, et al.	2012a	a0620
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	108.6	Reported	Static	Embryo	2	Rainieri, et al.	2017	181025
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	140.2	Unmeasured	Static	Embryo	0.96	Liu, et al.	2015	181408
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	84.0	Unmeasured	Not reported	Embryo	3	Zheng,et al.	2012	160547
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Multiple	EC50	16.0	Unmeasured	Static	Embryo	6	Ulhaq,et al.	2013	165818
Daphniidae	*Daphnia*	Water flea	*Daphnia magna*	Mortality	LC50	80.9	Unmeasured	Static	Neonate	2	Lu, et al.	2015	177104
Daphniidae	*Daphnia*	Water flea	*Daphnia magna*	Mortality	LC50	120.2	Unmeasured	Static	Not reported	2	Boudreau,	2002	175259
Daphniidae	*Daphnia*	Water flea	*Daphnia magna*	Mortality	EC50	151.0	Unmeasured	Static	Neonate	2	Ding,et al.	2012a	a0620
Daphniidae	*Daphnia*	Water flea	*Daphnia pulicaria*	Mortality	LC50	8.8	Unmeasured	Static	Not reported	21	Boudreau.	2002	175259
Pipidae	*Xenopus*	Clawed frog	*Xenopus sp.*	Morphology	EC50	234.9	Unmeasured	Renewal	Blastula	4	Kim,et al.	2013	170608

Table D.1.4-2 PFNA Genus Geomeans Acute LC/EC50 Values

Family	Genus	Genus Geomean (µg/L)
Chydoridae	*Chydorus*	28,000
Cyprinidae	*Danio*	31,659
Daphniidae	*Daphnia*	67,252
Pipidae	*Xenopus*	234,870

Table D.1.4-3 PFNA Freshwater ESV Derivation (per EPA 2012 Tier II Methodology)

Lowest GMAV	**28,000**		**Plant Values (IC50, µg/L)**		
Number of Tier I taxa out of 8	3		*Lemna*	89,103	Boudreau 2002
Secondary Acute Factor (SAF)	8				
Secondary Acute Value (SAV) (µg/L)	3,500				
Secondary Acute Chronic Ratio (SACR)[a]	207.5				
Secondary Chronic Value (SCV) (µg/L)	19.3				
Final Plant Value (FPV) (µg/L)	89,103				
Chronic Exposure ESV (µg/L)	**16.9**				

[a] The SACR was taken from the provisional value for PFOA in EPA's draft water quality criteria report for PFOA (EPA 2022a).

D.1.5 PFDA

Table D.1.5-1 PFDA Freshwater Acute LC/EC50 Values for Aquatic ESV Derivation

Family	Genus	Common Name	Scientific Name	Effect Measurement	Endpoint	Conc (mg/L)	Chemical Analysis	Exposure Type	Life Stage	Observed Duration (days)	Author	Year	ECOTOX Ref No.
Chydoridae	*Chydorus*	Daphnid	*Chydorus sphaericus*	Mortality	EC50	45	Not reported	Not reported	Not reported	2	Ding,et al.	2012a	a0620
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Multiple	EC50	5	Unmeasured	Static	Embryo	6	Ulhaq, et al.	2013	165818
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Mortality	EC50	163	Not reported	Not reported	Not reported	2	Ding, et al.	2012a	a0620
Daphniidae	*Daphnia*	Water flea	*Daphnia magna*	Mortality	LC50	258.6	Unmeasured	Static	Not reported	2	Boudreau	2002	175259
Daphniidae	*Daphnia*	Water flea	*Daphnia pulicaria*	Mortality	LC50	284.8	Unmeasured	Static	Not reported	2	Boudreau	2002	175259
Salmonidae	*Oncorhynchus*	Rainbow trout	*Oncorhynchus mykiss*	Mortality	LC50	32	Unmeasured	Static	Not reported	4	Hoke, et al.	2012	161077
Pipidae	*Xenopus*	Clawed frog	*Xenopus* sp.	Morphology	EC50	59.3	Unmeasured	Renewal	Blastula	4	Kim, et al.	2013	170608

Table D.1.5-2 PFDA Genus Geomeans of Acute LC/EC50 Values

Family	Genus	Genus Geomean (µg/L)
Cyprinidae	*Danio*	5,000
Salmonidae	*Oncorhynchus*	32,000
Chydoridae	*Chydorus*	45,000
Pipidae	*Xenopus*	59,325
Daphniidae	*Daphnia*	241,808

Table D.1.5-3 PFDA Freshwater ESV Derivation (per EPA 2012 Tier II Methodology)

Lowest GMAV	**5,000**		**Plant Values (IC50/EC50, µg/L)**		
Number of Tier I taxa out of 8	4		*Chlorella*	198,440	Boudreau 2002
Secondary Acute Factor (SAF)	7		*Pseudokircheriella*	218,490	Boudreau 2002
Secondary Acute Value (SAV) (µg/L)	714		*Pseudokircheriella*	10,600	Hoke et al. 2012
Secondary Acute Chronic Ratio (SACR)[a]	207.5		*Lemna*	99,220	Boudreau 2002
Secondary Chronic Value (SCV) (µg/L)	3.44				
Final Plant Value (FPV) (µg/L)	10,600				
Chronic Exposure ESV (µg/L)	**3.44**				

[a] The SACR was taken from the provisional value for PFOA in EPA's draft water quality criteria report for PFOA (EPA 2022a).

D.1.6 PFBS

Table D.1.6-1 PFBS Freshwater Acute LC/EC50 Values for Aquatic ESV Derivation

Family	Genus	Common Name	Scientific Name	Effect Measurement	Endpoint	Conc (mg/L)	Chemical Analysis	Exposure Type	Life Stage	Observed Duration (days)	Author	Year	ECOTOX Ref No.
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Multiple	EC50	1,529	Unmeasured	Static	Embryo	4	Hagenaars et al.	2011	152104
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Multiple	EC50	450	Unmeasured	Static	Embryo	6	Ulhaq et al.	2013	165818
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	922	Unmeasured	Renewal	Embryo	7	Stincken,,et al.	2018	184848
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	393	Unmeasured	Renewal	Embryo	5	Sant., et al.	2019	182595
Centrarchidae	*Lepomis*	Bluegill	*Lepomis macrochirus*	Mortality	LC50	6452	Measured	Static	Juvenile	3	Drottar and Krueger	2001	185938
Cyprinidae	*Pimephales*	Fathead minnow	*Pimephales promelas*	Mortality	LC50	1938	Measured	Static	Juvenile	3	Wildlife International	2001	185937

Table D.1.6-2 PFBS Genus Geomeans of Acute LC/EC50 Values

Family	Genus	Genus Geomean (µg/L)
Cyprinidae	*Danio*	706,694
Cyprinidae	*Pimephales*	1,938,000
Centrarchidae	*Lepomis*	6,452,000

Table D.1.6-3 PFBS Freshwater EVS Derivation (per EPA 2012 Tier II Methodology)

Lowest GMAV	**706,694**		**Plant Values (EC50, µg/L)**		
Number of Tier I taxa out of 8	2		Pseudokirchneriella	>20,250,000	Rosal et al. 2010
Secondary Acute Factor (SAF)	13				
Secondary Acute Value (SAV) (µg/L)	54,361				
Secondary Acute Chronic Ratio (SACR)[a]	122				
Secondary Chronic Value (SCV) (µg/L)	446				
Final Plant Value (FPV) (µg/L)	20,250,000				
Chronic Exposure ESV (µg/L)	**446**				

[a] The SACR was taken as the provisional ACR value for PFOS in EPA’s draft water quality criteria report for PFOS (EPA 2022b).

D.1.7 PFHxS

Table D.1.7-1 PFHxS Freshwater Acute LC/EC50 Values for Aquatic ESV Derivation

Family	Genus	Species Common Name	Species Scientific Name	Effect Measurement	End-point	Conc (mg/L)	Chemical Analysis	Exposure Type	Life Stage	Observed Duration (days)	Author	Year	ECO-TOX Ref No.
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	149	Unmeasured	Static	Embryo	5	Annunziato, et al.	2019	178562
Ranidae	*Lithobates*	Bronze Frog	*Lithobates clamitans*	Mortality	LC50	758	Unmeasured	Static	Larva	4	Tornabene, et al.	2021	185550
Ranidae	*Rana*	Bullfrog	*Rana catesbeiana*	Mortality	LC50	1105	Unmeasured	Static	Larva	4	Tornabene, et al.	2021	185550

Table D.1.7-2 PFHxS Genus Geomeans of Acute LC/EC50 Values

Family	Genus	Genus Geomean (µg/L)
Cyprinidae	*Danio*	149,331
Ranidae	*Lithobates*	758,000
Ranidae	*Rana*	1,105,000

Table D.1.7-3 PFHxS Freshwater ESV Derivation (per EPA 2012 Tier II Methodology)

Lowest GMAV	**149,331**
Number of Tier I taxa out of 8	2
Secondary Acute Factor (SAF)	13
Secondary Acute Value (SAV) (µg/L)	11,487
Secondary Acute Chronic Ratio (SACR)[a]	122
Secondary Chronic Value (SCV) (µg/L)	94.2
Final Plant Value (FPV) (µg/L)	Not available
Chronic Exposure ESV (µg/L)	**94.2**

[a] The SACR was taken as the provisional ACR value for PFOS in EPAs' draft water quality criteria report for PFOS (EPA 2022b).

D.1.8 PFOS

Table D.1.8-1 PFOS Freshwater Acute LC/EC50 Values for Aquatic ESV Derivation

Family	Genus	Species Common Name	Species Scientific Name	Effect	End-point	Conc (mg/L)	Chemical Analysis	Expo-sure Type	Life Stage	Dura-tion (days)	Author	Year	ECO-TOX Ref No.
Ambystomatidae	*Ambystoma*	Jefferson's Salamander	*Ambystoma jeffersonianum*	Mortality	LC50	64	Unmeasured	Static	Larva	4	Tornabene, et al.	2021	185550
Ambystomatidae	*Ambystoma*	Texas Salamander	*Ambystoma texanum*	Mortality	LC50	41	Unmeasured	Static	Larva	4	Tornabene, et al.	2021	185550
Ambystomatidae	*Ambystoma*	Tiger Salamander	*Ambystoma tigrinum*	Mortality	LC50	73	Unmeasured	Static	Larva	4	Tornabene, et al.	2021	185550
Baetidae	*Macrophthalmus*	Mayfly	*Neocloeon triangulifer*	Mortality	LC50	0.082	Measured	Static	Larva	4	Soucek, et al.	2023	--
bufonidae	*Anaxyrus*	American Toad	*Anaxyrus americanus*	Mortality	LC50	62	Unmeasured	Static	Larva	4	Tornabene, et al.	2021	185550
Brachionidae	*Brachionus*	Rotifer	*Brachionus calyciflorus*	Mortality	LC50	61.8	Reported	Static	Neonate	1	Zhang, et al.	2013	175669
Ranidae	*Bufo*	Asiatic toad	*Bufo gargarizans*	Mortality	LC50	48.2	Reported	Static	Tadpole	4	Yang, et al.	2014	175260
Cyprinidae	*Carassius*	Goldfish	*Carassius auratus*	Mortality	LC50	81.2	Reported	Static	Not reported	4	Yang, et al.	2014	175260
Chironomidae	*Chironomus*	Midge	*Chironomus plumosus*	Mortality	LC50	182	Reported	Static	Larva	4	Yang, et al.	2014	175260
Viviparidae	*Cipangopaludina*	Snail	*Cipangopaludina cathayensis*	Mortality	LC50	247	Reported	Static	Not reported	4	Yang, et al.	2014	175260
Cyprinidae	*Cyprinus*	Common carp	*Cyprinus carpio*	Mortality	LC50	8.41	Unmeasured	Static	--	4	Wang, et al.	2020	184300
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	54.5	Unmeasured	Renewal	Egg	4	Ding, et al.	2013	175221
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Deformation	EC50	1.12	Unmeasured	Static	Embryo	4	Huang, et al.	2010	151614
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	58.5	Unmeasured	Static	Embryo	4	Hagenaars, et al.	2011	152104
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	54.5	--	Renewal	Embryo	4	Ding, et al.	2012b	181737
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	47.5	Unmeasured	Renewal	Embryo	4	Blanc,et al.	2019	180988
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	31.0	Unmeasured	Renewal	Embryo	3.9	Annunziato, et al.	2020	184678
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	24.0	Measured	Renewal	Embryo	4	Nilen, et al.	2022	189337
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	7.70	Reported	Renewal	Embryo	2	Sharpe, et al.	2010	151619
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	34.2	Unmeasured	Renewal	Embryo	4	Stengel, et al.	2017	175499
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Deformation	EC50	2.09	Unmeasured	Static	Embryo	4.75	Haggard,et al.	2018	181483
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	79.1	Unmeasured	Static	Embryo	4	Ding, et al.	2012d	184882

Family	**Genus**	**Species Common Name**	**Species Scientific Name**	**Effect**	**End-point**	**Conc (mg/L)**	**Chemical Analysis**	**Expo-sure Type**	**Life Stage**	**Dura-tion (days)**	**Author**	**Year**	**ECO-TOX Ref No.**
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Deformation	EC50	1.37	Measured	Static	Embryo	5	Mylroie, et al.	2021	184776
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	108	Reported	Static	Embryo	2	Rainieri, et al.	2017	181025
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	71	Unmeasured	Renewal	Embryo	4	Ye, et al.	2007	185056
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	3.5	Unmeasured	Renewal	Embryo	4	Wang, et al.	2017	175190
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	3.5	Unmeasured	Static	Embryo	4	Du, et al.	2016a	177124
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	68	Unmeasured	Not reported	Embryo	3	Zheng, et al.	2012	160547
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	2.58	Unmeasured	Static	--	4	Wang, et al.	2020	184300
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	17	Unmeasured	Renewal	--	4	Wang, et al.	2013	179859
Cyprinidae	*Danio*	Zebra danio	*Danio rerio*	Mortality	LC50	9.81	Unmeasured	Renewal	Embryo	3	Martinez, et al.	2019a	180956
Daphniidae	*Daphnia*	Water flea	*Daphnia magna*	Mortality	LC50	49.2	Unmeasured	Static	Instar	2	3M Co.	2000a	186121
Daphniidae	*Daphnia*	Water flea	*Daphnia magna*	Mortality	LC50	52.7	Unmeasured	Static	Larva	4	Wang, et al.	2020	184300
Daphniidae	*Daphnia*	Water flea	*Daphnia magna*	Mortality	EC50	61	Measured	Static	Neonate	2	Drottar and Krueger	2000a	175365
Daphniidae	*Daphnia*	Water flea	*Daphnia magna*	Survival	LC50	130	Unmeasured	Static	Neonate	2	Boudreau, et al.	2003b	71875
Daphniidae	*Daphnia*	Water flea	*Daphnia magna*	Mortality	LC50	78.1	Reported	Static	Not reported	2	Yang, et al.	2014	175260
Daphniidae	*Daphnia*	Water flea	*Daphnia magna*	Mortality	LC50	49.3	Unmeasured	Static	Neonate	2	Lu, et al.	2015	177104
Daphniidae	*Daphnia*	Water flea	*Daphnia magna*	Mortality	EC50	14	Unmeasured	Static	--	2	3M Co.	2000b	186122
Daphniidae	*Daphnia*	Water flea	*Daphnia magna*	Mortality	LC50	22.8	Unmeasured	Static	Neonate	2	Yang, et al.	2019	182580
Daphniidae	*Daphnia*	Water flea	*Daphnia pulicaria*	Survival	LC50	169	Unmeasured	Static	Neonate	2	Boudreau, et al.	2003b	71875
Dugesiidae	*Dugesia*	Planaria	*Dugesia japonica*	Mortality	LC50	17	Unmeasured	Static	Not reported	4	Li	2008	111070
Dugesiidae	*Dugesia*	Planaria	*Dugesia japonica*	Mortality	LC50	23	Unmeasured	Not reported	Not reported	4	Li	2009	118450
Dugesiidae	*Dugesia*	Planaria	*Dugesia japonica*	Mortality	LC50	29.5	Unmeasured	Renewal	Not reported	4	Yuan, et al.	2014	175659
Unionidae	*Elliptio*	Eastern elliptio	*Elliptio complanata*	Mortality	LC50	59	Measured	Renewal	Not reported	4	Drottar and Krueger	2000b	175369
hylidae	*Hyla*	Gray Tree Frog	*Hyla versicolor*	Mortality	LC50	24	Unmeasured	Static	Larva	4	Tornabene, et al.	2021	185550
Unionidae	*Lampsilis*	Fatmucket clam	*Lampsilis siliquoidea*	Mortality	EC50	16.5	Measured	Static	Glochidia	1	Hazelton, et al.	2012	160209

Family	**Genus**	**Species Common Name**	**Species Scientific Name**	**Effect**	**End-point**	**Conc (mg/L)**	**Chemical Analysis**	**Expo-sure Type**	**Life Stage**	**Dura-tion (days)**	**Author**	**Year**	**ECO-TOX Ref No.**
Centrarchidae	*Lepomis*	Bluegill	*Lepomis macrochirus*	Mortality	LC50	68	Unmeasured	Static	--	4	3M Co.	2000a	186121
Unionidae	*Ligumia*	Black sandshell	*Ligumia recta*	Mortality	EC50	13.5	Measured	Static	Glochidia	1	Hazelton, et al.	2012	160209
Tubificidae	*Limnodrilus*	Redworm	*Limnodrilus hoffmeisteri*	Mortality	LC50	23.8	Unmeasured	Renewal	Not reported	2	Qu, et al.	2016	175703
Tubificidae	*Limnodrilus*	Redworm	*Limnodrilus hoffmeisteri*	Mortality	LC50	121	Reported	Static	Not reported	4	Yang, et al.	2014	175260
Ranidae	*Lithobates*	Bronze Frog	*Lithobates clamitans ssp. clamitans*	Mortality	LC50	113	Unmeasured	Static	Larva	4	Tornabene, et al.	2021	185550
Ranidae	*Lithobates*	Northern leopard frog	*Lithobates pipiens*	Mortality	LC50	73	Unmeasured	Static	Larva	4	Tornabene, et al.	2021	185550
Ranidae	*Lithobates*	Wood Frog	*Lithobates sylvaticus*	Mortality	LC50	130	Unmeasured	Static	Larva	4	Tornabene, et al.	2021	185550
Palaemonidae	*Macrobrachium*	Oriental river prawn	*Macrobrachium nipponense*	Mortality	LC50	19.8	Reported	Static	Not reported	4	Yang, et al.	2014	175260
Moinidae	*Moina*	Water flea	*Moina macrocopa*	Mortality	EC50	17.9	Unmeasured	Renewal	Neonate	2	Ji, et al.	2008	114976
Atyidae	*Neocaridina*	Cherry shrimp	*Neocaridina denticulata*	Mortality	LC50	10	Unmeasured	Not reported	Not reported	4	Li	2009	118450
Salmonidae	*Oncorhynchus*	Rainbow trout	*Oncorhynchus mykiss*	Mortality	LC50	11	Unmeasured	Static	--	4	3M Co.	2000a	186121
Salmonidae	*Oncorhynchus*	Rainbow trout	*Oncorhynchus mykiss*	Mortality	LC50	22	Measured	Static	Juvenile	4	Palmer, et al.	2002	184983
Salmonidae	*Oncorhynchus*	Rainbow trout	*Oncorhynchus mykiss*	Mortality	LC50	2.5	Reported	Renewal	Parr	4	Sharpe, et al.	2010	151619
Physidae	*Physella*	European physa	*Physella acuta*	Mortality	LC50	178	Unmeasured	Not reported	Not reported	4	Li	2009	118450
Cyprinidae	*Pimephales*	Fathead minnow	*Pimephales promelas*	Mortality	LC50	9.5	Measured	Static	Juvenile	4	Drottar and Krueger	2000c	180423
Cyprinidae	*Pimephales*	Fathead minnow	*Pimephales promelas*	Mortality	LC50	4.65	Unmeasured	Static	--	4	3M Co.	2000c	181682
Astacidae	*Pontastacus*	Narrow-clawed Crayfish	*Pontastacus leptodactylus*	Mortality	LC50	48.8	Unmeasured	Renewal	Intermolt	4	Belek, et al.	2022	189734
Cyprinidae	*Pseudorasbora*	Stone moroco	*Pseudorasbora parva*	Mortality	LC50	67.7	Reported	Static	Not reported	4	Yang, et al.	2014	175260
Ranidae	*Rana*	Bullfrog	*Rana catesbeiana*	Mortality	LC50	163	Unmeasured	Static	Larva	4	Tornabene, et al.	2021	185550
Ranidae	*Rana*	Bullfrog	*Rana catesbeiana*	Mortality	LC50	144	Unmeasured	Static	Tadpole	4	Flynn, et al.	2019	180580
Unionidae	*Sinanodonta*	Adventive Swan-mussel	*Sinanodonta woodiana*	Mortality	LC50	28.4	Unmeasured	Static	--	2	Xia, et al.	2018	184302
Unionidae	*Unio*	Freshwater mussel	*Unio ravoisieri*	Mortality	LC50	65.9	Unmeasured	Renewal	Not reported	4	Amraoui, et al.	2018	177085

Family	**Genus**	**Species Common Name**	**Species Scientific Name**	**Effect**	**End-point**	**Conc (mg/L)**	**Chemical Analysis**	**Expo-sure Type**	**Life Stage**	**Dura-tion (days)**	**Author**	**Year**	**ECO-TOX Ref No.**
Pipidae	*Xenopus*	African clawed frog	*Xenopus laevis*	Mortality	LC50	17.6	Measured	Renewal	Embryo	4	Palmer and Krueger	2001	175357
Pipidae	*Xenopus*	African clawed frog	*Xenopus laevis*	Mortality	LC50	15.3	Measured	Renewal	Embryo	4	Palmer and Krueger	2001	175357
Pipidae	*Xenopus*	African clawed frog	*Xenopus laevis*	Mortality	LC50	13.8	Measured	Renewal	Embryo	4	Palmer and Krueger	2001	175357

Table D.1.8-2 PFOS Genus Geomeans of Acute LC/EC50 Values

Family	Genus	Genus Geomean (ug/L)	Rank
Baetidae	Macrophthalmus	82	1
Cyprinidae	*Pimephales*	6,646	2
Cyprinidae	*Cyprinus*	8,410	3
Salmonidae	*Oncorhynchus*	8,458	4
Atyidae	*Neocaridina*	10,000	5
Unionidae	*Ligumia*	13,500	6
Pipidae	*Xenopus*	15,489	7
Cyprinidae	*Danio*	15,943	8
Unionidae	*Lampsilis*	16,500	9
Moinidae	*Moina*	17,950	10
Palaemonidae	*Macrobrachium*	19,770	11
Dugesiidae	*Dugesia*	22,584	12
hylidae	*Hyla*	24,000	13
Unionidae	*Sinanodonta*	28,388	14
Ranidae	*Bufo*	48,210	15
Astacidae	*Pontastacus*	48,810	16
Tubificidae	*Limnodrilus*	53,668	17
Ambystomatidae	*Ambystoma*	57,645	18
Unionidae	*Elliptio*	59,000	19
Brachionidae	*Brachionus*	61,800	20
bufonidae	*Anaxyrus*	62,000	21
Unionidae	*Unio*	65,900	22
Cyprinidae	*Pseudorasbora*	67,740	23
Centrarchidae	*Lepomis*	68,000	24
Cyprinidae	*Carassius*	81,180	25
Daphniidae	*Daphnia*	89,452	26
Ranidae	*Lithobates*	102,356	27
Ranidae	*Rana*	153,206	28
Physidae	*Physella*	178,000	29
Chironomidae	*Chironomus*	182,120	30
Viviparidae	*Cipangopaludina*	247,140	31

Table D.1.8-3 PFOS Freshwater ESV Derivation (per EPA 2012 Tier I Methodology)

			Plant Values (µg/L)		
Number of Tier I taxa out of 8	8		*Lemna*	31,100	Boudreau et al. 2003a
Final Acute Value (FAV) (µg/L)	592		Green algae	71,000	Drottar and Krueger 2000d
Final Acute Chronic Ratio (FACR)[a]	122		*Scenedesmus*	77,800	Liu et al. 2008
Final Plant Value (µg/L)	31,100		*Pseudokirchneriella*	35,000	Rosal et al. 2010
Chronic Exposure ESV (ug/L)	**4.85**				

[a] The FACR was taken from the provisional value in EPAs' draft water quality criteria report for PFOS (EPA 2022b).

D.2 MARINE

D.2.1 PFOA MARINE

Table D.2.1-1 PFOA Marine Acute LC/EC50 Values for Aquatic Derivation

Family	Genus	Species Common Name	Species Scientific Name	Effect	End-point	Conc (mg/L)	Chemical Analysis	Exposure Type	Life Stage	Dura-tion (days)	Author	Year	ECO-TOX Ref No.
Mysidae	*Americamysis*	Opossum shrimp	*Americamysis bahia*	Mortality	LC50	24	Unmeasured	Static	Juvenile	4	Hayman, et al.	2021	185535
Coryphaenidae	*Coryphaena*	Dolphin fish	*Coryphaena hippurus*	Mortality	LC50	4	Reported	Static	Embryo	2	Gebreab, et al.	2022	189556
Mytilidae	*Mytilus*	Mediterranean mussel	*Mytilus galloprovincialis*	Mortality	LC50	10	Measured	Static	Embryo	2	Hayman, et al.	2021	185535
Parechinidae	*Paracentrotus*	Sea urchin	*Paracentrotus lividus*	Growth	EC50	110	Unmeasured	Static	Embryo	2	Mhadhbi, et al.	2012	160548
Scophthalmidae	*Psetta*	Turbot	*Psetta maxima*	Multiple	EC50	11.9	Unmeasured	Renewal	Embryo	6	Mhadhbi, et al.	2012	160548
Mysidae	*Siriella*	Mysid shrimp	*Siriella armata*	Mortality	EC50	15.5	Unmeasured	Static	Neonate	4	Mhadhbi, et al.	2012	160548
Strongylocentrotidae	*Strongylocentrotus*	Purple Sea Urchin	*Strongylocentrotus purpuratus*	Development	EC50	19	Measured	Static	Embryo	4	Hayman, et al.	2021	185535

Table D.2.1.-2 PFOA Marine Genus Geomeans of Acute LC/EC50 Values

Family	Genus	Genus Geomean (µg/L)
Coryphaenidae	*Coryphaena*	4,000
Mytilidae	*Mytilus*	9,980
Scophthalmidae	*Psetta*	11,900
Mysidae	*Siriella*	15,500
Strongylocentrotidae	*Strongylocentrotus*	19,000
Mysidae	*Americamysis*	24,000
Parechinidae	*Paracentrotus*	110,000

Table D.2.1-3 PFOA Marine ESV Derivation (per EPA 2012 Tier II Methodology)

Lowest GMAV (ug/L)	**4,000**		**Plant Values (EC50, µg/L)**		
Number of Tier I taxa out of 8[a]	5		*Isochrysis galbana*	163,600	Mhadhbi et al. 2012
Secondary Acute Factor (SAF)	6.1		*Skeletonema marinoi*	368,523	Latala et al. 2009
Secondary Acute Value (SAV) (µg/L)	656		*Geitlerinema amphibium*	248,442	Latala et al. 2009
Secondary Acute Chronic Ratio (SACR)[b]	**207.5**		*Chlorella vulgaris*	977,207	Latala et al. 2009
Secondary Chronic Value (SCV) (µg/L)	3.16				
Final Plant Value (FPV) (µg/L)	163,600				
Chronic Exposure ESV (µg/L)	**3.16**				

[a] The number of diverse taxa was estimated as the number of distinct classes relative to 8 needed for tier I determinations in freshwater for the purpose of estimating an SAF.

[b] The SACR was taken from the provisional value for PFOA in EPA's draft water quality criteria report for PFOA (EPA 2022a).

D.2.2 PFOS MARINE

Table D.2.2-1 PFOS Marine Acute LC/EC50 Values for Aquatic Derivation

Family	Genus	Species Common Name	Species Scientific Name	Effect	End-point	Conc (mg/L)	Chemical Analysis	Expo-sure Type	Life Stage	Dura-tion (days)	Author	Year	ECO-TOX Ref No.
Mysidae	*Americamysis*	Opossum shrimp	*Americamysis bahia*	Mortality	LC50	3.6	Measured	Static	Juvenile	4	Drottar and Krueger	2000e	175364
Ostreidae	*Crassostrea*	Eastern oyster	*Crassostrea virginica*	Morphology	EC50	>3	Measured	Static	Not Reported	4	Drottar and Krueger	2000f	175360
Gammaridae	*Gammarus*	Scud	*Gammarus insensibilis*	Mortality	LC50	10	Unmeasured	Static	Adult	2	Touaylia,et al.	2019	184254
Mytilidae	*Mytilus*	Mediterranean mussel	*Mytilus galloprovincialis*	Mortality	LC50	1.1	Measured	Static	Embryo	2	Hayman,et al.	2021	185535
Parechinidae	*Paracentrotus*	Sea urchin	*Paracentrotus lividus*	Growth	EC50	20	Unmeasured	Static	Embryo	2	Mhadhbi,et al.	2012	160548
Parechinidae	*Paracentrotus*	Sea urchin	*Paracentrotus lividus*	Development	EC50	1.8	Unmeasured	Static	Embryo	3	Gunduz,et al.	2013	176044
Mysidae	*Siriella*	Mysid shrimp	*Siriella armata*	Mortality	EC50	6.9	Unmeasured	Static	Neonate	4	Mhadhbi,et al.	2012	160548
Strongylocentrotidae	*Strongylocentrotus*	Purple Sea Urchin	*Strongylocentrotus purpuratus*	Development	EC50	1.7	Measured	Static	Embryo	4	Hayman,et al.	2021	185535

Table D.2.2-2 PFOS Marine Genus Geomeans of Acute LC/EC50 Values

Family	Genus	Genus Geomean (µg/L)
Mytilidae	Mytilus	1,070
Strongylocentrotidae	Strongylocentrotus	1,700
Ostreidae	Crassostrea	3,000
Mysidae	Americamysis	3,600
Parechinidae	Paracentrotus	5,992
Mysidae	Siriella	6,900
Gammaridae	Gammarus	9,990

Table D.2.2-3 PFOS Marine ESV Derivation (per EPA 2012 Tier II Methodology)

Lowest GMAV	1,070
Number of Tier I taxa out of 8[a]	5
Secondary Acute Factor (SAF)	6.1
Secondary Acute Value (SAV) (µg/L)	175
Secondary Acute Chronic Ratio (SACR)[b]	**122**
Secondary Chronic Value (SCV) (µg/L)	1.44
Final Plant Value (FPV) (µg/L)	Not available
Chronic Exposure ESV (µg/L)	**1.44**

[a] The number of diverse taxa was estimated as the number of distinct classes relative to 8 needed for tier I determinations in freshwater for the purpose of estimating an SAF.

[b] The SACR was taken from the provisional value in EPAs' draft water quality criteria report for PFOS (EPA 2022b).

D.3 FRESHWATER NOEC HC5 VALUES

D.3.1 PFOA NOEC HC5 VALUES

Table D.3.1-1 PFOA Freshwater NOEC Values

Family	Genus	Species Common Name	Species Scientific Name	Effect	End-point	Conc (mg/L)	Chemical Analysis	Expo-sure Type	Life-Stage	Dura-tion (days)	Author	Year	ECO-TOX Ref No.
Ambystomatidae	Ambystoma	Tiger salamander	*Ambystoma tigrinum*	Growth	NOEC	1	Unmeasured	Renewal	Larva	31	Hoover	2018	180874
Baetidae	*Macrophthalmus*	Mayfly	*Neocloeon triangulifer*	Mortality	NOEC	3.085	Measured	Static	Larva	4	Soucek, et al.	2023	--
Bufonidae	Anaxyrus	American toad	*Anaxyrus americanus*	Growth	NOEC	0.873	Measured	Renewal	Larva	Not Reported	Flynn, et al.	2022	189338
Bufonidae	Anaxyrus	American toad	*Anaxyrus americanus*	Growth	NOEC	1	Unmeasured	Renewal	Tadpole	36.7	Hoover	2018	180874
Brachionidae	Brachionus	Rotifer	*Brachionus calyciflorus*	Mortality	NOEC	0.125	Unmeasured	Renewal	Neonate	6	Zhang, et al.	2014	168456
Brachionidae	Brachionus	Rotifer	*Brachionus calyciflorus*	Development	NOEC	0.25	Reported	Renewal	Neonate	Not Reported	Zhang, et al.	2013	175669
Ranidae	Bufo	Asiatic toad	*Bufo gargarizans*	Growth	NOEC	38.0	Reported	Renewal	Tadpole	30	Yang, et al.	2014	175260
Chironomidae	Chironomus	Midge	*Chironomus dilutus*	Mortality	NOEC	59.4	Measured	Renewal	Larva	19	McCarthy, et al.	2021	185968
Chironomidae	Chironomus	Midge	*Chironomus tentans*	Mortality	NOEC	100	Unmeasured	Renewal	Larva	10	MacDonald, et al.	2004	87173
Subclass Copepoda	Cyclops	Cyclopoid	*Cyclops sp.*	Population	NOEC	30	Unmeasured	Static	Not Reported	7	Sanderson, et al.	2003	68253
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Morphology	NOEC	3	Unmeasured	Renewal	Embryo	5	Kim, et al.	2021	184724
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Mortality	NOEC	200	Unmeasured	Not Reported	Embryo	2	Zheng, et al.	2012	160547
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Mortality	NOEC	50	Unmeasured	Static	Embryo	Not Reported	Hagenaar, et al.	2011	152104
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Mortality	NOEC	>1000	Unmeasured	Static	Embryo	Not Reported	Ulhaq, et al.	2013	165818
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Mortality	NOEC	26.5	Unmeasured	Static	Embryo	4.75	Truong, et al.	2014	182827
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Growth	NOEC	0.0828	Unmeasured	Static	Embryo	4.88	Jantzen, et al.	2016	175223
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Mortality	NOEC	0.0414	Unmeasured	Static	Embryo	0.79	Satbhai, et al.	2022	189936
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Development	NOEC	0.414	Unmeasured	Static	Larva	4	Kalasekar, et al.	2015	172976
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Morphology	NOEC	0.0083	Unmeasured	Static	Embryo	13.9	Annunziato	2018	180803
Daphniidae	Daphnia	Water flea	*Daphnia carinata*	Reproduction	NOEC	0.01	Unmeasured	Renewal	Neonate	21	Logeshwaran, et al.	2021	185823

Family	Genus	Species Common Name	Species Scientific Name	Effect	End-point	Conc (mg/L)	Chemical Analysis	Expo-sure Type	Life-Stage	Dura-tion (days)	Author	Year	ECO-TOX Ref No.
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Reproduction	NOEC	20	Measured	Renewal	Neonate	21	Colombo, et al.	2008	151611
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Population	NOEC	10	Unmeasured	Static	Not Reported	1	Sanderson, et al.	2003	68253
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Reproduction	NOEC	20	Measured	Renewal	Neonate	21	Centre International de Toxicologie	2003	188555
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Reproduction	NOEC	0.032	Unmeasured	Renewal	Neonate	21	Lu, et al.	2016	184769
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Reproduction	NOEC	38.0	Reported	Renewal	Not Reported	21	Yang, et al.	2014	175260
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Reproduction	NOEC	6.25	Unmeasured	Renewal	Neonate	21	Ji, et al.	2008	114976
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Reproduction	NOEC	6.71	Unmeasured	Renewal	Neonate	21	Yang, et al.	2019	182580
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Mortality	NOEC	4.14	Unmeasured	Renewal	Egg	4	Seyoum, et al.	2020	183541
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Reproduction	NOEC	3.2	Unmeasured	Renewal	Juvenile	1	Li	2010	152183
Dugesiidae	Dugesia	Planaria	*Dugesia japonica*	Growth	NOEC	1	Unmeasured	Renewal	Not Reported	5	Yuan, et al.	2015	177055
Dugesiidae	Dugesia	Planaria	*Dugesia japonica*	Mortality	NOEC	150	Unmeasured	Not Reported	Not Reported	1	Li	2009	118450
Dugesiidae	Dugesia	Planaria	*Dugesia japonica*	Mortality	NOEC	400	Unmeasured	Static	Not Reported	4	Li	2008	111070
Dugesiidae	Dugesia	Planaria	*Dugesia japonica*	Growth	NOEC	15	Unmeasured	Renewal	Not Reported	18	Zhang, et al.	2020	182585
Hyalellidae	Hyalella	Amphipod	*Hyalella azteca*	Development	NOEC	0.84	Measured	Renewal	Juvenile	42	Bartlett, et al.	2021	184676
Ranidae	Lithobates	Northern leopard frog	*Lithobates pipiens*	Growth	NOEC	0.125	Measured	Renewal	Larva	30	Flynn, et al.	2022	189338
Ranidae	Lithobates	Northern leopard frog	*Lithobates pipiens*	Development	NOEC	1	Reported	Renewal	Tadpole	20	Hoover, et al.	2017	176982
Ranidae	Lithobates	Northern leopard frog	*Lithobates pipiens*	Mortality	NOEC	1.38	Measured	Renewal	Larva	30	Flynn, et al.	2022	189338
Moinidae	Moina	Water flea	*Moina macrocopa*	Reproduction	NOEC	3.13	Unmeasured	Renewal	Neonate	7	Ji, et al.	2008	114976
Atyidae	Neocaridina	Cherry shrimp	*Neocaridina denticulata*	Mortality	NOEC	250	Unmeasured	Not Reported	Not Reported	2	Li	2009	118450
Salmonidae	Oncorhynchus	Rainbow trout	*Oncorhynchus mykiss*	Mortality	NOEC	40	Measured	Flow-through	Egg	85	Colombo, et al.	2008	151611
Adrianichthyidae	Oryzias	Japanese rice fish	*Oryzias latipes*	Mortality	NOEC	1	Unmeasured	Renewal	Adult	28	Ji, et al.	2008	114976
Adrianichthyidae	Oryzias	Japanese rice fish	*Oryzias latipes*	Morphology	NOEC	10	Unmeasured	Renewal	Adult	21	Kang, et al.	2019	179846

Family	**Genus**	**Species Common Name**	**Species Scientific Name**	**Effect**	**End-point**	**Conc (mg/L)**	**Chemical Analysis**	**Expo-sure Type**	**Life-Stage**	**Dura-tion (days)**	**Author**	**Year**	**ECO-TOX Ref No.**
Adrianichthyidae	Oryzias	Japanese rice fish	*Oryzias latipes*	Reproduction	NOEC	3	Reported	Renewal	Adult	119	Lee, et al.	2017	177079
Physidae	Physella	European physa	*Physella acuta*	Mortality	NOEC	250	Unmeasured	Not Reported	Not Reported	4	Li	2009	118450
Cyprinidae	Pimephales	Fathead minnow	*Pimephales promelas*	Mortality	NOEC	76	Measured	Renewal	Embryo	21	Bartlett, et al.	2021	184676
Cyprinidae	Pseudorasbora	Stone moroco	*Pseudorasbora parva*	Growth	NOEC	75.9	Reported	Renewal	Not Reported	30	Yang, et al.	2014	175260
Ranidae	Lithobates	Bullfrog	*Rana catesbeiana*	Growth	NOEC	0.144	Unmeasured	Renewal	Tadpole	72	Flynn, et al.	2019	180580
Pipidae	Xenopus	Clawed frog	*Xenopus sp.*	Growth	NOEC	103.5	Unmeasured	Renewal	Blastula	4	Kim, et al.	2013	170608

Table D.3.1-2 PFOA Mean Genus NOECs for Deriving HC5 using GLI Equations

Family	Genus	Genus Geomean	Rank
Brachionidae	Brachionus	177	1
Ranidae	Lithobates	262	2
Bufonidae	Anaxyrus	307	3
Hyalellidae	Hyalella	840	4
Ambystomatidae	Ambystoma	932	5
Cyprinidae	Danio	2,762	6
Daphniidae	Daphnia	2,774	7
Baetidae	Neocloeon	3,085	8
Adrianichthyidae	Oryzias	3,107	9
Moinidae	Moina	3,125	10
Subclass Copepoda	Cyclops	30,000	11
Dugesiidae	Dugesia	30,801	12
Ranidae	Bufo	37,970	13
Salmonidae	Oncorhynchus	40,000	14
Chironomidae	Chironomus	59,400	15
Cyprinidae	Pseudorasbora	75,940	16
Cyprinidae	Pimephales	76,000	17
Chironomidae	Chironomus	100,000	18
Pipidae	Xenopus	103,518	19
Physidae	Physella	250,000	20
Atyidae	Neocaridina	250,000	21

Table D.3.1-3 PFOA Freshwater NOEC HC5 using GLI equations (µg/L)

Number of genera	21
HC5 =	**156**

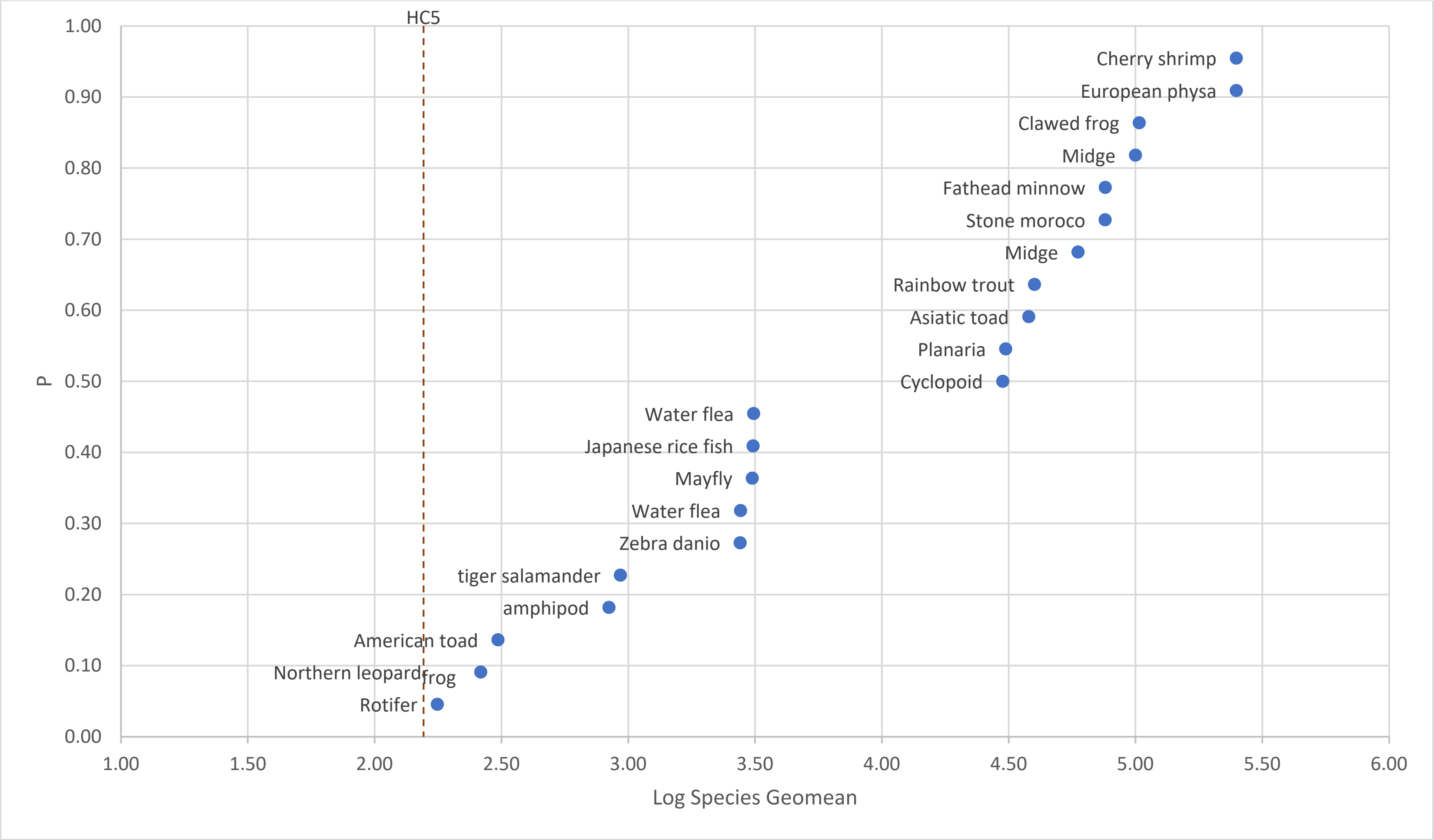

Figure D.3-1 PFOA Freshwater NOEC Species Sensitivity Distribution Showing HC5 Derived Using GLI Equations

D.3.2 PFOS NOEC HC5 VALUES

Table D.3.2-1 PFOS Freshwater NOEC Values

Family	Genus	Species Common Name	Species Scientific Name	Effect	End-point	Conc (mg/L)	Chemical Analysis	Expo-sure Type	Life Stage	Dura-tion (days)	Author	Year	ECO-TOX Ref No.
Brachionidae	Brachionus	Rotifer	*Brachionus calyciflorus*	Population	NOEC	0.50	Analysis reported	Renewal	Neonate	Not reported	Zhang, et al.	2013	175669
Daphniidae	Ceriodaphnia	Water flea	*Ceriodaphnia dubia*	Survival	NOEC	13.0	Measured	Renewal		6	Krupa et al.	2022	189336
Chironomidae	Chironomus	Midge	*Chironomus dilutus*	Growth	NOEC	0.014	Measured	Renewal	Larva	16	Krupa et al.	2022	189336
Chironomidae	Chironomus	Midge	*Chironomus dilutus*	Mortality	NOEC	0.00045	Measured	Renewal	Larva	19	McCarthy, et al.	2021	185968
Chironomidae	Chironomus	Midge	*Chironomus tentans*	Mortality	NOEC	0.022	Measured	Renewal	Larva	20	MacDonald, et al.	2004	87173
Cyprinidae	Cyprinus	Common carp	*Cyprinus carpio*	Morphology	NOEC	0.10	Unmeasured	Renewal	Juvenile	14	Hagenaars, et al.	2008	114715
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Growth	NOEC	0.50	Unmeasured	Static	Embryo	5	Hagenaars, et al.	2011	152104
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Development	NOEC	0.50	Unmeasured	Renewal	Egg	3	Ortiz-Villanueva, et al.	2018	181477
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Development	NOEC	0.50	Unmeasured	Renewal	Embryo	4	Dang, et al.	2018	178026
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Mortality	NOEC	0.50	Unmeasured	Static	Embryo	3	Shi, et al.	2008	114603
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Morphology	NOEC	0.40	Unmeasured	Static	Embryo	4	Du, et al.	2016a	177124
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Reproduction	NOEC	0.25	Unmeasured	Renewal		28	Xin, et al.	2020	182584
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Growth	NOEC	0.20	Unmeasured	Renewal	Embryo	15	Shi, et al.	2009	119304
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Growth	NOEC	0.23	Measured	Renewal	Embryo	3.92	Wu, et al.	2022	188755
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Mortality	NOEC	8.09	Unmeasured	Renewal	Embryo	3	Martinez, et al.	2019a	180956
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Development	NOEC	8.002	Unmeasured	Static	Embryo	4	Chen, et al.	2014	168368
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Morphology	NOEC	8.002	Unmeasured	Renewal	Blastula	3.88	Sant, et al.	2018	178022
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Mortality	NOEC	>10	Unmeasured	Static	Embryo	NR	Ulhaq, et al.	2013	165818
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Growth	NOEC	8.82	Unmeasured	Renewal	Embryo	3.88	Annunziato, et al.	2020	184678
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Mortality	NOEC	3.31	Unmeasured	Static	Embryo	4.75	Truong, et al.	2014	182827
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Mortality	NOEC	2.06	Unmeasured	Static	Embryo	449.8	Christou, et al.	2021	188865
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Growth	NOEC	0.092	Measured	Renewal	Embryo	30	Krupa et al.	2022	189336

Family	Genus	Species Common Name	Species Scientific Name	Effect	End-point	Conc (mg/L)	Chemical Analysis	Expo-sure Type	Life Stage	Dura-tion (days)	Author	Year	ECO-TOX Ref No.
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Growth	NOEC	0.70	Unmeasured	Renewal	Egg	6	Hagenaars, et al.	2014	175658
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Morphology	NOEC	8.0	Unmeasured	Renewal	Embryo	7	Sant, et al.	2017	175217
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Mortality	NOEC	5.0	Unmeasured	Renewal	Embryo	3	Martinez, et al.	2019b	182554
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Mortality	NOEC	4.0	Unmeasured	Static	Embryo	1.75	Huang, et al.	2010	151614
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Growth	NOEC	0.050	Unmeasured	Renewal	Embryo	180	Cui, et al.	2017	176905
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Growth	NOEC	0.020	Unmeasured	Renewal		21	Guo, et al.	2019	179565
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Growth	NOEC	0.092	Measured	Renewal	Embryo	30	Krupa, et al.	2022	189336
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Reproduction	NOEC	0.090	Unmeasured	Static	Sperm	0.001	Xia and Niu	2017	177144
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Growth	NOEC	0.010	Unmeasured	Static	Embryo	4.88	Jantzen, et al.	2016	175223
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Reproduction	NOEC	0.005	Unmeasured	Renewal	Embryo	152.2	Wang, et al.	2011	164068
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Growth	NOEC	0.001	Measured	Flow-through	Embryo	316	Keiter, et al.	2012	160092
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Growth	NOEC	0.010	Unmeasured	Renewal	Fry	70	Du, et al.	2009	116895
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Mortality	NOEC	0.10	Unmeasured	Renewal	Embryo	120	Du, et al.	2018	179529
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Growth	NOEC	0.12	Measured	Renewal	Embryo	14	Du, et al.	2016b	177092
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Morphology	NOEC	0.10	Unmeasured	Static	Embryo	13.88	Annunziato	2018	180803
Cyprinidae	Danio	Zebra danio	*Danio rerio*	Growth	NOEC	0.17	Measured	Renewal	Embryo	4	Wang, et al.	2017	175190
Daphniidae	Daphnia	Water Flea	*Daphnia carinata*	Reproduction	NOEC	0.001	Unmeasured	Renewal	Neonate	21	Logeshwaran, et al.	2021	185823
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Mortality	NOEC	5.3	Unmeasured	Renewal	Neonate	21	Boudreau, et al.	2003b	71875
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Population	NOEC	4.0	Unmeasured	Renewal	Neonate	21	Liang, et al.	2017	177138
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Reproduction	NOEC	0.008	Unmeasured	Renewal	Neonate	21	Lu, et al.	2015	177104
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Reproduction	NOEC	7.43	Analysis reported	Renewal	Not reported	21	Yang, et al.	2014	175260
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Reproduction	NOEC	11.5	Measured	Renewal	Neonate	21	Drottar and Krueger	2000g	175367
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Population	NOEC	30	Unmeasured	Static	Not reported	28	Sanderson, et al.	2002	64956
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Reproduction	NOEC	0.010	Unmeasured	Renewal	Neonate	25	Jeong, et al.	2016	177169
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Reproduction	NOEC	1.0	Unmeasured	Renewal	Juvenile	21	Li	2010	152183

Family	Genus	Species Common Name	Species Scientific Name	Effect	End-point	Conc (mg/L)	Chemical Analysis	Expo-sure Type	Life Stage	Dura-tion (days)	Author	Year	ECO-TOX Ref No.
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Reproduction	NOEC	1.25	Unmeasured	Renewal	Neonate	21	Ji, et al.	2008	114976
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Reproduction	NOEC	0.50	Unmeasured	Renewal	Neonate	21	Seyoum, et al.	2020	183541
Daphniidae	Daphnia	Water flea	*Daphnia magna*	Growth	NOEC	0.67	Unmeasured	Renewal	Neonate	21	Yang, et al.	2019	182580
Dugesiidae	Dugesia	Planaria	*Dugesia japonica*	Growth	NOEC	8.0	Unmeasured	in Vitro	Not intact	7	Yuan, et al.	2014	175659
Dugesiidae	Dugesia	Planaria	*Dugesia japonica*	Mortality	NOEC	10	Unmeasured	Not reported	Not reported	4	Li	2009	118450
Dugesiidae	Dugesia	Planaria	*Dugesia japonica*	Mortality	NOEC	12	Unmeasured	Static	Not reported	4	Li	2008	111070
Coenagrionidae	Enallagma	Common blue damselfly	*Enallagma cyathigerum*	Development	NOEC	0.010	Unmeasured	Renewal	Embryo	>300	Bots, et al.	2010	151607
Unionidae	Lampsilis	Fatmucket clam	*Lampsilis siliquoidea*	Development	NOEC	0.005	Measured	Renewal	Glochidia	2	Hazelton, et al.	2012	160209
Ranidae	Lithobates	Northern leopard frog	*Lithobates pipiens*	Development	NOEC	0.010	Analysis reported	Renewal	Tadpole	40	Hoover, et al.	2017	176982
Ranidae	Lithobates	Northern leopard frog	*Lithobates pipiens*	Growth	NOEC	0.12	Measured	Renewal	Larva	30	Flynn, et al.	2022	189338
Ranidae	Lithobates	Northern leopard frog	*Lithobates pipiens*	Development	NOEC	0.97	Measured	Flow-through	Embryo	NR	Ankley, et al.	2004	77666
Moinidae	Moina	Water flea	*Moina macrocopa*	Reproduction	NOEC	0.31	Unmeasured	Renewal	Neonate	7	Ji, et al.	2008	114976
Atyidae	Neocaridina	Cherry shrimp	*Neocaridina denticulata*	Mortality	NOEC	5.0	Unmeasured	Not reported	Not reported	4	Li	2009	118450
Baetidae	Neocloeon	Mayfly	*Neocloeon triangulifer*	Growth	NOEC	0.00021	Measured	Static	Larva	14	Soucek et al.	2023	--
Physidae	Physella	European physa	*Physella acuta*	Mortality	NOEC	100	Unmeasured	Not reported	Not reported	3	Li	2009	118450
Cyprinidae	Pimephales	Fathead minnow	*Pimephales promelas*	Growth	NOEC	0.044	Measured	Renewal	Sexually mature	42	Suski, et al.	2021	185548
Cyprinidae	Pimephales	Fathead minnow	*Pimephales promelas*	Mortality	NOEC	0.28	Measured	Flow-through	Sexually mature	45	Ankley, et al.	2005	81515
Cyprinidae	Pimephales	Fathead minnow	*Pimephales promelas*	Mortality	NOEC	3.30	Measured	Static	Juvenile	4	Drottar and Krueger	2000c	180423
Cyprinidae	Pimephales	Fathead minnow	*Pimephales promelas*	Mortality	NOEC	0.30	Measured	Flow-through	Egg	47	Drottar and Krueger	2000h	175366
Cyprinidae	Pseudorasbora	Stone moroco	*Pseudorasbora parva*	Growth	NOEC	5.57	Analysis reported	Renewal	Not reported	30	Yang, et al.	2014	175260
Phylum Rotifera	Rotifera	Rotifer	*Rotifera*	Population	NOEC	30	Unmeasured	Static	Not reported	28	Sanderson, et al.	2002	64956
Pipidae	Xenopus	African clawed frog	*Xenopus laevis*	Development	NOEC	48	Analysis reported	Renewal	Gastrula	4	San-Segundo, et al.	2016	175663
Poeciliidae	Xiphophorus	Green swordtail	*Xiphophorus helleri*	Morphology	NOEC	0.10	Unmeasured	Renewal	Fry	90	Han and Fang	2010	151613

Table D.3.2-2 PFOS Mean Genus NOECs for Deriving HC5 using GLI Equations

Family	Genus	Genus Geomean (ug/L)	Rank
Baetidae	Neocloeon	0.21	1
Chironomidae	Chironomus	3.11	2
Unionidae	Lampsilis	4.50	3
Coenagrionidae	Enallagma	10.0	4
Chironomidae	Chironomus	14.0	5
Poeciliidae	Xiphophorus	100.0	6
Cyprinidae	Cyprinus	100.0	7
Ranidae	Lithobates	106	8
Moinidae	Moina	313	9
Cyprinidae	Pimephales	333	10
Cyprinidae	Danio	348	11
Brachionidae	Brachionus	500	12
Daphniidae	Daphnia	591	13
Atyidae	Neocaridina	5000	14
Cyprinidae	Pseudorasbora	5570	15
Dugesiidae	Dugesia	9865	16
Daphniidae	Ceriodaphnia	13000	17
Phylum Rotifera	Rotifera	30000	18
Pipidae	Xenopus	48000	19
Physidae	Physella	100000	20

Table D.3.2-3 PFOS Freshwater NOEC HC5 Using GLI Equations (µg/L)

Number of genera	20
GLI HC5 =	**0.31**

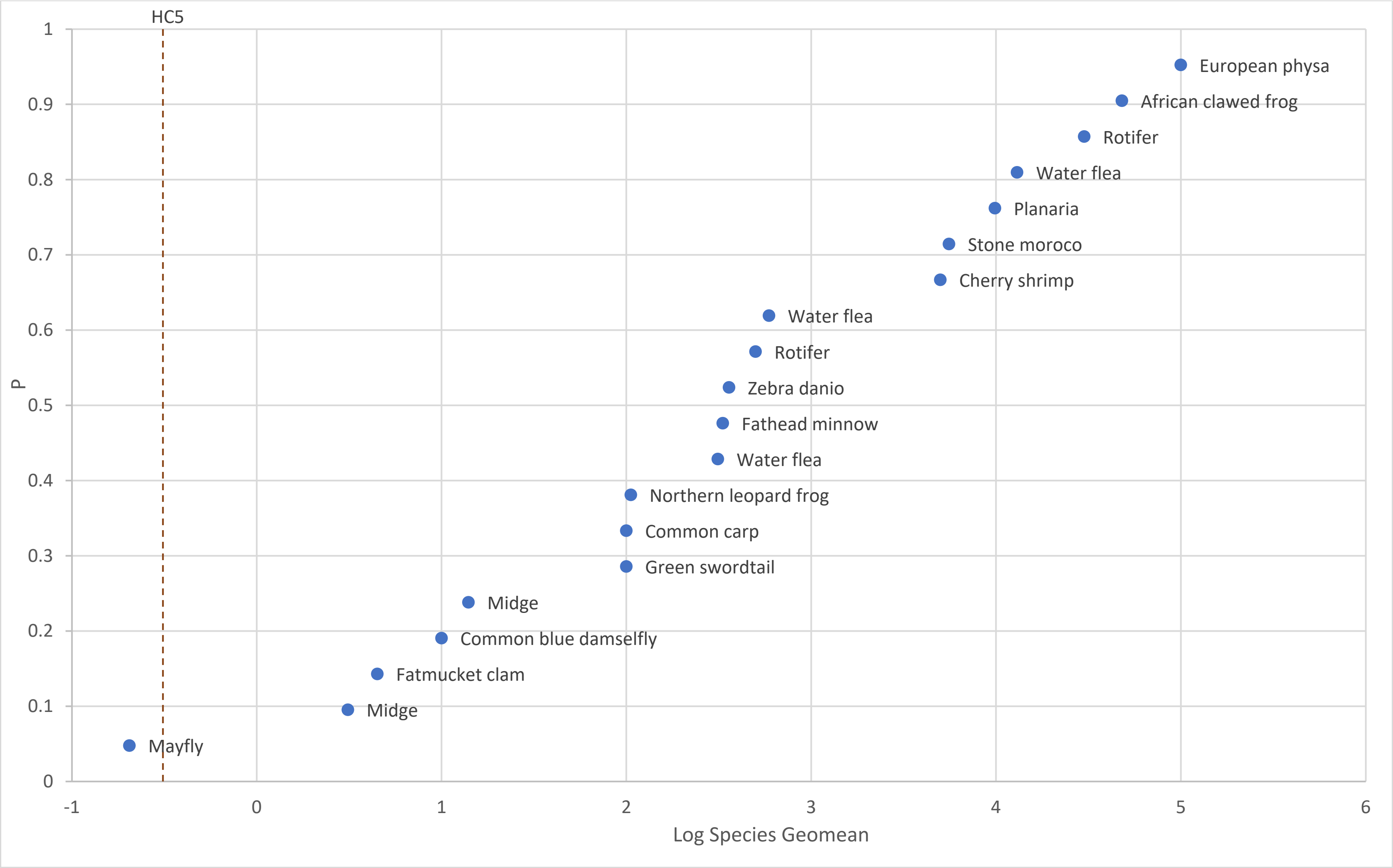

Figure D.3-2 PFOS Freshwater NOEC Species Sensitivity Distribution showing HC5 Derived using GLI Equations

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APPENDIX E: AQUATIC-DEPENDENT WILDLIFE

E.1 EXPOSURE FACTORS FOR AQUATIC-DEPENDENT WILDLIFE

Table E.1-1 Input Exposure Factors Estimating ESVs for Aquatic Wildlife Surrogate Receptors

	Receptor						
Model Parameter	**Belted Kingfisher**	**Herring Gull**	**Osprey**	**Spotted Sandpiper**	**Mallard**	**Mink**	**River Otter**
Bodyweight (kg)	0.15[a]	1.1[a]	1.6[a]	0.042[b]	1.134[b]	0.8[a]	7.4 [a]
Diet Composition (%)							
Sediment	0	0	0	0.18[c]	0.03[l]	0	0
Plants	0	0	0	0	0.42[d]	0	0
Invertebrates	0	0	0	0.82[e]	0.56[d]	0	0
Fish TL 3	1.00[a]	0.72[a]	1.00[a]	0	0	0.90[a]	0.80[a]
Fish TL4	0	0.18[a]	0	0	0	0	0.20[a]
Ingestion Rate (kg/d) ww Total	0.0675[a]	0.2805[a]	0.3040[a]	0.0278[f]	0.3308[f]	0.2945[g]	1.7885[h]
Sediment	0	0	0	0.0050[i]	0.0109[i]	0	0
Plants	0	0	0	0	0.1389	0	0
Invertebrates	0	0	0	0.0228	0.1853	0	0
Fish TL 3 0	0.0675	0.2020	0.3040	0	0	0.2651	1.4308
Fish TL4	0	0.0505	0	0	0	0	0.3577
Water Ingestion Rate (L/d)	0.017[a]	0.063[j]	0.083[j]	0.007[k]	0.054[k]	0.083[j]	0.599[j]

[a] GLWQI Technical Support Document for Wildlife Criteria, EPA (1995a).

[b] Average of adult male and female weights from Wildlife Exposure Handbook, EPA (1993).

[c] Based on average (18%) sediment diet contribution for semipalmated, western, stilt, and least sandpipers in EPA (1993).

[d] Average of male and female values from EPA (1993).

[e] Assumes diet is only invertebrates minus the 18% sediment component (EPA 1993).

[f] Derived using allometric equation; $Fi = 0.301W^{0.751}$ (EPA 1993).

[g] Average of small and large mink food ingestion rates from EPA (2009).

[h] Average of range from EPA (2009); 1.032–2.545.

[i] Calculated as the product of the corresponding diet percentage and the total food ingestion rate.

[j] Derived using water ingestion rate (g/g-day) from EPA (1993) and bodyweight from EPA (1995b), and converted to L/day.

[k] Derived from average of male and female rates in EPA (1993), converted from g/g-day to L/day.

[l] EPA (1993).

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E.2 BIOACCUMULATION FACTORS (BAFs), BIOCONCENTRATION FACTORS (BCFs), AND BIOMAGNIFICATION FACTORS (BMFs) FOR ESTIMATING EXPOSURE TO AQUATIC WILDLIFE

Table E.2-1 Input Values for Estimating Food Chain Exposure of Aquatic Wildlife

PFAS	BAF Benthic Invertebrates[a] (L/kg ww)	BAF Pelagic Invertebrates[b] (L/kg ww)	BAF Fish[c] (L/kg ww)	BMF Fish	Aquatic Plant BAF (L/kg)
Carboxylic Acids					
PFBA	137	12.9	145	0.007[d]	dg[e]
PFHxA	456	85.7	17.8	0.019[d]	25[f]
PFOA	65.2	165.6	145	0.039[g]	28[f]
PFNA	265	867	708	0.23[h]	58[f]
PFDA	577	8,091	3,162	0.23[d]	110[f]
Sulfonic Acids					
PFBS	200	2.2	100	0.02[h]	19[f]
PFHxS	501	37.4	200	0.16[i]	28[f]
PFOS	156	17,100	3,548	0.37[j]	90[f]

[a] Burkhard (2021). Supplemental Materials; median BAF for gastropoda (snails, slugs), soft body, whole body, soft tissue.

[b] Burkhard (2021). Supplemental Materials; median BAF for insecta (midges, mayfly), whole body.

[c] Burkhard (2021). Supplemental Materials; median BAF for teleostei (fishes), whole body.

[d] Martin et al. (2003a). Lab-derived estimate (fish carcass) with trout and spiked food.

[e] dg = data gap.

[f] Pi et al. (2017).

[g] Geometric mean of Martin et al. (2003a; 0.038) and Goeritz et al. (2013; 0.04).

[h] Chen et al. (2018).

[i] Geometric mean of Martin et al. (2003a; 0.14) and Goeritz et al. (2013; 0.18).

[j] Geometric mean of Martin et al. (2003b; 0.32) and Goeritz et al. (2013; 0.42).

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E.3 TEST DOSE (TD) VALUES USED FOR DEVELOPING AQUATIC WILDLIFE ESVS

Table E.3-1 Test Dose (mg/kg BW/day; either a NOAEL or LOAEL)

PFAS	Belted Kingfisher	Herring Gull	Osprey	Spotted Sandpiper	Mallard	Mink	River Otter
Carboxylic Acids							
PFBA	dg[a]	dg	dg	dg	dg	35[b]	35[b]
PFHxA	dg	dg	dg	dg	dg	100[c]	100[c]
PFOA	dg	dg	dg	dg	dg	1.75[d]	1.75[d]
PFNA	dg	dg	dg	dg	dg	0.83[e]	0.83[e]
PFDA	dg	dg	dg	dg	dg	3.0[f]	3.0[f]
Sulfonic Acids							
PFBS	3,160[g]	3,160[g]	3,160[g]	3,160[g]	3,160[g]	53[h]	53[h]
PFHxS	dg	dg	dg	dg	dg	5.72[i]	5.72[i]
PFOS	1.5[j]	1.5[j]	1.5[j]	1.5[j]	1.5[j]	0.12[k]	0.12[k]

[a] dg = data gap.

[b] Das et al. (2008). NOAEL for multiple reproductive and growth endpoints.

[c] Iwai and Hoberman (2014). NOAEL for mice pup development (bodyweight).

[d] DeWitt et al. (2008). Benchmark dose low (BMD-low) value for immunomodulation effects in female mice as derived by Johnson et al. (2021) citing this study.

[e] Wolf et al. (2010). No significant difference in reproduction. Next highest dose (1.1 mg/kg-day) resulted in 46% reduction in live births.

[f] Harris and Birnbaum (1989). LOEL reduced fetal bodyweight by 6%, not considered adverse. Next highest dose had 23% reduction (LOAEL).

[g] Newsted et al. (2008). LOAEL of 3,160 mg/kg-day for growth (bodyweight) in bobwhite in acute exposures.

[h] Leider et al. (2009). PFBS NOAEL of 60 mg/kg-day for hematological effects in mice in sub-chronic (90-day) exposures converted to a TRV of 5.3 mg/kg-day by Johnson et al. (2021), citing this study after adjusting for the molecular weight of potassium in the salt form used in the study (60 × 0.8 = 53).

[i] Narizzano et al. (2021). Benchmark dose – low (BMDL) for deer mouse increased stillbirths.

[j] Newsted et al. (2007); Gallagher et al. (2003a,b). NOAEL for reproductive effects in bobwhite and mallard in chronic exposures as identified by Johnson et al. (2021) citing these studies.

[k] Narizzano et al. (2021). BMDL for white-footed mouse increased total litter loss.

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E.4 UNCERTAINTY FACTORS

Development of aquatic wildlife ESVs following the Great Lakes Water Quality Initiative guidance (EPA 1995) includes use of uncertainty factors for extrapolating across taxa, exposure durations, and endpoints. For each extrapolation category, uncertainty factors may range from 1 (no extrapolation required) to 10 (greatest extrapolation). See Section 3.6.2 for further discussion.

Table E.4-1 Uncertainty Factors for Inter-taxon Extrapolation (UF_A), Extrapolation Across Exposure Durations (UF_S), and Extrapolating across Endpoints (UF_L) Used in Developing Aquatic ESVs for Protection of Wildlife

PFAS		Belted Kingfisher (Aves Coraciformes Alcedinidae)	Herring Gull (Aves Charadriformes Laridae)	Osprey (Aves Accipotriformes Pandionidae)	Spotted Sandpiper (Aves Charadriformes Scolopacidae)	Mallard (Aves Anseriformes Anatidae)	Mink (Mammalia Carnivora Mustelidae)	River Otter (Mammalia Carnivora Mustelidae)
Carboxylic Acids								
PFBA								
	UF_A	dg[a]	dg	dg	dg	dg	8[b]	8[b]
	UF_S	dg	dg	dg	dg	dg	1[c]	1[c]
	UF_L	dg	dg	dg	dg	dg	1[d]	1[d]
PFHxA								
	UF_A	dg	dg	dg	dg	dg	8[e]	8[e]
	UF_S	dg	dg	dg	dg	dg	5[f]	5[f]
	UF_L	dg	dg	dg	dg	dg	1[g]	1[g]
PFOA								
	UF_A	dg	dg	dg	dg	dg	1[h]	1[h]
	UF_S	dg	dg	dg	dg	dg	1[i]	1[i]
	UF_L	dg	dg	dg	dg	dg	1[j]	1[j]
PFNA								
	UF_A	dg	dg	dg	dg	dg	8[k]	8[k]
	UF_S	dg	dg	dg	dg	dg	5[l]	5[l]
	UFl	dg	dg	dg	dg	dg	1[m]	1[m]
PFDA								
	UF_A	dg	dg	dg	dg	dg	8[n]	8[n]
	UFs	dg	dg	dg	dg	dg	5[o]	5[o]
	UF_L	dg	dg	dg	dg	dg	1[p]	1[p]
Sulfonic Acids								
PFBS								
	UF_{Tot}	30[q]	30[q]	30[q]	30[q]	30[q]	10[r]	10[r]
PFHxS								
	UF_A	dg	dg	dg	dg	dg	8[s]	8[s]

Table E.4-1 Uncertainty Factors for Inter-taxon Extrapolation (UF_A), Extrapolation Across Exposure Durations (UF_S), and Extrapolating across Endpoints (UF_L) Used in Developing Aquatic ESVs for Protection of Wildlife

PFAS		Belted Kingfisher (Aves Coraciformes Alcedinidae)	Herring Gull (Aves Charadriformes Laridae)	Osprey (Aves Accipotriformes Pandionidae)	Spotted Sandpiper (Aves Charadriformes Scolopacidae)	Mallard (Aves Anseriformes Anatidae)	Mink (Mammalia Carnivora Mustelidae)	River Otter (Mammalia Carnivora Mustelidae)
	UF_S	dg	dg	dg	dg	dg	1[t]	1[t]
	UF_L	dg	dg	dg	dg	dg	1[u]	1[u]
PFOS	UF_A	10[v]	10[v]	10[v]	10[v]	10[v]	8[y]	8[y]
	UF_S	1[w]	1[w]	1[w]	1[w]	1[w]	1[z]	1[z]
	UF_L	1[x]	1[x]	1[x]	1[x]	1[x]	1[aa]	1[aa]

[a] data gap

[b] Das et al. (2008). Mouse study: different species, genus, family, and order.

[c] Das et al. (2008). Chronic study, 294-day duration. Sub-chronic. Only dosed for 90 days; a small fraction of life cycle.

[d] Das et al. (2008). NOAEL for multiple reproductive and growth endpoints.

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[f] Iwai and Hoberman (2014). Sub-chronic study; 18 days.

[g] Iwai and Hoberman (2014). Mouse study; NOAEL, no effect level for pup growth.

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[i] DeWitt et al. (2008). Sub-chronic (15-day) exposures. UFs =1 applied as the cited TD was to be used without application of UFs.

[j] DeWitt et al. (2008). Benchmark dose-low for immunomodulation effects in female mice.

[k] Wolf et al. (2010). Mouse study; different species, genus, family, and order.

[l] Wolf et al. (2010). Sub-chronic tests with 18-day exposure period during critical post-gestational days of 1–18.

[m] Wolf et al. (2010). NOAEL. No significant difference in reproduction. Next highest dose 1.1 mg/kg/day resulted in 46% reduction in live pup births.

[n] Harris and Birnbaum (1989, as cited in Conder et al. 2019). Mouse study. Different species, genus, family, and order.

[o] Harris and Birnbaum (1989). Sub-chronic, 18-day. Reproduction, development.

[p] Harris and Birnbaum (1989). NOAEL reduced fetal bodyweight by 6%, not considered adverse. Next highest dose had 23% reduction (LOAEL).

[q] Newsted et al. (2008). LOAEL for growth for Bobwhite in acute exposures study cited by Johnson et al. (2021) in deriving an Avian TRV applying a UF_{tot} = 30.

[r] Leider et al. (2009). 90-day mouse NOAEL for hematological effects study cited by Johnson et al. (2021) in deriving TRV for class Mammalia applying a $UF_{tot} = 10$.

[s] Narizzano et al. (2021). ACPH study with deer mouse; different species, genus, family, and order.

[t] Narizzano et al. (2021). Chronic 28-day prenatal exposure.

[u] Narizzano et al. (2021). BMDL for increased stillbirth.

[v] Newsted et al. (2007); Gallagher et al. (2003a,b). Bobwhite quail cited by Johnson et al. (2021) to derive TRV applying $UF_{tot} = 10$.

[w] Newsted et al. (2007); Gallagher et al. (2003a,b). Chronic exposures.

[x] Newsted et al. (2007); Gallagher et al. (2003a,b). NOAEL for reproductive effects.

[y] Narizzano et al. (2021). ACPH study with white-footed mouse; different species, genus, family, and order.

[z] Narizzano et al. (2021). Chronic 28-day prenatal exposure.

[aa] Narizzano et al. (2021). BMDL for total litter loss.

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E.5 Derivation of Surface Water ESVs for Aquatic-Dependent Wildlife

Table E.5-1 Derivation of PFOS Aquatic Wildlife ESV

	Belted Kingfisher	**Herring Gull**	**Osprey**	**Spotted Sandpiper**	**Mallard**	**Mink**	**River Otter**
PFOS TD; mg/kg-d; NOAEL, LOAEL or BMDL	1.5	1.5	1.5	1.5	1.5	0.12	0.12
Wt kg; average weight in kg	0.150	1.1	1.6	0.042	1.134	0.8	7.4
Water Ingestion; average daily water consumptions L/d	0.017	0.063	0.083	0.007	0.054	0.083	0.599
Total Daily Food Ingestion rate kg/d	0.068	0.281	0.304	0.028	0.331	0.295	1.789
Ingestion Rate of Sediment; kg/d	0.00	0.00	0.00	0.005	0.011	0.00	0.00
Ingestion Rate of Benthic Inverts; kg/d	0.00	0.00	0.00	0.023	0.185	0.00	0.00
Ingestion Rate of Pelagic Inverts; kg/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ingestion Rate of Plants; kg/d	0.00	0.00	0.00	0.00	0.139	0.00	0.00
Ingestion Rate of Trophic Level 3 Fish; kg/d	0.068	0.202	0.304	0.00	0.00	0.265	1.431
Ingestion Rate of Trophic Level 4 Fish; kg/d	0.00	0.050	0.00	0.00	0.00	0.00	0.358
Ingestion Rate of Birds; kg/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Food Trophic Level 1 and 2; Benthic Inverts BAF L/kg	156	156	156	156	156	156	156
Food Trophic Level 1 and 2; Pelagic Inverts BAF L/kg	17,100	17,100	17,100	17,100	17,100	17,100	17,100
Food Trophic Level; Plants BAF L/kg	90	90	90	90	90	90	90
Food Fish Trophic Level 3; BAF L/kg	3,548	3,548	3,548	3,548	3,548	3,548	3,548
Food Fish Trophic Level 4; BAF L/kg	0.37	0.37	0.37	0.37	0.37	0.37	0.37
UFa across species	10	10	10	10	10	8	8
UFs subchronic to chronic	1	1	1	1	1	1	1
UFl LOAEL to NOAEL	1	1	1	1	1	1	1
Total UF	10	10	10	10	10	8	8
TD /Total UF (mg/kg-d)	0.15	0.15	0.15	0.15	0.15	0.015	0.015
(TD/Total UF) x Wt (mg/d)	0.0225	0.165	0.240	0.0063	0.170	0.0120	0.111
Daily Ingestion Sediment [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.782	1.703	0.00	0.00

Daily Ingestion Trophic Level 3 Fish [kg/d] x BAF [L/kg]; L/d	239.5	716.6	1078.6	0.0	0.0	940	5076
Daily Ingestion Trophic Level 4 Fish [kg/d] x BAF [L/kg]; L/d	0.00	0.019	0.000	0.00	0.00	0.00	0.132
Daily Ingestion Benthic Inverts [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	3.561	28.90	0.00	0.00
Daily Ingestion Pelagic Inverts [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Daily Ingestion Plants [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.00	12.505	0.00	0.00
Total: L/d	239.5	716.6	1078.6	4.34	43.11	940.4	5077
Total Daily Food Ingestion + Water Daily Ingestion; L/d	239.51	716.64	1078.68	4.35	43.16	940.5	5077
WV ug PFOS/L	0.0939	0.230	0.222	1.45	3.94	0.0128	0.0219
Final Aquatic Avian Wildlife Value ug/L	0.487[a]		0.169[b]	2.39[c]			
Final Aquatic Mammal Wildlife Value ug/L	0.0167[d]		0.0167[d]	0.0167[d]			
PFOS Final Wildlife Value ug/L	**0.0167[e]**		**0.0167[e]**	**0.0167[e]**			

[a] Geometric mean of all five avian receptor WVs.

[b] Geometric mean only of belted kingfisher, herring gull, and osprey WVs.

[c] Geometric mean only of spotted sandpiper and mallard WVs.

[d] Geometric mean of mink and river otter WVs.

[e] Lowest of final avian and mammal WVs.

Table E.5-2 Derivation of PFHxS Aquatic Wildlife ESV

	Belted Kingfisher	Herring Gull	Osprey	Spotted Sandpiper	Mallard	Mink	River Otter
PFHxS TD; mg/kg-d; NOAEL, LOAEL or BMDL	na[a]	na[a]	na[a]	na[a]	na[a]	5.72	5.72
Wt kg; average weight in kg	0.150	1.10	1.60	0.042	1.134	0.80	7.40
Water Ingestion; average daily water consumptions L/d	0.017	0.063	0.083	0.007	0.054	0.083	0.599
Total Daily Food Ingestion rate kg/d	0.068	0.281	0.304	0.028	0.331	0.295	1.789
Ingestion Rate of Sediment; kg/d	0.00	0.00	0.00	0.005	0.011	0.00	0.00
Ingestion Rate of Benthic Inverts; kg/d	0.00	0.00	0.00	0.023	0.185	0.00	0.00
Ingestion Rate of Pelagic Inverts; kg/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ingestion Rate of Plants; kg/d	0.00	0.00	0.00	0.00	0.139	0.00	0.00
Ingestion Rate of Trophic Level 3 Fish; kg/d	0.068	0.202	0.304	0.00	0.00	0.265	1.431
Ingestion Rate of Trophic Level 4 Fish; kg/d	0.00	0.050	0.00	0.00	0.00	0.00	0.358
Ingestion Rate of Birds; kg/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Food Trophic Level 1 and 2; Benthic Inverts BAF L/kg	501	501	501	501	501	501	501
Food Trophic Level 1 and 2; Pelagic Inverts BAF L/kg	37.4	37.4	37.4	37.4	37.4	37.4	37.4
Food Trophic Level; Plants BAF L/kg	28	28	28	28	28	28	28
Food Fish Trophic Level 3; BAF L/kg	200	200	200	200	200	200	200
Food Fish Trophic Level 4; BAF L/kg	0.16	0.16	0.16	0.16	0.16	0.16	0.16
UFa across species	na[a]	na[a]	na[a]	na[a]	na[a]	8	8
UFs subchronic to chronic	na[a]	na[a]	na[a]	na[a]	na[a]	1	1
UFl LOAEL to NOAEL	na[a]	na[a]	na[a]	na[a]	na[a]	1	1
Total UF	na[a]	na[a]	na[a]	na[a]	na[a]	8	8
TD /Total UF; mg/kg-d	na[a]	na[a]	na[a]	na[a]	na[a]	0.715	0.715
(TD/Total UF) x Wt; mg/d	na[a]	na[a]	na[a]	na[a]	na[a]	0.572	5.29
Daily Ingestion Sediment [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	2.510	5.469	0.00	0.00
Daily Ingestion Trophic Level 3 Fish [kg/d] x BAF [L/kg]; L/d	13.50	40.39	60.80	0.00	0.00	53.01	286.16
Daily Ingestion Trophic Level 4 Fish [kg/d] x BAF [L/kg]; L/d	0.00	0.008	0.00	0.00	0.00	0.00	0.057
Daily Ingestion Benthic Inverts [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	11.436	92.813	0.00	0.00

Daily Ingestion Pelagic Inverts [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Daily Ingestion Plants [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.00	3.890	0.00	0.00
Total: L/d	13.50	40.40	60.80	13.95	102.2	53.01	286.2
Total Daily Food Ingestion + Water Daily Ingestion; L/d	13.52	40.46	60.88	13.95	102.2	53.09	286.8
WV ug PFHxS/L	na[a]	na[a]	na[a]	na[a]	na[a]	10.77	18.45
Final Aquatic Avian Wildlife Value ug/L	na[a]						
Final Aquatic Mammal Wildlife Value ug/L	14.1[b]						
PFHxS Final Wildlife Value ug/L	**14.1[b]**						

[a] Test dose not available (na).

[b] Geometric mean of mink and river otter WVs.

[c] Lowest of final avian and mammal WVs.

Table E.5-3 Derivation of PFBS Aquatic Wildlife ESV

	Belted Kingfisher	Herring Gull	Osprey	Spotted Sandpiper	Mallard	Mink	River Otter
PFBS TD; mg/kg-d; NOAEL, LOAEL or BMDL	3,160	3,160	3,160	3,160	3,160	53	53
Wt kg; average weight in kg	0.15	1.10	1.60	0.04	1.13	0.80	7.40
Water Ingestion; average daily water consumptions L/d	0.017	0.063	0.083	0.007	0.054	0.083	0.599
Total Daily Food Ingestion rate kg/d	0.068	0.28	0.30	0.028	0.33	0.29	1.79
Ingestion Rate of Sediment; kg/d	0.00	0.00	0.00	0.005	0.011	0.00	0.00
Ingestion Rate of Benthic Inverts; kg/d	0.00	0.00	0.00	0.023	0.185	0.00	0.00
Ingestion Rate of Pelagic Inverts; kg/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ingestion Rate of Plants; kg/d	0.00	0.00	0.00	0.00	0.14	0.00	0.00
Ingestion Rate of Trophic Level 3 Fish; kg/d	0.068	0.20	0.30	0.00	0.00	0.27	1.43
Ingestion Rate of Trophic Level 4 Fish; kg/d	0.00	0.05	0.00	0.00	0.00	0.00	0.36
Ingestion Rate of Birds; kg/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Food Trophic Level 1 and 2; Benthic Inverts BAF L/kg	200	200	200	200	200	200	200
Food Trophic Level 1 and 2; Pelagic Inverts BAF L/kg	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Food Trophic Level; Plants BAF L/kg	19	19	19	19	19	19	19
Food Fish Trophic Level 3; BAF L/kg	100	100	100	100	100	100	100
Food Fish Trophic Level 4; BAF L/kg	0.02	0.02	0.02	0.02	0.02	0.02	0.02
UFa across species	-	-	-	-	-	-	-
UFs subchronic to chronic	-	-	-	-	-	-	-
UFl LOAEL to NOAEL	-	-	-	-	-	-	-
Total UF	30	30	30	30	30	10	10
TD /Total UF; mg/kg-d	105.3	105.3	105.3	105.3	105.3	5.30	5.30
(TD/Total UF) x Wt; mg/d	15.80	115.9	168.5	4.42	119.5	4.24	39.22
Daily Ingestion Sediment [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	1.00	2.18	0.00	0.00
Daily Ingestion Trophic Level 3 Fish [kg/d] x BAF [L/kg]; L/d	6.75	20.20	30.40	0.00	0.00	26.51	143.08

Daily Ingestion Trophic Level 4 Fish [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Daily Ingestion Benthic Inverts [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	4.57	37.05	0.00	0.00
Daily Ingestion Pelagic Inverts [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Daily Ingestion Plants [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.00	2.64	0.00	0.00
Total: L/d	6.75	20.20	30.40	5.57	41.87	26.51	143.09
Total Daily Food Ingestion + Water Daily Ingestion; L/d	6.77	20.26	30.48	5.57	41.93	26.59	143.69
WV ug PFBS/L	2,335	5,719	5,529	794	2,849	159.5	273.0
Final Aquatic Avian Wildlife Value ug/L	2,783[a]		4,195[b]	1,504[c]			
Final Aquatic Mammal Wildlife Value ug/L	209[d]		209[d]	209[d]			
PFBS Final Wildlife Value ug/L	**209[e]**		**209[e]**	**209[e]**			

[a] Geometric mean of all five avian receptor WVs.
[b] Geometric mean only of belted kingfisher, herring gull, and osprey WVs.
[c] Geometric mean only of spotted sandpiper and mallard WVs.
[d] Geometric mean of mink and river otter WVs.
[e] Lowest of final avian and mammal WVs.

Table E.5-4 Derivation of PFDA Aquatic Wildlife ESV

	Belted Kingfisher	Herring Gull	Osprey	Spotted Sandpiper	Mallard	Mink	River Otter
PFDA TD; mg/kg-d; NOAEL, LOAEL or BMDL	na[a]	na[a]	na[a]	na[a]	na[a]	3.00	3.00
Wt kg; average weight in kg	0.15	1.10	1.60	0.04	1.13	0.80	7.40
Water Ingestion; average daily water consumptions L/d	0.017	0.063	0.083	0.007	0.054	0.083	0.60
Total Daily Food Ingestion rate kg/d	0.068	0.281	0.304	0.028	0.331	0.29	1.79
Ingestion Rate of Sediment; kg/d	0.00	0.00	0.00	0.005	0.011	0.00	0.00
Ingestion Rate of Benthic Inverts; kg/d	0.00	0.00	0.00	0.023	0.185	0.00	0.00
Ingestion Rate of Pelagic Inverts; kg/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ingestion Rate of Plants; kg/d	0.00	0.00	0.00	0.00	0.139	0.00	0.00
Ingestion Rate of Trophic Level 3 Fish; kg/d	0.068	0.202	0.304	0.00	0.00	0.27	1.43
Ingestion Rate of Trophic Level 4 Fish; kg/d	0.00	0.051	0.00	0.00	0.00	0.00	0.36
Ingestion Rate of Birds; kg/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Food Trophic Level 1 and 2; Benthic Inverts BAF L/kg	577	577	577	577	577	577	577
Food Trophic Level 1 and 2; Pelagic Inverts BAF L/kg	8,091	8,091	8,091	8,091	8,091	8,091	8,091
Food Trophic Level; Plants BAF L/kg	110	110	110	110	110	110	110
Food Fish Trophic Level 3; BAF L/kg	3,162	3,162	3,162	3,162	3,162	3,162	3,162
Food Fish Trophic Level 4; BAF L/kg	0.23	0.23	0.23	0.23	0.23	0.23	0.23
UFa across species	na[a]	na[a]	na[a]	na[a]	na[a]	8	8
UFs subchronic to chronic	na[a]	na[a]	na[a]	na[a]	na[a]	5	5
UFl LOAEL to NOAEL	na[a]	na[a]	na[a]	na[a]	na[a]	1	1
Total UF	na[a]	na[a]	na[a]	na[a]	na[a]	40	40
TD /Total UF; mg/kg-d	na[a]	na[a]	na[a]	na[a]	na[a]	0.075	0.075
(TD/Total UF) x Wt; mg/d	na[a]	na[a]	na[a]	na[a]	na[a]	0.060	0.555
Daily Ingestion Sediment [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	2.89	6.30	0.00	0.00
Daily Ingestion Trophic Level 3 Fish [kg/d] x BAF [L/kg]; L/d	213	639	961	0	0	838	4,524

Daily Ingestion Trophic Level 4 Fish [kg/d] x BAF [L/kg]; L/d	0.00	0.01	0.00	0.00	0.00	0.00	0.08
Daily Ingestion Benthic Inverts [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	13.17	106.89	0.00	0.00
Daily Ingestion Pelagic Inverts [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Daily Ingestion Plants [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.00	15.28	0.00	0.00
Total: L/d	213	639	961	16.06	128.47	838	4,524
Total Daily Food Ingestion + Water Daily Ingestion; L/d	213	639	961	16.07	128.53	838	4,525
WV ug PFDA/L	na[a]	na[a]	na[a]	na[a]	na[a]	0.0716	0.1227
Final Aquatic Avian Wildlife Value ug/L	na[a]						
Final Aquatic Mammal Wildlife Value ug/L	0.0937[b]						
PFDA Final Wildlife Value ug/L	**0.0937[c]**						

[a] Test dose not available (na).

[b] Geometric mean of mink and river otter WVs.

[c] Lowest of final avian and mammal WVs.

Table E.5-5 Derivation of PFNA Aquatic Wildlife ESV

	Belted Kingfisher	**Herring Gull**	**Osprey**	**Spotted Sandpiper**	**Mallard**	**Mink**	**River Otter**
PFNA TD; mg/kg-d; NOAEL, LOAEL or BMDL	na[a]	na[a]	na[a]	na[a]	na[a]	0.83	0.83
Wt kg; average weight in kg	0.150	1.1	1.6	0.042	1.134	0.80	7.40
Water Ingestion; average daily water consumptions L/d	0.017	0.063	0.083	0.007	0.054	0.083	0.599
Total Daily Food Ingestion rate kg/d	0.068	0.281	0.304	0.028	0.331	0.295	1.789
Ingestion Rate of Sediment; kg/d	0.00	0.00	0.00	0.005	0.011	0.00	0.00
Ingestion Rate of Benthic Inverts; kg/d	0.00	0.00	0.00	0.023	0.185	0.00	0.00
Ingestion Rate of Pelagic Inverts; kg/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ingestion Rate of Plants; kg/d	0.00	0.00	0.00	0.00	0.139	0.000	0.00
Ingestion Rate of Trophic Level 3 Fish; kg/d	0.068	0.202	0.304	0.00	0.00	0.265	1.431
Ingestion Rate of Trophic Level 4 Fish; kg/d	0.00	0.05	0.00	0.00	0.00	0.00	0.358
Ingestion Rate of Birds; kg/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Food Trophic Level 1 and 2; Benthic Inverts BAF L/kg	265	265	265	265	265	265	265
Food Trophic Level 1 and 2; Pelagic Inverts BAF L/kg	867	867	867	867	867	867	867
Food Trophic Level; Plants BAF L/kg	58	58	58	58	58	58	58
Food Fish Trophic Level 3; BAF L/kg	708	708	708	708	708	708	708
Food Fish Trophic Level 4; BAF L/kg	0.23	0.23	0.23	0.23	0.23	0.23	0.23
UFa across species	na[a]	na[a]	na[a]	na[a]	na[a]	8	8
UFs subchronic to chronic	na[a]	na[a]	na[a]	na[a]	na[a]	5	5
UFl LOAEL to NOAEL	na[a]	na[a]	na[a]	na[a]	na[a]	1	1
Total UF	na[a]	na[a]	na[a]	na[a]	na[a]	40	40
TD /Total UF; mg/kg-d	na[a]	na[a]	na[a]	na[a]	na[a]	0.021	0.021
(TD/Total UF) x Wt; mg/d	na[a]	na[a]	na[a]	na[a]	na[a]	0.017	0.154
Daily Ingestion Sediment [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	1.33	2.89	0.00	0.00
Daily Ingestion Trophic Level 3 Fish [kg/d] x BAF [L/kg]; L/d	47.79	143.0	215.2	0.00	0.00	187.66	1013.01

Daily Ingestion Trophic Level 4 Fish [kg/d] x BAF [L/kg]; L/d	0.00	0.012	0.000	0.000	0.000	0.000	0.082
Daily Ingestion Benthic Inverts [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	6.05	49.09	0.00	0.00
Daily Ingestion Pelagic Inverts [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Daily Ingestion Plants [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.00	8.06	0.00	0.00
Total: L/d	47.79	143.0	215.2	7.377	60.04	187.7	1013.1
Total Daily Food Ingestion + Water Daily Ingestion; L/d	47.81	143.1	215.3	7.384	60.10	187.7	1013.7
WV ug PFNA/L	na[a]	na[a]	na[a]	na[a]	na[a]	0.088	0.151
Final Aquatic Avian Wildlife Value ug/L	na[a]						
Final Aquatic Mammal Wildlife Value ug/L	0.116[b]						
PFNA Final Wildlife Value ug/L	**0.116[c]**						

[a] Test dose not available (na).
[b] Geometric mean of mink and river otter WVs.
[c] Lowest of final avian and mammal WVs.

Table E.5-6 Derivation of PFOA Aquatic Wildlife ESV

	Belted Kingfisher	Herring Gull	Osprey	Spotted Sandpiper	Mallard	Mink	River Otter
PFOA TD; mg/kg-d; NOAEL, LOAEL or BMDL	na[a]	na[a]	na[a]	na[a]	na[a]	1.75	1.75
Wt kg; average weight in kg	0.15	1.10	1.60	0.04	1.13	0.80	7.40
Water Ingestion; average daily water consumptions L/d	0.017	0.063	0.083	0.007	0.054	0.083	0.599
Total Daily Food Ingestion rate kg/d	0.068	0.281	0.304	0.028	0.331	0.295	1.789
Ingestion Rate of Sediment; kg/d	0.00	0.00	0.00	0.005	0.011	0.00	0.00
Ingestion Rate of Benthic Inverts; kg/d	0.00	0.00	0.00	0.023	0.185	0.00	0.00
Ingestion Rate of Pelagic Inverts; kg/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ingestion Rate of Plants; kg/d	0.00	0.00	0.00	0.00	0.14	0.00	0.00
Ingestion Rate of Trophic Level 3 Fish; kg/d	0.07	0.20	0.30	0.00	0.00	0.27	1.43
Ingestion Rate of Trophic Level 4 Fish; kg/d	0.00	0.05	0.00	0.00	0.00	0.00	0.36
Ingestion Rate of Birds; kg/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Food Trophic Level 1 and 2; Benthic Inverts BAF L/kg	65.2	65.2	65.2	65.2	65.2	65.2	65.2
Food Trophic Level 1 and 2; Pelagic Inverts BAF L/kg	165.6	165.6	165.6	165.6	165.6	165.6	165.6
Food Trophic Level; Plants BAF L/kg	28	28	28	28	28	28	28
Food Fish Trophic Level 3; BAF L/kg	145	145	145	145	145	145	145
Food Fish Trophic Level 4; BAF L/kg	0.039	0.039	0.039	0.039	0.039	0.039	0.039
UFa across species	na[a]	na[a]	na[a]	na[a]	na[a]	1	1
UFs subchronic to chronic	na[a]	na[a]	na[a]	na[a]	na[a]	1	1
UFl LOAEL to NOAEL	na[a]	na[a]	na[a]	na[a]	na[a]	1	1
Total UF	na[a]	na[a]	na[a]	na[a]	na[a]	1	1
TD /Total UF; mg/kg-d	na[a]	na[a]	na[a]	na[a]	na[a]	1.75	1.75
(TD/Total UF) x Wt; mg/d	na[a]	na[a]	na[a]	na[a]	na[a]	1.40	12.95
Daily Ingestion Sediment [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.33	0.71	0.00	0.00
Daily Ingestion Trophic Level 3 Fish [kg/d] x BAF [L/kg]; L/d	9.79	29.28	44.08	0.00	0.00	38.43	207.5
Daily Ingestion Trophic Level 4 Fish [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.00	0.00	0.00	0.01

Daily Ingestion Benthic Inverts [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	1.49	12.08	0.00	0.00
Daily Ingestion Pelagic Inverts [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Daily Ingestion Plants [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.00	3.89	0.00	0.00
Total: L/d	9.79	29.29	44.08	1.81	16.68	38.43	207.5
Total Daily Food Ingestion + Water Daily Ingestion; L/d	9.80	29.35	44.16	1.82	16.73	38.52	208.1
WV ug PFOA/L	na[a]	na[a]	na[a]	na[a]	na[a]	36.35	62.24
Final Aquatic Avian Wildlife Value ug/L	na[a]						
Final Aquatic Mammal Wildlife Value ug/L	47. 6[b]						
PFOA Final Wildlife Value ug/L	**47. 6[c]**						

[a] Test dose not available (na).

[b] Geometric mean of mink and river otter WVs.

[c] Lowest of final avian and mammal WVs.

Table E.5-7 Derivation of PFHxA Aquatic Wildlife ESV

	Belted Kingfisher	**Herring Gull**	**Osprey**	**Spotted Sandpiper**	**Mallard**	**Mink**	**River Otter**
PFHxA TD; mg/kg-d; NOAEL, LOAEL or BMDL	na[a]	na[a]	na[a]	na[a]	na[a]	100	100
Wt kg; average weight in kg	0.15	1.10	1.60	0.04	1.13	0.80	7.40
Water Ingestion; average daily water consumptions L/d	0.017	0.063	0.083	0.007	0.054	0.083	0.60
Total Daily Food Ingestion rate kg/d	0.068	0.281	0.304	0.028	0.331	0.295	1.79
Ingestion Rate of Sediment; kg/d	0.00	0.00	0.00	0.005	0.011	0.00	0.00
Ingestion Rate of Benthic Inverts; kg/d	0.00	0.00	0.00	0.023	0.185	0.00	0.00
Ingestion Rate of Pelagic Inverts; kg/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ingestion Rate of Plants; kg/d	0.00	0.00	0.00	0.00	0.14	0.00	0.00
Ingestion Rate of Trophic Level 3 Fish; kg/d	0.068	0.202	0.304	0.00	0.00	0.27	1.43
Ingestion Rate of Trophic Level 4 Fish; kg/d	0.00	0.050	0.00	0.00	0.00	0.00	0.36
Ingestion Rate of Birds; kg/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Food Trophic Level 1 and 2; Benthic Inverts BAF L/kg	456	456	456	456	456	456	456
Food Trophic Level 1 and 2; Pelagic Inverts BAF L/kg	85.7	85.7	85.7	85.7	85.7	85.7	85.7
Food Trophic Level; Plants BAF L/kg	25	25	25	25	25	25	25
Food Fish Trophic Level 3; BAF L/kg	17.8	17.8	17.8	17.8	17.8	17.8	17.8
Food Fish Trophic Level 4; BAF L/kg	0.019	0.019	0.019	0.019	0.019	0.019	0.019
UFa across species	na[a]	na[a]	na[a]	na[a]	na[a]	8	8
UFs subchronic to chronic	na[a]	na[a]	na[a]	na[a]	na[a]	5	5
UFl LOAEL to NOAEL	na[a]	na[a]	na[a]	na[a]	na[a]	1	1
Total UF	na[a]	na[a]	na[a]	na[a]	na[a]	40	40
TD /Total UF; mg/kg-d	na[a]	na[a]	na[a]	na[a]	na[a]	2.50	2.50
(TD/Total UF) x Wt; mg/d	na[a]	na[a]	na[a]	na[a]	na[a]	2.00	18.50
Daily Ingestion Sediment [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	2.28	4.98	0.00	0.00
Daily Ingestion Trophic Level 3 Fish [kg/d] x BAF [L/kg]; L/d	1.20	3.59	5.41	0.00	0.00	4.72	25.47

Daily Ingestion Trophic Level 4 Fish [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Daily Ingestion Benthic Inverts [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	10.41	84.48	0.00	0.00
Daily Ingestion Pelagic Inverts [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Daily Ingestion Plants [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.00	3.47	0.00	0.00
Total: L/d	1.20	3.60	5.41	12.69	92.93	4.72	25.48
Total Daily Food Ingestion + Water Daily Ingestion; L/d	1.22	3.66	5.49	12.70	92.98	4.80	26.07
WV ug PFHxA/L	na[a]	na[a]	na[a]	na[a]	na[a]	416.6	709.5
Final Aquatic Avian Wildlife Value ug/L	na[a]						
Final Aquatic Mammal Wildlife Value ug/L	544[b]						
PFHxA Final Wildlife Value ug/L	**544[c]**						

[a] Test dose not available (na).

[b] Geometric mean of mink and river otter WVs.

[c] Lowest of final avian and mammal WVs.

Table E.5-8 Derivation of PFBA Aquatic Wildlife ESV							
	Belted Kingfisher	**Herring Gull**	**Osprey**	**Spotted Sandpiper**	**Mallard**	**Mink**	**River Otter**
PFBA TD; mg/kg-d; NOAEL, LOAEL or BMDL	na[a]	na[a]	na[a]	na[a]	na[a]	35.00	35.00
Wt kg; average weight in kg	0.15	1.10	1.60	0.04	1.13	0.80	7.40
Water Ingestion; average daily water consumptions L/d	0.017	0.063	0.083	0.007	0.054	0.083	0.60
Total Daily Food Ingestion rate kg/d	0.068	0.281	0.304	0.028	0.331	0.295	1.79
Ingestion Rate of Sediment; kg/d	0.00	0.00	0.00	0.005	0.011	0.00	0.00
Ingestion Rate of Benthic Inverts; kg/d	0.00	0.00	0.00	0.023	0.19	0.00	0.00
Ingestion Rate of Pelagic Inverts; kg/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ingestion Rate of Plants; kg/d	0.00	0.00	0.00	0.00	0.14	0.00	0.00
Ingestion Rate of Trophic Level 3 Fish; kg/d	0.068	0.20	0.30	0.00	0.00	0.27	1.43
Ingestion Rate of Trophic Level 4 Fish; kg/d	0.00	0.05	0.00	0.00	0.00	0.00	0.36
Ingestion Rate of Birds; kg/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Food Trophic Level 1 and 2; Benthic Inverts BAF L/kg	137	137	137	137	137	137	137
Food Trophic Level 1 and 2; Pelagic Inverts BAF L/kg	12.9	12.9	12.9	12.9	12.9	12.9	12.9
Food Trophic Level; Plants BAF L/kg	25	25	25	25	25	25	25
Food Fish Trophic Level 3; BAF L/kg	145	145	145	145	145	145	145
Food Fish Trophic Level 4; BAF L/kg	0.007	0.007	0.007	0.007	0.007	0.007	0.007
UFa across species	na[a]	na[a]	na[a]	na[a]	na[a]	8	8
UFs subchronic to chronic	na[a]	na[a]	na[a]	na[a]	na[a]	1	1
UFl LOAEL to NOAEL	na[a]	na[a]	na[a]	na[a]	na[a]	1	1
Total UF	na[a]	na[a]	na[a]	na[a]	na[a]	8	8
TD /Total UF; mg/kg-d	na[a]	na[a]	na[a]	na[a]	na[a]	4.38	4.38
(TD/Total UF) x Wt; mg/d	na[a]	na[a]	na[a]	na[a]	na[a]	3.50	32.4
Daily Ingestion Sediment [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.69	1.50	0.00	0.00
Daily Ingestion Trophic Level 3 Fish [kg/d] x BAF [L/kg]; L/d	9.79	29.28	44.08	0.00	0.00	38.43	207.5

Daily Ingestion Trophic Level 4 Fish [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Daily Ingestion Benthic Inverts [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	3.13	25.38	0.00	0.00
Daily Ingestion Pelagic Inverts [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Daily Ingestion Plants [kg/d] x BAF [L/kg]; L/d	0.00	0.00	0.00	0.00	3.47	0.00	0.00
Total: L/d	9.79	29.28	44.08	3.81	30.35	38.43	207.5
Total Daily Food Ingestion + Water Daily Ingestion; L/d	9.80	29.35	44.16	3.82	30.40	38.52	208.1
WV ug PFBA/L	na[a]	na[a]	na[a]	na[a]	na[a]	90.87	155.6
Final Aquatic Avian Wildlife Value ug/L	na[a]						
Final Aquatic Mammal Wildlife Value ug/L	119[b]						
PFBA Final Wildlife Value ug/L	**119[c]**						

[a] Test dose not available (na).

[b] Geometric mean of mink and river otter WVs.

[c] Lowest of final avian and mammal WVs.

Table E.5-9 Summary of Aquatic Wildlife Values

PFAS	Avian WV 5 Species[a] (ug/L)	Avian WV 3 Species[b] (ug/L)	Avian WV 2 Species[c] (ug/L)	Mammalian WV (ug/L)		Final Wildlife Value[d] (ug/L)
PFOS	0.487	0.169	2.39	**0.0167**		**0.0167**
PFHxS	--	--	--	**14.1**		**14.1**
PFBS	2,783	4,195	1,504	**209**		**209**
PFDA	--	--	--	**0.0937**		**0.0937**
PFNA	--	--	--	**0.116**		**0.116**
PFOA	--	--	--	**47. 6**		**47. 6**
PFHxA	--	--	--	**544**		**544**
PFBA	--	--	--	**119**		**119**

[a] Avian Wildlife Value determined as the geometric mean of all five avian receptor WVs.

[b] Avian Wildlife Value determined as the geometric mean of the belted kingfisher, herring gull, and osprey WVs.

[c] Avian Wildlife Value determined as the geometric mean of the spotted sandpiper and mallard WVs.

[d] The Final Wildlife Value was taken as the lower of the Avian 5-Species WV or the Mammalian WV.

APPENDIX F: LITERATURE REVIEW

CONTENTS

F.1 STUDIES ACCEPTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT

TABLE F.1.1 STUDIES ACCEPTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—AQUATIC

Author and Year	Major Taxa	Species	PFOA	PFOS	PFBA	PFBS	PFDA	PFHxA	PFHxS	PFNA	Test Period	ECOTOX Ref. No.
3M	Fish	*Pimephales promelas*		X							Acute 4 days	181682
3M	Fish	*Oncorhynchus mykiss* *Lepomis macrochirus*		X							Acute 4 days	186121
3M	Fish	*Daphnia magna*		X							Acute 2 days	186122
Amraoui et al. 2018	Mollusk	*Unio ravoisieri*		X							Acute 4 days	177085
Ankley et al. 2005	Fish	*Pimephales promelas*		X							Chronic	81515
Ankley et al. 2004	Amphibian	*Rana pipiens*		X							Chronic	77666
Annunzio et al 2019	Fish	*Danio rerio*						X	X		Acute	178562
Annunziato 2018	Fish	*Danio rerio*						X	X		5 dpf	180803
Annunziato et al. 2020.	Fish	*Danio rerio*		X					X		96hr hpf	184678
Barmentlo et al. 2015	Crustacean	*Daphnia magna*	X		X			X			Acute and chronic	175699
Bartlett et al. 2021	Fish and crustacean	*Pimephales promelas; Hyalella azteca*	X	X							21 d chronic	184676
Belek et al. 2022	Crustacean	*Astacus leptodactylus Eschscholtz*		X							96 h acute	189734
Blanc et al. 2019	Fish	*Danio rerio*		X		X					96 hr acute	180988
Bots et al. 2010	Insect	*Enallagma cyathigerum.*		X							Acute and chronic	151607
Boudreau 2002	Crustacean and plant	*Daphnia magna and lemma gibba*	X		X		X			X	Acute	175259

TABLE F.1.1 STUDIES ACCEPTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—AQUATIC

Author and Year	Major Taxa	Species	PFOA	PFOS	PFBA	PFBS	PFDA	PFHxA	PFHxS	PFNA	Test Period	ECOTOX Ref. No.
Boudreau, Wilson et al. 2003a	Rotifers, crustaceans, algae and plant	92 species of Rotifera, Cladocera, Copepoda, macroinvertebrates, and Ostracoda and *Lemna gibba*		X							Chronic	71735
Boudreau et al. 2003b	Algae, plants, crustaceans	*Selenastrum capricornutum, Chlorella vulgaris, Lemna gibba, Daphnia magna*, and *Daphnia pulicaria*		X							Acute and chronic	71875
Brown et al. 2021	Amphibian	*Lithobates pipiens*							X		20d chronic	181722
Centre International de Toxicologie 2003	Crustacean	*Daphnia magna*	X								21d chronic	188555
Chen et al. 2014	Fish	*Danio rerio*		X							Acute 4 days	168368
Chen et al. 2018	Fish	*Oryzias melastigma*				X					6 mo	181474
Chen et al. 2018	Fish	*Oryzias melastigma*		X		X					Chronic	181479
Chen et al. 2019	Fish	*Oryzias melastigma*				X					Chronic (30d)	181478
Christou et al. 2021	Fish	*Danio rerio*		X							Chronic	188865
Colombo et al. 2008	Algae, crustacean, fish	*Pseudokirchneriella subcapitata, Daphnia magna, Oncorhynchus mykiss,*	X								Acute and chronic	151611
Corrales et al. 2017	Fish	*Pimephales promelas and Danio rerio*	X								Acute	177136
Cui et al. 2017	Fish	*Danio rerio*		X							Chronic	176905
Dang et al. 2018	Fish	*Danio rerio*		X							Acute 4 days	178026

TABLE F.1.1 STUDIES ACCEPTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—AQUATIC

Author and Year	**Major Taxa**	**Species**	**PFOA**	**PFOS**	**PFBA**	**PFBS**	**PFDA**	**PFHxA**	**PFHxS**	**PFNA**	**Test Period**	**ECOTOX Ref. No.**
Desjardines et al. 2001	Plant	*Lemna gibba*		X							7 d	180421
Ding et al. 2012a	Crustacean	*Daphnia magna* and *Chydorus sphaericus*	X		X		X			X	Acute	160946
Ding et al. 2012b	Algae	*Pseudokirchneriella subcapitata*	X		X		X			X	Acute	160551
Ding et al. 2012c	Fish	*Danio rerio*	X	X							72 and 96 hr	181737
Ding et al. 2012d	Fish	*Danio rerio*		X							6 to 120 h	184882
Ding et al. 2013	Fish	*Danio rerio*	X	X							Acute 4 days	175221
Drottar and Krueger 2000	Fish	*Pimephales promelas*		X							Acute and chronic	175366
Drottar and Krueger 2000	Marine mollusc	*Crassostrea virginica*		X							Acute 4 days	175360
Drottar and Krueger 2000	Marine crustacean	*Mysidopsis bahia*		X							Acute 96 hr	175364
Drottar and Krueger 2000	Marine Crustacean	*Mysidopsis bahia*		X							Chronic 35 days	175363
Drottar and Krueger 2000	Crustacean	*Daphnia magna*		X							Acute 48 hr	175365
Drottar and Krueger 2000	Crustacean	*Daphnia magna*		X							Chronic 21 days	175367
Drottar and Krueger 2000	Algae	*Selenastrum capricornutum*		X							Acute	175368
Drottar and Krueger 2000	Mollusc	*Unio complamatus*		X							Acute 4 days	175369
Drotter and Kreuger 2000	Fish	*Pimephales promelas*		X							96 hr acute	180423
Drotter and Krueger 2001	Fish	*Lepomis macrochirus*				X					96hr acute	185938
Drottar et al. 2001	Fish	*Lepomis macrochirus*		X							Chronic	175359
Du et al. 2009	Fish	*Danio rerio*		X							Chronic	116895
Du et al. 2016	Fish	*Danio rerio*		X							Acute	177092
Du et al. 2016	Fish	*Danio rerio*		X							Acute	177124
Du et al. 2018	Fish	*Danio rerio*		X							120d	179529

TABLE F.1.1 STUDIES ACCEPTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—AQUATIC

Author and Year	Major Taxa	Species	PFOA	PFOS	PFBA	PFBS	PFDA	PFHxA	PFHxS	PFNA	Test Period	ECOTOX Ref. No.
DuPont Co. 1994	Fish	*Lepomis macrochirus*	X								Acute	151364
DuPont Co. 1994	Fish	*Oncorhynchus mykiss*	X								Acute	151364
Elnabarawy 1980	Fish	*Pimephales promelas*	X								96 hr Acute	188557
Fabbri et al. 2014	Marine mollusc	*Mytilus galloprovincialis*	X	X							Acute	169855
Fang et al. 2012	Marine fish	*Oryzias melastigma*		X							Chronic	160550
Fang et al. 2013	Fish	*Oryzias melastigma*		X							10d chronic	175213
Flynn et al. 2019	Amphibian	*Rana catesbeiana*	X	X							96hr acute and 72d chronic	180580
Flynn et al. 2022	Amphibian	*Rana catesbeiana*	X	X					X		Chronic	189338
Fort et al. 2019	Amphibians	*Silurana tropicalis*		X							150 d chronic	NA; In EPA report
Gebreab et al. 2020	Fish	*Danio rerio*	X								7d	184984
Gebreab et al. 2022	Fish	*Coryphaena hippurus*	X								24hr and 48hr acute	189556
Godfrey et al. 2017	Fish	*Danio rerio*	X		X						Acute	177139
Gonzalez-Naranjo and Boltes 2014	Algae	*Pseudokirchneriella subcapitata,*	X								Chronic	176911
Gunduz et al. 2013	Echinoderm	*Paracentrotus lividus*		X							Chronic	176044
Guo et al. 2019	Fish	*Danio rerio*		X							7d chronic	179565
Guo et al 2021	Fish	*Danio rerio*						X			120hr	188867
Hagenaars et al. 2008	Fish	*Cyprinus carpio*		X							Chronic	114715
Hagenaars et al. 2011	Fish	*Danio rerio*	X	X	X	X					Acute	152104
Hagenaars et al. 2014	Fish	*Danio rerio*		X							Chronic and acute	175658
Haggard et al. 2018	Fish	*Danio rerio*		X							6-120hpf	181483

TABLE F.1.1 STUDIES ACCEPTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—AQUATIC

Author and Year	**Major Taxa**	**Species**	**PFOA**	**PFOS**	**PFBA**	**PFBS**	**PFDA**	**PFHxA**	**PFHxS**	**PFNA**	**Test Period**	**ECOTOX Ref. No.**
Han and Fang 2010	Fish	*Xiphophorus helleri*		X							Chronic	151613
Han et al. 2011	Fish	*Oreochromis niloticus*	X	X								184334
Han et al. 2015	Crustacean	*Tigriopus japonicus*		X							Chronic	175656
Hanson et al. 2005	Plants	*Myriophyllum sibiricum* and *M. spicatum*		X							Chronic	80833
Hayman et al. 2021	Marine invertebrates and algae	*purple sea urchin (Strongylocentrotus purpuratus); Mediterranean mussel (Mytilus galloprovincia); opossum shrimp (Americamysis bahia); dinoflagellate Pyrocystis lunula*	X	X							acute	185535
Hazelton et al. 2012	Mollusk	*Lampsilis siliquoidea* and *Ligumia recta*	X	X							Acute	160209
Hoke et al. 2012	Fish, crustacean, algae	*Oncorhynchus mykiss* *D. magna* *P. subcapitata*					X				Acute	161077
Hoover et al. 2017	Amphibians	*Rana pipiens*	X	X					X		Chronic	176982
Hoover et al. 2018	Amphibians	*Ambystoma tigrinum* *Anaxyrus americanus*	X								Chronic	180874
Hoskins et al 2022	Amphibians	*Rana pipiens*		X					X		30 d Chronic	189935
Hu et al. 2014	Algae	*Chlamydomonas reinhardtii and Scenedesmus obliquus*	X								Acute and chronic	177126
Hu et al. 2020	Fish	*Danio rerio*				X					28 d	184764

TABLE F.1.1 STUDIES ACCEPTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—AQUATIC

Author and Year	**Major Taxa**	**Species**	**PFOA**	**PFOS**	**PFBA**	**PFBS**	**PFDA**	**PFHxA**	**PFHxS**	**PFNA**	**Test Period**	**ECOTOX Ref. No.**
Huang et al. 2010	Fish	*Danio rerio*		X							Chronic	151614
Huang et al. 2021	Fish	*Danio rerio*		X							Up to 96h post-hatch	187074
Jacobson et al. 2010	Crustacean	*Monoporeia affinis*		X							Chronic	152160
Jantzen et al. 2016	Fish	*Danio rerio*	X	X						X	Chronic	175223
Jantzen et al. 2016	Fish	*Danio rerio*	X	X						X	Up to 120 hpf	187445
Jeong et al. 2016	Crustacean	*Daphnia magna*		X							Chronic	177169
Ji et al. 2008	Fish and Crustaceans	*Daphnia magna, Moina macrocopa* and *Oryzias latipes*	X	X							Chronic	114976
Jo et al. 2014	Fish	*Danio rerio*					X				Chronic	
Jo et al. 2014	Fish	*Danio rerio*					X				120 days	175706
Kalasekar et al. 2015	Fish	*Danio rerio*	X								Acute 4 days	172976
Kang et al. 2019	Fish	*Oryzias latipes*	X	X							Up to 21d	179846
Keiter et al. 2012	Fish	*Danio rerio*		X							Chronic	160092
Kim et al. 2013	Amphibians	*Xenopus* sp.	X								Acute	170608
Krupa et al. 2022	Invertebrates and fish	*Ceriodaphnia dubia, Chironomus dilutus, Danio rerio, and Hyalella azteca.*		X							Chronic	189336
Krzykwa et al. 2021	Fish	*Pimaphales promelus*		X							Up to 5 dpf	187169
Kusk et al. 2018	Algae	*Pseudokirchneriella subcapitata*		X	X	X	X	X			48hr	180320
Latala et al. 2009	Marine Algae	*Chlorella vulgaris, Skeletonema marinoi* and *Geitlerinema amphibium*	X					X		X	Acute	118463
Le and Peijnenburg 2013	Algae	*Chydorus sphaericus*	X								48hr acute	NA; in EPA report

TABLE F.1.1 STUDIES ACCEPTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—AQUATIC

Author and Year	Major Taxa	Species	PFOA	PFOS	PFBA	PFBS	PFDA	PFHxA	PFHxS	PFNA	Test Period	ECOTOX Ref. No.
Lee et al. 2017	Fish	*Oryzias latipes*	X								Chronic	177079
Li 2008	Planaria	*Dugesia japonica.*	X	X							Acute	111070
Li 2009	Planaria, crustacean, mollusk	*Dugesia japonica, green neon Neocaridina denticulate, Physa acuta*	X	X							Acute	118450
Li 2010	Crustacean	*Daphnia magna*	X	X							Chronic	152183
Li et al. 2021	Algae	*Chlorella pyrenoidosa*	X								12d	185963
Liang et al. 2017	Crustacean	*Daphnia magna*		X							Chronic	177138
Liu et al. 2008	Algae	*Scenedesmus obliquus*		X		X					Acute	170323
Liu et al. 2014	Marine mollusc	*Perna viridis*	X	X							Chronic	177196
Liu et al. 2015	Fish	*Danio rerio*								X	Chronic	181408
Liu et al. 2016	Worm	*Limnodrilus hoffmeisteri*		X							Acute	117071
Logeshwaran et al. 2021	Crustacean	*Daphnia carinata*	X	X							Acute and chronic	185823
Lu et al. 2015	Crustacean	*Daphnia magna*		X						X	Acute and Chronic	177104
Lu et al. 2016	Crustacean	*Daphnia magna*	X								Acute (48hr) and chronic (21d)	184769
MacDonald et al 2004	Insect	*Chironomus tentans*	X	X							Chronic	87173
Martinez et al. 2019a	Fish	*Danio rerio*		X							Up to 6d dpf	180956
Martinez et al. 2019b	Fish	*Danio rerio*		X							Up to 6d dpf	182554
Marziali et al. 2019	Insect	*Chironomus riparius*	X	X		X					Chronic	178850
McCarthy et al. 2021	Insect	*Chironomus dilutus*	X	X		X		X	X	X	10d acute and 20 d Chronic	185968

TABLE F.1.1 STUDIES ACCEPTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—AQUATIC

Author and Year	Major Taxa	Species	PFOA	PFOS	PFBA	PFBS	PFDA	PFHxA	PFHxS	PFNA	Test Period	ECOTOX Ref. No.
Mhadhbi et al. 2012	Marine algae, echinoderm, crustacean, and fish	*Isochrysis galbana, Paracentrotus lividus, Siriella armata* and *Psetta maxima*	X	X							Acute	160548
Mylroie et al. 2021	Fish	*Danio rerio*		X							5d	184776
Nilen et al. 2022	Fish	*Danio rerio*		X								189337
Oakes et al. 2004	Fish	*Pimephales promelas*	X								Chronic	105756
Oakes et al. 2005	Fish	*Pimephales promelas, Oncorhynchus mykiss, Semotilus atromaculatus, Notropis hudsonius,* and *Catostomus commersonii*		X							Acute	93441
Ortiz-Villanueva et al. 2018	Fish	*Danio rerio*		X							120 hr	181477
Palmer 2002	Fish	*Oncorhynchus mykiss*		X							96hr acute	184983
Palmer and Krueger. 2001	Amphibians	*Xenopus*		X							Acute 4 days	175357
Park et al. 2015	Crustacean	*Macrophthalmus japonicus.*		X							Acute 4 days	177086
Pecquet et al. 2020	Fish	*Danio rerio*	X								48hr acute	184778
Rainieri et al. 2017	Fish	*Danio rerio*	X	X						X	Acute	181025
Qu et al. 2016	Worms	*Limnodrilus hoffmeisteri*		X							Acute 2 days	175703
Rosal et al. 2010	Algae and bacteria	*Vibrio fischeri Pseudokirchneriella subcapitata*	X	X		X					Chronic	151618

TABLE F.1.1 STUDIES ACCEPTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—AQUATIC

Author and Year	**Major Taxa**	**Species**	**PFOA**	**PFOS**	**PFBA**	**PFBS**	**PFDA**	**PFHxA**	**PFHxS**	**PFNA**	**Test Period**	**ECOTOX Ref. No.**
Sanderson et al. 2002	Crustaceans and rotifers	*Cyclops diaptomus, Cyclops strenuus, Cyclops canthocamptus staphylinus, Daphnia magna, Keratella quadrata, Phyllopoda sp., Echninorhynchus sp., Ostracoda sp., and total Rotifera sp*		X							Chronic	64956
Sanderson et al. 2003	Crustaceans and rotifers	*Daphnia magna; Cyclops canthocamptus staphylinus; Cylops diaptomus; Rotifera sp.*	X								Chronic	68253
Sanderson et al. 2004	Crustaceans And rotifers	*Cyclops diaptomus, C. strenuus, Canthocamptus staphylinus, Daphnia magna, Keratella quadrata, Phyllopoda* sp., *Echninorhynchus* sp., *Ostracoda* sp., *and total Rotifera* sp.	X	X							Chronic	95705
San-Segundo et al. 2016	Amphibian	*Xenopus laevis*		X							Acute	175663
Sant et al. 2017	Fish	*Danio rerio*		X							Acute 4 days and chronic	175217
Sant et al. 2018	Fish	*Danio rerio*		X							Acute 4 days	178022
Sant et al. 2019	Fish	*Danio rerio*				X					Up to 7dpf	182595
Satbhai and Crago 2022	Fish	*Danio rerio*	X								24hr acute	189936

TABLE F.1.1 STUDIES ACCEPTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—AQUATIC

Author and Year	**Major Taxa**	**Species**	**PFOA**	**PFOS**	**PFBA**	**PFBS**	**PFDA**	**PFHxA**	**PFHxS**	**PFNA**	**Test Period**	**ECOTOX Ref. No.**
Seyoum et al. 2020	Crustacean	*Daphnia magna*	X	X							Acute and chronic	183541
Sharpe 2010	Fish	*Danio rerio* and *Oncorhynchus mykiss*		X							Acute	151619
Shi et al. 2008	Fish	*Danio rerio*		X							Chronic	114603
Shi et al. 2009	Fish	*Danio rerio*		X							Chronic	119304
Soucek et al. 2023	Insect	*Neocloeon triangulifer*	X	X							Acute and Chronic	--
Stengel et al. 2017	Fish	*Danio rerio*	X	X							Acute	176328
Stengel et al. 2017	Fish	*Danio rerio*		X							Acute	175499
Stengel et al. 2018	Fish	*Danio rerio*	X	X							96hr	188159
Stinckens et al. 2018	Fish	*Danio rerio*	X			X					120 and 168 hpf	184848
Sun et al. 2021	Fish	*Danio rerio*				X					168hr	189041
Suski et al. 2021	Fish	*Pimephales promelas*		X					X		Chronic	185548
Sutherland and Krueger 2001	Algae	*Navicula pelliculosa*		X							Acute 96 hr	175358
Tang et al 2020	Fish	*Japanese medaka*				X					5 days post-fertilization	184236
Tang et al. 2020	Fish	*Japanese medaka*				X					28 d	184244
Tilton et al. 2008	Fish	*Oncorhynchus mykiss*	X								Chronic	113316

TABLE F.1.1 STUDIES ACCEPTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—AQUATIC												
Author and Year	**Major Taxa**	**Species**	**PFOA**	**PFOS**	**PFBA**	**PFBS**	**PFDA**	**PFHxA**	**PFHxS**	**PFNA**	**Test Period**	**ECOTOX Ref. No.**
Tornabene et al. 2021	Amphibians	Jefferson salamander (*Ambystoma jeffersonianum*); Small-mouthed salamander (*Ambystoma texanum*); Eastern tiger salamander (*Ambystoma tigrinum*); American toad (*Anaxyrus americanus*); Gray tree frog (*Hyla versicolor*); American bullfrog (*Rana catesbaeiana*); Green frog (*Rana clamitans*); Northern leopard frog (*Rana pipiens*); Wood frog (*Rana sylvatica*)	X	X					X		96hr	185550
Touaylia et al. 2019	Invertebrate	*Gammarus insensibilis*		X							Acute; Up to 96 hr	184254
Truong et al. 2014	Fish	*Danio rerio*	X	X							4.75 d	182827
Tu et al. 2019	Fish	*Danio rerio*		X							4d	184259
Ulhaq et al. 2013	Fish	*Danio rerio*	X	X	X	X	X			X	Chronic and acute	165818
Wang et al. 2011	Fish	*Danio rerio*		X							Chronic	164068
Wang et al. 2013	Fish	*Danio rerio*		X							4	179859
Wang et al. 2014	Rotifer	*Brachionus calyciflorus*			X			X			Acute and chronic	175717
Wang et al. 2017	Fish	*Danio rerio*		X							Acute	175190

TABLE F.1.1 STUDIES ACCEPTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—AQUATIC

Author and Year	Major Taxa	Species	PFOA	PFOS	PFBA	PFBS	PFDA	PFHxA	PFHxS	PFNA	Test Period	ECOTOX Ref. No.
Wang et al. 2020	Fish	*Danio rerio*	X								Chronic	182577
Wang et al. 2020	Crustacean, fish, algae	*Daphnia magna, chlorella vulgaris Danio rerio, and carp*		X							Acute	184300
Weiss-Errico et al. 2017	Fish	*Danio rerio*	X								7 day	181466
Wildlife International, 2001	Crustacean	*(Mysidopsis bahia*				X					96hr acute	185939
Wildlife International 2001	Algae	*Selenastrum capricornutum*				X					96hr	185468
Wildlife International 2001	Fish	*Pimephales promelas*				X					96hr acute	185937
Wildlife International 2001	crustacean	*Daphnia magna*				X					Chronic	185469
Wildlife International 2001	crustacean	*Daphnia magna*				X					48hr acute	185936
Wu et al. 2012	Marine fish	*Oryzias melastigma*		X							Chronic	159194
Wu et al. 2022	Fish	*Danio rerio*		X							120hr	188755
Xia and Niu 2017	Fish	*Danio rerio*		X							Acute	177144
Xia et al. 2018	Bivalve	*Anodonta woodiana*	X	X							48hr	184302
Xin et al. 2020	Fish	*Danio rerio*		X							7d	182584
Xu et al. 2013	Algae -2	*Chlorella pyrenoidosa* and *Selenastrum capricornutum*	X								Chronic and acute	170546
Xu et al. 2016	Algae	*Chlorella pyrenoidosa*	X								96hr and 8d chronic	185669
Xue et al. 2022	Algae	*Scenedesmus obliquus*		X		X					7d	190156

TABLE F.1.1 STUDIES ACCEPTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—AQUATIC													
Author and Year	**Major Taxa**	**Species**	**PFOA**	**PFOS**	**PFBA**	**PFBS**	**PFDA**	**PFHxA**	**PFHxS**	**PFNA**	**Test Period**	**ECOTOX Ref. No.**
Yang et al. 2014	Fish -2 Amphibian-1 Crustacean-2 Insects -1 Worm-1 Mollusk -1 Algae-1	*Carassius auratus, pseudorasbora parva, bufo gargarizans, daphnia magna, macrobrachium Nipponese; Chironomus plumosus; limnodrilus hoffmeisteri, cipangopaludina cathayensis; Scenedesmus quadricauda*	X	X							Acute and chronic	175260
Yang et al. 2019	Crustacean	*Daphnia magna*	X	X							Acute and chronic	182580
Ye et al. 2007	Fish	*Danio rerio*	X	X							96hr	185056
Yu et al. 2022	Fish	*Danio rerio*	X								30 hr	188869
Yuan et al. 2014	Planarian	*Dugesia japonica*	X	X							Acute	175659
Yuan et al. 2015	Planarian	*Dugesia japonica*	X								Acute	177055
Zhang et al. 2012	Fish	*Danio rerio*								X	Chronic	160553
Zhang et al. 2012	Algae	*Chlorella pyrenoidosa*		X							96hr	185559
Zhang et al. 2012	Algae	*Scenedesmus obliqnus*		X							96hr	185558
Zhang et al. 2013	Rotifer	*Brachionus calyciflorus*	X	X							Acute and chronic	175669
Zhang et al. 2014	Rotifer	*Brachionus calyciflorus*	X	X							Chronic	168456
Zhang et al. 2016	Fish	*Danio rerio*								X	Chronic 180 days	175216
Zhang et al. 2022	Fish	*Danio rerio*						X			96hr	188400
Zheng et al. 2012	Fish	*Danio rerio*	X	X						X	Acute	160547
Zhao et al. 2016	Fish	*Danio rerio*	X								24-72hr	188617

TABLE F.1.2 STUDIES ACCEPTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—TERRESTRIAL													
Author and Year	**Major Taxa**	**Species**	**PFOA**	**PFOS**	**PFBA**	**PFBS**	**PFDA**	**PFHxA**	**PFHxS**	**PFNA**	**Test Period**	**ECOTOX Ref. No.**
3M Co. 2001	Arthropod	*Apis*		X							Acute	181617
Abbott et al. 2007	Mammal	Mice	X								Chronic	
Abbott et al. 2009	Mammal	Mice		X							Acute	
Bursian et al 2020	Bird	*Coturnix japonica*	X	X							21d	182175
Bursian et al. 2021	Bird	*Coturnix japonica*		X							20 week	187171
Brignole et al. 2003	Plants	*Lactuca sativa, Lolium perenne, Lycopersicon esculentum, Allium cepa, Medicago saliva,* and *Linum usitatissimum*		X							Chronic	175361
Butenhoff et al. 2004	Mammal	Rat	X								Chronic	
Butenhoff et al. 2009	Mammals	Rat							X		Sub-chronic	
Butenhoff et al. 2012	Mammals	Rat		X							Chronic	
Case et al. 2001	Mammals -2	Rabbit and rat		X								
Chang et al. 2018	Mammal	Mice							X		Sub-chronic	
Chen et al. 2012	Mammal	Rat		X							Acute	
Cook et al. 1992	Mammal	Rat	X								Chronic	
Cui et al. 2009	Mammal	Rat	X	X							Chronic	
Das et al. 2008	Mammal	Mice			X						Chronic	
Das et al. 2015	Mammal	Mice								X	Chronic	
Dennis et al. 2020	Bird	*Colinus virginianus*		X							21d chronic	182174
Dennis et al. 2021	Bird	*Colinus virginianus*						X			90 d chronic	187173
DeWitt et al. 2008	Mammal	Mice	X								Sub-chronic	
DeWitt et al. 2016	Mammal	Mice	X								Chronic	
Du eta al. 2020	Plant	*Cucumis sativus*	X								60d	182464

TABLE F.1.2 STUDIES ACCEPTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—TERRESTRIAL

Author and Year	Major Taxa	Species	PFOA	PFOS	PFBA	PFBS	PFDA	PFHxA	PFHxS	PFNA	Test Period	ECOTOX Ref. No.
DuPont Co. 1982	Mammal	Mice	X								Chronic	
DuPont Co. 1985	Mammal	Mice								X	Chronic	
DuPont Co. 1995	Mammal	Rat	X								Chronic	
Era et al. 2009	Mammal	Mice		X							Chronic	
Flynn et al. 2021	Amphibians	*Ambystoma tigrinum*	X	X					X		30 d	185604
Gadelhak 1993	Arthropod	*Blattella germanica*		X							Chronic	167754
Gallagher et al. 2003a	Bird	*Colinus virginianus*		X							Chronic	180082
Gallagher et al 2003b	Bird	*Anas platyrhynchos*		X							Chronic	180057
Gonzalez-Naranjo et al. 2014	Plant	*monocotyledonous Sorghum bicolor*	X								Acute	176911
Grasty et al. 2003	Mammal	Mice		X							Acute	
Harris and Birnbaum 1989	Mammals	Mice					X				Chronic	
Harris et al. 1989	Mammals	Mice					X				Acute	
Hines et al. 2009	Mammal	Mice	X								Chronic	
Iwai and Hoberman 2014	Mammal	Mice						X			Chronic	
Jeong et al. 2010	Worm	*Eisenia fetida*	X	X							14d acute	184060
Karnjanapiboonwong et al 2018	Earthworm	*Eisenia fetida*				X			X	X	Chronic	177143
Kwak et al. 2020	Plant, springtails, worms	*Vigna radiata, Oryza sativa, Lobella Sokamensi,s Folsomia candida, Caenorhabditis. Elegans, Eisenia andrei*	X								Acute and Chronic	181724
Lau et al. 2003.	Mammals	Rat		X							Chronic	

TABLE F.1.2 STUDIES ACCEPTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—TERRESTRIAL													
Author and Year	**Major Taxa**	**Species**	**PFOA**	**PFOS**	**PFBA**	**PFBS**	**PFDA**	**PFHxA**	**PFHxS**	**PFNA**	**Test Period**	**ECOTOX Ref. No.**
Lau et al. 2006	Mammal	Mice	X								Chronic	
Lee et al. 2015	Mammal	Mice		X							Chronic	
Li et al. 2016	Mammal	Rats	X								Chronic	
Lieder et al. 2009a	Mammal	Rats				X					Sub-chronic	
Lieder et al. 2009b	Mammal	Rats				X					Sub-chronic	
Liu et al. 1996	Mammal	Rats	X								Chronic	
Loveless et al. 2006	Mammal	Rats and mice	X								Chronic	
Luebker et al. 2005a	Mammal	Rats		X							Chronic	
Luebker et al. 2005b	Mammal	Rats		X							Chronic	
Mommaerts et al. 2011	Arthropod	*Bombus terrestris*		X							Chronic	163148
Narizzano et al. 2021	Mammal	*Peromyscus leucopus*	X	X		X			X	X	28 days	187172
Narizzano and Bohannon 2021	Mammal	*Peromyscus leucopus* and *Peromyscus maniculatus*		X					X	X		
Newsted et al. 2006	Birds-2	*Anas platyrhynchos and Colinus virginianus*		X							Chronic	175224
Newsted et al. 2007	Birds-2	*Anas platyrhynchos* and *Colinus virginianus*		X							Chronic	175224
Newsted et al. 2008	Birds-2	*Anas platyrhynchos* and *Colinus virginianus*				X					Acute and Chronic	110984
Ngo et al. 2014	Mammal	Mice	X								Chronic	
Princz et al. 2018	Arthropods-2	*Folsomia candida*, and *Oppia nitens*.		X							Chronic	178027
Sindermann et al. 2002	Worm	*Eisenia fetida*		X							Acute	177116
Son et al. 2008	Mammal	Mice	X								Chronic	
Sonter et al. 2021	Insects	*Apis mellifera*		X							4 weeks	187362

TABLE F.1.2 STUDIES ACCEPTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—TERRESTRIAL

Author and Year	**Major Taxa**	**Species**	**PFOA**	**PFOS**	**PFBA**	**PFBS**	**PFDA**	**PFHxA**	**PFHxS**	**PFNA**	**Test Period**	**ECOTOX Ref. No.**
Thibodeaux et al. 2003	Mammals	Rat and mouse		X							Chronic	
Thomford 2002	Mammal	Rats		X							Chronic	
Van Gossum et al. 2010	Arthropod	*Drosophila hydei*		X							Chronic	177127
Wang et al 2010	Arthropod	*Drosophila sp*	X								Chronic	177114
Wan et al. 2011	Mammal	*Mice*		X							Chronic	
Wang et al. 2021	Worm	*Eisenia fetida*	X								3 to 42 d	188516
Wang et al. 2021	Worm	*Eisenia fetida*	X								28d	188202
White et al. 2011	Mammal	Mice	X								Chronic	
Wolf et al. 2007	Mammal	Mice	X								Chronic	
Wolf et al. 2010	Mammal	Mice								X	Chronic	
Xing et al. 2016	Mammal	Mice		X							Chronic	
Xu et al. 2013	Worms	*Eisenia fetida*		X							Acute	166647
Yahia et al. 2010	Mammal	Mice	X								Chronic	
Yu et al. 2018	Plant	*Lactuca sativa*		X							45d	182588
Yu et al. 2021	Plant	*Lactuca sativa*		X							14d	187869
Zareitalabad et al. 2013	Worm	*Aporrectodea caliginosa*	X	X							Chronic	175666
Zhang et al. 2020	Reptile	*Eremias argus*	X								60d	182586
Zhao et al. 2011	Plant	*Brassica chinensis*	X	X							Chronic	175188
Zheng et al. 2016	Worm	*Eisenia fetida*	X	X							Chronic	176944
Zhou et al. 2016	Plant	*Triticum aestivum L*	X								Chronic	175702

F.2 STUDIES REJECTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT

TABLE F.2.1 STUDIES REJECTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—AQUATIC

ECOTOX Ref No.[1]	Author and Year	Major Taxa	Species	PFOA	PFOS	PFBA	PFBS	PFDA	PFHxA	PFHxS	PFNA	Reject Reason
188866	Annunziato et al. 2022	Fish	Danio rerio				X					Reject; no ecologically relavant effects found
158213	Anselmo et al., 2011	Echinoderm	*Psammechinus miliaris*		X							Reject; no effect reported
166317	Arukwe et al. 2013	Fish	*Salmo salar*	X	X							Reject; only one treatment level
184506	Bao et al. 2019	Fish	*Danio rerio*		X							Reject; no ecologically relevant biological effect reported
184677	Bao,et al. 2020	Fish	*Danio rerio*		X							PFOS treatment increased growth
188753	Bednarz et al 2022	Corals	Stylophora pistillata		X							Reject; one treatment level.
182226	Benninghoff et al. 2012	Fish	*Oncorhynchus mykiss*	X			X			X		Reject; dietary study
182573	Benninghoff et al. 2011	Fish	*Oncorhynchus mykiss*		X			X			X	No ecologically relevant effect
185975	Bernardini,et al. 2021	Mollusk	*Ruditapes philippinarum*	X								Only one treatment level
185821	Cheloni et al. 2021	algae	*Chlamydomonas reinhardtii*		X							No effect related to growth, reproduction, or mortality
175685	Chen et al. 2016	Fish	*Danio rerio*		X							Reject; only one treatment level
185018	Chen et al. 2016	Fish	*Oryzias latipes*		X							No effect related to growth, reproduction, or mortality
184469	Chen et al. 2020	Fish	*Danio rerio*				X					No effect related to growth, reproduction, or mortality
157821	Cheng et al. 2011	Amphibians	*Xenopus laevis*		X							Reject no effects reported for growth development or reproduction
175649	Cheng et al. 2016	Fish	*Danio rerio*		X							Reject: only one treatment level used

TABLE F.2.1 STUDIES REJECTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—AQUATIC												
ECOTOX Ref No.[1]	**Author and Year**	**Major Taxa**	**Species**	**PFOA**	**PFOS**	**PFBA**	**PFBS**	**PFDA**	**PFHxA**	**PFHxS**	**PFNA**	**Reject Reason**
184736	Christou et al. 2020	Fish	*Danio rerio*		X							No effect related to growth, reproduction, or mortality
184303	Cormier et al. 2019	Fish	*Danio rerio*		X							No effect related to growth, reproduction, or mortality
181671	Dasgupta et al. 2020	Fish	*Danio rerio*		X							Reject; only one treatment level
175362	Desjardins et al. 2001	Algae	*Skeletonema costatum*		X							Reject, only one treatment level used
188864	Dong et al. 2021	Fish	*Danio rerio*		X							Reject; one treatment level
154960	Dorts et al. 2011	Fish	*Cottus gobio*		X							Reject; no effects reported for growth development or reproduction
175708	Du et al. 2013	Fish	*Danio rerio*	X								Reject; only NOEC for development and mortality
169773	Feng et al. 2015	fish	*Carassius auratus*	X	X							Reject; no effects reported for growth development or reproduction
184760	Foguth et al. 2020	Amphibian	*Rana pipiens*		X							Reject; only one treatment level
177964	Giari et al. 2016	fish	*Cyprinus carpio*	X								Reject; no effects reported for growth, development, or reproduction
177131	Godfrey et al. 2017	Fish	*Danio rerio*	X		X						Reject; only one treatment level
177139	Godfrey et al. 2017	Fish	*Danio rerio*	X		X						Reject; only one exposure level used
182536	Godfrey et al. 2019	Fish	*Oryzias latipes*	X		X						Reject; only one treatment level
156287	Hagenaars et al. 2011	Fish	*Scophthalmus maximus*		X							Reject; only one treatment level used
175710	Hagenaars et al. 2013	Fish	*Danio rerio*	X								Reject because no effect on fecundity, fertility or hatching was found

TABLE F.2.1 STUDIES REJECTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—AQUATIC

ECOTOX Ref No.[1]	Author and Year	Major Taxa	Species	PFOA	PFOS	PFBA	PFBS	PFDA	PFHxA	PFHxS	PFNA	Reject Reason
168388	Honda et al. 2016	Fish	*Takifugu rubripes*		X							Reject
184680	Hu et al. 2020	Algae	*Chlorella pyrenoidosa*	X								Reject; no effects detected based on exposure alone
189040	Hu et al. 2021	Fish	*Danio rerio*				X					Reject; one treatment level
156047	Huang et al. 2011	Fish	*Oryzias melastigma*		X							Reject; no ecologically relevant endpoint was assessed
176956	Huang et al. 2015	Fish	*Oryzias melastigma*		X							Reject; no effect on growth, mortality, or reproduction
177122	Huang et al. 2016	Fish	*Danio rerio*		X							Reject; no effects reported
185977	Huang et al. 2021	Fish	*Danio rerio*		X							Reject; only one treatment level
160552	Inoue et al. 2012	Fish	*Cyprinus carpio*	X	X							Reject; no effects on growth, mortality, or reproduction
109137	Ishisbashi et al. 2008	Fish	*Oryzias latipes*					X				Reject; no effect on growth, mortality, or reproduction
175223	Jantzen et al. 2016b	Fish	*Danio rerio*	X	X						X	Reject; only one exposure concentration used
175760	Jantzen et al. 2016	Fish	*Danio rerio*	X	X						X	Reject; one treatment level
177166	Jantzen et al. 2017	Fish	*Danio rerio*	X								Reject; only one exposure concentration used
150289	Jeon et al. 2010a	Mollusk	*Crassostrea gigas*	X	X			X				Reject; no effects reported
175199	Jeon et al. 2010b	Fish	*Sebastes schlegeli*		X							Reject; no effects to growth, mortality or reproduction
182544	Kawamoto et al. 2010	Paramecium	*Paramecium caudatum*		X							Effects not related to growth, survival or reproduction
177167	Keiter et al. 2016	Fish	*Danio rerio*		X							Reject; a mixture was used with only one PFOS treatment level
151615	Kim et al. 2010	Fish	*Cyprinus carpio*	X	X							Reject; no effects on growth reported after 4-day exposure
158519	Kim et al. 2011	Fish	*Danio rerio*		X							Reject; only one treatment level

TABLE F.2.1 STUDIES REJECTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—AQUATIC												
ECOTOX Ref No.[1]	**Author and Year**	**Major Taxa**	**Species**	**PFOA**	**PFOS**	**PFBA**	**PFBS**	**PFDA**	**PFHxA**	**PFHxS**	**PFNA**	**Reject Reason**
184724	Kim et al. 2021	Fish	*Danio rerio*	X								Reject; no ecologically relevant effects
177119	Li 2011	Fish	*Poecilia reticulate*	X	X							Reject; no effects on growth, mortality or reproduction
114574	Liu et al. 2008	Algae	*Scenedesmus obliquus*	X					X			Reject due to no effect on a relevant endpoint
116910	Liu et al. 2009	Algae	*Scenedesmus obliquus*		X							Reject; no effect found
170323	Liu et al. 2013	Fish	*Danio rerio*		X							Reject; only one treatment level used
182461	Liu et al. 2013	Mollusc	*Perna viridis*	X				X			X	No effects related to growth, mortality, or reproduction
177196	Liu et al. 2014b	Mollusc	*Perna viridis*	X	X			X			X	Reject; no effects on growth, mortality, or reproduction
185960	Liu et al. 2021	Fish	*Danio rerio*				X					Only one treatment level
184883	Liu et al. 2021	Fish	*Danio rerio*				X					No effects related to growth, mortality, or reproduction
170602	Lou et al. 2013	Amphibian	*Xenopus laevis*		X		X					Reject; no effect on growth mortality, or reproduction
177157	Manera et al. 2017	Fish	*Cyprinus carpio*	X								Reject; no effects on growth, mortality, or reproduction
182553	Manera et al. 2019	Fish	*Cyprinus carpio*	X								No effects related to growth, mortality, or reproduction
178355	Marziali et al. 2019	Insect	*Chironomus riparius*	X	X							Reject because only one treatment level was used for PFOA
110755	Matsubara et al. 2006	Cilliate	*Paramecium caudatum*	X	X		X	X			X	Reject; studies cells
177070	Meng et al. 2016	Worms	*Limnodrilus hoffmeisteri*		X							Reject; one treatment level used
182556	Miranda et al. 2020	Fish	*Melanotaenia fluviatilis*	X								No effects related to growth, mortality, or reproduction
178388	Mitchell 2009	Amphibian	*Xenopus*					X			X	Reject; only one treatment level
175198	Mortensen et al. 2011	Fish	*Salmo salar*	X	X							Reject; no effect on growth, mortality or reproduction

TABLE F.2.1 STUDIES REJECTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—AQUATIC												
ECOTOX Ref No.[1]	**Author and Year**	**Major Taxa**	**Species**	**PFOA**	**PFOS**	**PFBA**	**PFBS**	**PFDA**	**PFHxA**	**PFHxS**	**PFNA**	**Reject Reason**
175222	Oh et al. 2013	Fish	*Oryzias latipes*	X	X							Reject because only one treatment level; no effect on growth, mortality or reproduction
161191	Padilla et al. 2012	Fish	*Danio rerio*	X								Reject; high throughput screening study
185888	Palmer et al. 2001	Fish	*Cypridon variagatus*		X							Reject; only one treatment level
175185	Preus-Olsen et al. 2014	Fish	*Gadus morhua*		X							Reject; no effect described
175667	Qiang et al. 2015	Fish	*Danio rerio*		X							Reject; no observed effect and only one treatment level
177202	Qiang et al. 2016a	Fish	*Cyprinus carpio*		X							Reject; only one treatment level was used; no effect reported
177094	Qiang et al. 2016b	Fish	*Danio rerio, Ctenopharyngodon idella, Hypostomus plecostomus*		X							Reject; no effects on growth, mortality, or reproduction
188559	Rericha et al. 2021	Fish	*Danio rerio*	X		X			X			Reject; one treatment level
170799	Rodea-Palomares et al. 2015	Cyanobacteria	*Anabaena*	X	X							Reject; study of effects on bioluminescence
175716	Roland et al. 2014	Fish	*Anguilla anguilla*		X							Reject; no effect reported
177262	Rotondo et al. 2018	Fish	*Cyprinus carpio*	X								Reject; no affect reported on growth, mortality, or reproduction
177135	Sakurai et al. 2017	Worms	*Perinereis wilsoni*		X							Reject; only one treatment level used; no effect found
182532	Sant et al. 2016	Fish	*Danio rerio*		X							No effects related to growth, mortality, or reproduction
118237	Shi et al. 2009b	Fish	*Danio rerio*		X							Reject; only one treatment level
159201	Spachmo et al. 2012.	Fish	*Salmo salar*	X	X							Reject; only one treatment group;

TABLE F.2.1 STUDIES REJECTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—AQUATIC												
ECOTOX Ref No.[1]	**Author and Year**	**Major Taxa**	**Species**	**PFOA**	**PFOS**	**PFBA**	**PFBS**	**PFDA**	**PFHxA**	**PFHxS**	**PFNA**	**Reject Reason**
175220	Stefani et al. 2014	Insect	*Chironomus riparius*	X	X		X					Reject; only one treatment level
184746	Tang et al. 2021	Fish	*Danio rerio*				X					No effects related to growth, mortality, or reproduction
181467	Tse et al. 2016	Fish	*Danio rerio*		X							No effects related to growth, mortality, or reproduction
175655	Ulhaq et al. 2015	Fish	*Danio rerio*	X								Reject; no effects on growth, mortality, or reproduction
185624	Wasel et al. 2020	Fish	*Danio rerio*	X		X	X		X			Reject
114785	Williams et al. 2008	Fish	*Platichthys flesus*	X								Reject; only one treatment level; injection study
182581	Yi et al. 2019	Fish	*Danio rerio*		X							One treatment level; No effects related to growth, mortality, or reproduction
178033	Yuan et al. 2018	Planarians	*Dugesia japonica*		X							Reject
177074	Zhai et al. 2016	Insect	*Chironomus plumosus*	X				X			X	Reject; sediment study; one treatment and no ecologically relevant effect
182585	Zhang et al. 2020	Planarian	*Dugesia japonica*	X								Only on treatment level and growth, mortality, and reproduction not assessed; Accept for NOEC
179618	Zhao et al. 2018	Planarian	*Dugesia japonica*		X							Reject; only one treatment level
185971	Zhu et al. 2021	Fish	*Danio rerio*		X							Growth, mortality, and reproduction not assessed

TABLE F.2.2 STUDIES REJECTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—TERRESTRIAL												
ECOTOX Ref No.[1]	**Author and Year**	**Major Taxa**	**Species**	**PFOA**	**PFOS**	**PFBA**	**PFBS**	**PFDA**	**PFHxA**	**PFHxS**	**PFNA**	**Reject Reason**
94239	Abdellatif et al. 1990	Mammal	Rats	X								Reject; only one treatment level; No effects reported for growth, mortality or reproduction
N/A	Biegel et al. 2001	Mammals	Rats	X								Reject; one treatment level
151364	DuPont Co. 1965	Mammal	Dogs	X								Reject; no endpoint calculated
151364	DuPont Co. 1981	Mammal	Rats	X								Reject; no control
151364	DuPont Co. 1981	Mammal	Rats	X								Reject; no control
151364	DuPont Co. 1981	Mammal	Rats	X								Reject; no control
151364	DuPont Co. 1981	Mammal	Guinea pigs	X								Reject; no control
151364	DuPont Co. 1983	Mammal	Rats	X								Reject; no endpoint calculated
N/A	Fuentes et al. 2007	Mammal	Mice		X							Reject; only one treatment level
177180	He et al. 2016	Worm	*Eisenia fetida*	X								Reject; no effect on growth, reproduction, or mortality reported
178466	Hu et al. 2002	Mammal	Rats		X							Reject; only 1 treatment level used for live exposure
N/A	Kawabata et al. 2017	Mammal	Rats					X				Reject; one treatment level
N/A	Kawashima et al. 1995	Mammal	Rats	X				X				Reject; no effect reported
N/A	Klaunig et al. 2015	Mammal	Rats						X			Reject; high control mortality
182460	Lankadurai et al. 2012	Worms	*Eisenia fetida*	X	X							Reject; no effects on growth, reproduction or mortality reported
189038	Lupton et al. 2022	Plant	*Medicago sativa*	X								Reject; one treatment level

TABLE F.2.2 STUDIES REJECTED FOR ECOLOGICAL SCREENING LEVEL DEVELOPMENT—TERRESTRIAL

ECOTOX Ref No.[1]	Author and Year	Major Taxa	Species	PFOA	PFOS	PFBA	PFBS	PFDA	PFHxA	PFHxS	PFNA	Reject Reason
104399	Martin et al. 2007	Mammals	Rats	X	X							Reject; only one treatment level used
N/A	Ngo et al. 2014	Mammals	Mice		X							Reject; no effect documented for PFOS
185620	Omagamre et al. 2020	Insect	*Spodoptera exigua*			X						Reject; treatments increased growth and hatching; no adverse effects reported
N/A	Pastoor et al. 1987	Mammals	Rats	X								Reject; only one treatment level
N/A	Qazi et al. 2010	Mammals	Mice		X							Reject; only one treatment level
N/A	Rogers 2014	Mammals	Rats		X						X	Reject; one treatment level
175684	Smits and Nain 2013	Bird	*Coturnix japonica*	X								Reject; no effect on growth, reproduction, or mortality reported
185965	Sobhani et a. 2021	Earthworms	*Eisenia fetida*	X	X							Reject; mixture study with only 1 PFAS treatment level
N/A	Staples et al. 1984	Mammal	Rats	X								Reject; only one treatment level used
N/A	Vetvicka and Vetvickova 2013	Mammal	Mice	X	X							Reject; only one treatment level
N/A	White et al. 2007	Mammal	Mice	X								Reject; only one treatment level
N/A	Xie et al. 2003	Mammal	Mice	X								Reject; only one exposure dose
189036	Xu et al. 2022	Plant	Raphanus sativus	X								Reject; One treatment level
N/A	Yang, 2000	Mammal	mice	X								Reject; only one exposure dose
N/A	Yang et al. 2002	Mammal	Mice	X								Reject; only one exposure dose
177158	Yuan et al. 2017	Worm	*Eisenia fetida*	X	X							Reject; only LC_{50} calculated

[1] Papers with N/A in the reference number column were not found through ECOTOX.

APPENDIX G: SUMMARY OF BASIS FOR CHANGE IN ECOLOGICAL SCREENING VALUE

For ease of reference, the following tables present the 2024 ecological screening values (ESVs) compared to the 2021 ESVs and provide a summary of the basis for the change as reflected in the 2024 ESVs. Please refer to the detailed information provided in the appropriate report appendix for details.

Table G-1 Terrestrial Plants – Soil ESVs (mg/kg)

Chemical	2024 ESV	Increase/Decrease from 2021	2021 ESV	Basis for Change
PFBA	—	No Change	—	—
PFHxA	—	No Change	—	—
PFOA	101	Increase	79.5	2024 ESV update included a 2020 study (Kwak, et al., 2020), which was not included in the 2021 ESV derivation. The 2020 study identified a MATC of 245 mg/kg for rice and an EC10 of 274 mg/kg for mung bean. Recalculating a geometric mean with these two values from the 2020 study along with the eight values used in the 2021 ESV derivation is the basis of the increased ESV.
PFNA	—	No Change	—	—
PFDA	—	No Change	—	—
PFBS	—	No Change	—	—
PFHxS	—	No Change	—	—
PFOS	17.3	Decrease	40.2	2024 ESV update included a 2018 study (Yu, et al., 2018), which was not included in the 2021 ESV derivation. The 2018 study identified three MATC values for head, leaf, and romaine lettuces. Each MATC value was 0.43 mg/kg. Recalculating a geometric mean with these three values from the 2018 study along with the 13 values used in the 2021 ESV derivation is the basis of the decreased ESV.

—: Dash indicates data gap; data not available.
ESV: Ecological screening value
EC10: Effect concentration at which x% effect (mortality, inhibition of growth, reproduction, etc.) is observed compared to the control group.
MATC: Maximal acceptable toxicant concentration; Geometric mean of the no observed effect concentration and the lowest observed effect concentration.
mg/kg: Milligram per kilogram

Table G-2 Terrestrial Invertebrates – Soil ESVs (mg/kg)

Chemical	2024 ESV	Increase/Decrease from 2021	2021 ESV	Basis for Change
PFBA	—	No Change	—	—
PFHxA	—	No Change	—	—
PFOA	77.8	Increase	22.4	2024 ESV update included four additional studies (Joung, et al., 2010; Kwak, et al., 2020; Wang, et al., 2021; and Wang, et al., 2022), which were not included in the 2021 ESV derivation. These studies identified seven additional values (LOAEL or MATC) for the worm, earthworm, springtail, and nematode ranging from 10 to 612 mg/kg. Recalculating a geometric mean using these seven values along with the two values used in the 2021 ESV derivation is the basis of the increased ESV.
PFNA	10	No Change	10	—
PFDA	—	No Change	—	—
PFBS	100	No Change	100	—
PFHxS	10	No Change	10	—
PFOS	57.6	Increase	48.1	2024 ESV update included a 2010 study (Joung, et al., 2010), which was not included in the 2021 ESV derivation. This study identified a MATC concentration of 202 mg/kg for the earthworm. Recalculating the geometric mean using this additional value along with the seven values used in the 2021 ESV derivation is the basis of the increased ESV.

—: Dash indicates data gap; data not available.
ESV: Ecological screening value
LOAEL: Lowest observed adverse effect level is the lowest dose of a chemical at which adverse health effects are identified between the study animals or population and the control animals or population.
MATC: Maximal acceptable toxicant concentration is a calculated value, and it is the geometric mean of the no observed effect concentration and the lowest observed effect concentration.
mg/kg: Milligram per kilogram

Table G-3 Terrestrial Mammals – Soil ESVs (mg/kg)				
Chemical	**2024 ESV**	**Increase/Decrease from 2021**	**2021 ESV**	**Basis for Change**
PFBA	2.98	No Change	2.98	—
PFHxA	6.20	No Change	6.20	—
PFOA	3.84	No Change	3.84	—
PFNA	0.0242	No Change	0.0242	—
PFDA	0.0677	No Change	0.0677	—
PFBS	0.817	No Change	0.817	—
PFHxS	0.145	Increase	0.0028	2024 and 2021 ESVs were based on mammalian ground invertivore (short-tailed shrew) as this receptor resulted in the more conservative ESVs. 2024 ESV update incorporated a larger PFHxS TRV for the shrew (0.715 mg/kg-day based on BMDL from Narizzano et al., 2021) compared to the value used for the 2021 ESV (0.014 mg/kg-day). The increase in the TRV for the shrew is the basis for the increased ESV.
PFOS	0.0040	Decrease	0.0087	2024 and 2021 ESVs were based on mammalian ground invertivore (short-tailed shrew) as this receptor resulted in the more conservative ESVs. 2024 ESV update incorporated a lower UF adjusted PFOS TRV for the shrew (0.015 mg/kg-day based on BMDL from Narizzano et al., 2021) compared to the value used for the 2021 ESV (0.0327 mg/kg-day). The 2024 ESV used a larger test dose (0.12 mg/kg BW/day BMDL from Narizzano et al. [2021] vs 0.0327 mg/kg BW/day for the 2021 ESV). In addition, the combined value for the uncertainty factors increased in 2024 (8 vs 1 in 2021). Although the test dose increased, the increase in the uncertainty factor is the primary basis for the decreased ESV.

BMDL: Benchmark dose low
ESV: Ecological screening value
mg/kg: Milligram per kilogram
mg/kg-day: Milligram per kilogram per day
TRV: Toxicity reference value

Table G-4 Terrestrial Birds – Soil ESVs (mg/kg)				
Chemical	**2024 ESV**	**Increase/Decrease from 2021**	**2021 ESV**	**Basis for Change**
PFBA	—	No Change	—	—
PFHxA	—	No Change	—	—
PFOA	—	No Change	—	—
PFNA	—	No Change	—	—
PFDA	—	No Change	—	—
PFBS	15.8	No Change	15.8	—
PFHxS	—	No Change	—	—
PFOS	0.0386	No Change	0.0386	—

—: Dash indicates data gap; data not available.
ESV: Ecological screening value
mg/kg: Milligram per kilogram

Table G-5 Aquatic Life – Surface Water (Fresh Water) ESVs (µg/L)

Chemical	2024 ESV	Increase/Decrease from 2021	2021 ESV	Basis for Change
PFBA	75.7	Increase	64.6	2024 ESV update used a SACR of 207.5 in the derivation of the SCV, while the 2021 ESV used a SACR of 243.5 in the derivation of the SCV used in that report. 2024 ESV update derived a SCV of 75.7 µg/L, while the 2021 ESV derived a SCV of 64.6 µg/L. The SCV was used as the ESV. The decrease in the SACR is the basis of the increased ESV.
PFHxA	33.8	Increase	28.8	2024 ESV update used a SACR of 207.5 in the derivation of the SCV, while the 2021 ESV used a SACR of 243. This resulted in a 2024 SCV of 33.8 µg/L compared to a 2021 SCV of 28.8 µg/L. The SCV was used as the ESV. The decrease in the SACR is the basis of the increased ESV.
PFOA	109	Decrease	307	2024 ESV update used a FAV of 22,707 µg/L and a FACR of 207.5, while the 2021 ESV used a FAV of 92,146 µg/L and a FACR of 300. The decrease in the FAV and FAR values used in the 2024 udpate is the basis of the decreased ESV.
PFNA	16.9	Increase	16.4	2024 ESV update used a lower SAV of 3,500 µg/L and lower SACR of 207.5 compared to the 2021 ESV values (SAV of 4,000 µg/L and SACR of 243). The decrease in the SACR is the basis of the increased ESV.*
PFDA	3.44	Increase	2.94	2024 ESV update used a SACR of 207.5, while the 2021 ESV used a SACR of 243. The decrease in the SACR is the basis of the increased ESV.
PFBS	446	Increase	400	2024 ESV update used a SAF of 13, while the 2021 ESV used a SAF of 21.9. The decreased SAF led to a higher SAV at 54,361 µg/L in the 2024 ESV update. The SAF in the 2021 ESV was 37,880 µg/L. The SACR used in the 2024 ESV update was 122, while the 2021 ESV used a SACR of 94.8. The increase in the SAV is the basis of the increased ESV.
PFHxS	94.2	Increase	65.3	2024 ESV update used a SAF of 13, while the 2021 ESV used a SAF of 21.9. The decreased SAF led to a higher SAV at 11,487 µg/L in the 2024 ESV update. The SAF in the 2021 ESV was 6,196 µg/L. The SACR used in the 2024 ESV update was 122, while the 2021 ESV used a SACR of 94.8. The increase in the SAV is the basis of the increased ESV.
PFOS	4.85	Decrease	22.6	2024 ESV update used a FAV of 592 µg/L and a FACR of 122, while the 2021 ESV used a FAV of 2,139 and a FACR of 94.8. The decrease in the FAV and increase of the FACR is the basis of the decreased ESV.

ESV: Ecological screening level
FACR: Final acute chronic ratio
FAV: Final acute value
SACR: Secondary acute chronic ratio
SAF: Secondary acute factor
SAV: Secondary acute value
SCV: Secondary chronic value
µg/L: Microgram per liter

Table G-6 Aquatic-Dependent Mammals – Surface Water (Fresh Water) ESVs (µg/L)

Chemical	2024 ESV	Increase/Decrease from 2021	2021 ESV	Basis for Change
PFBA	119	Decrease	8,370	2024 ESV update used a geometric mean of the mink and otter wildlife values. BAFs for benthic and pelagic invertebrates, and fish increased based on data in Burkhard (2021) compared to BAFs used in the 2021 ESV derivation. Incorporation of the larger BAF values is the basis of the decreased ESV.
PFHxA	544	Decrease	2,210	2024 ESV update used a geometric mean of the mink and otter wildlife values. BAFs for benthic and pelagic invertebrates, and fish increased based on data in Burkhard (2021) compared to BAFs used in the 2021 ESV derivation. Incorporation of the larger BAF values is the basis of the decreased ESV.
PFOA	47.6	Decrease	1,580	2024 ESV update used a geometric mean of the mink and otter wildlife values. BAFs for benthic and pelagic invertebrates, and fish increased based on data in Burkhard (2021) compared to BAFs used in the 2021 ESV derivation. Incorporation of the larger BAFs is the basis of the decreased ESV.
PFNA	0.116	Decrease	2.08	2024 ESV update used a geometric mean of the mink and otter wildlife values. BAFs for benthic and pelagic invertebrates, and fish increased based on data in Burkhard (2021) compared to BAFs used in the 2021 ESV derivation. Incorporation of the larger BAFs is the basis of the decreased ESV.
PFDA	0.0937	Decrease	0.66	2024 ESV update used a geometric mean of the mink and otter wildlife values. BAFs for benthic and pelagic invertebrates, and fish increased based on data in Burkhard (2021) compared to BAFs used in the 2021 ESV derivation. Incorporation of the larger BAFs is the basis of the decreased ESV.
PFBS	209	Decrease	5,710	2024 ESV update used a geometric mean of the mink and otter wildlife values. BAFs for benthic and pelagic invertebrates, and fish increased based on data in Burkhard (2021) compared to BAFs used in the 2021 ESV derivation. Incorporation of the larger BAFs is the basis of the decreased ESV.
PFHxS	14.1	Increase	5.50	2024 ESV update used a geometric mean of the mink and otter wildlife values. BAFs for benthic invertebrates and fish increased, while the BAF for the pelagic invertebrates decreased based on data in Burkhard (2021) compared to BAFs used in the 2021 ESV derivation. The 2024 ESV used a larger test dose (5.72 mg/kg BW/day BMDL from Narizzano et al. [2021] vs 1 mg/kg BW/day for the 2021 ESV). In addition, the combined value for the uncertainty factors decreased in 2024 (8 vs 72 in 2021). Although the BAFs used were larger, the increase in the test dose coupled with the decrease in the uncertainty factor is the basis of the increased ESV.
PFOS	0.0167	Decrease	0.117	2024 ESV update used a geometric mean of the mink and otter wildlife values. BAFs for benthic and pelagic invertebrates, and fish increased based on the data from Burkhard (2021) compared to BAFs used in the 2021 ESV derivation. The 2024 ESV used a larger test dose (0.12 mg/kg BW/day BMDL from Narizzano et al. [2021] vs 0.0327 mg/kg BW/day for the 2021 ESV). In addition, the combined value for the uncertainty factors increased in 2024 (8 vs 1 in 2021). Although the test dose increased, the larger BAFs coupled with the increase in the uncertainty factor is the basis for the decreased ESV.

BAF: Bioaccumulation factor
BMDL: Benchmark dose low
ESV: Ecological screening value
L/kg ww: Liter per kilogram (wet weight)
mg/kg BW/Day: Milligram per kilogram body weight per day

Table G-7 Aquatic-Dependent Birds – Surface Water (Fresh Water) ESVs (µg/L)

Chemical	**2024 ESV**	**Increase/Decrease from 2021**	**2021 ESV**	**Basis for Change**
PFBA	—	No Change	—	—
PFHxA	—	No Change	—	—
PFOA	—	No Change	—	—
PFNA	—	No Change	—	—
PFDA	—	No Change	—	—
PFBS	2,783	Decrease	88,600	2024 ESV update used a geometric mean of the values for the five avian receptors. BAFs for benthic and pelagic invertebrates, and fish increased based on data in Burkhard (2021) compared to BAFs used in the 2021 ESV derivation. Incorporation of larger BAFs is the basis of the decreased ESV.
PFHxS	—	No Change	—	—
PFOS	0.487	Decrease	2.57	2024 ESV update used a geometric mean of the values for the five avian receptors. BAFs for benthic and pelagic invertebrates, and fish increased based on data in Burkhard (2021) compared to BAFs used in the 2021 ESV derivation. Incorporation of larger BAFs is the basis of the decreased ESV.

—: Dash indicates data gap; data not available.
BAF: Bioaccumulation factor
BCF: Bioconcentration factor
ESV: Ecological screening value
L/kg: Liter per kilogram
µg/L: Microgram per liter

Table G-8 Aquatic Life – Marine ESVs (µg/L)

Chemical	2024 ESV	Increase/Decrease from 2021	2021 ESV	Basis for Change
PFBA	—	No Change	—	—
PFHxA	—	No Change	—	—
PFOA	3.16	Decrease	6.12	2024 ESV update had a decrease in GMAV from 11,900 µg/L in 2021 to 4,000 µg/L in 2024. The decreased GMAV led to a decrease in SAV from 1,487 µg/L in 2021 to 656 µg/L in 2024. The SACR decreased from 243 in 2021 to 207.5 in 2024. The decrease in SAV is the basis of the decreased ESV.
PFNA	—	No Change	—	—
PFDA	—	No Change	—	—
PFBS	—	No Change	—	—
PFHxS	—	No Change	—	—
PFOS	1.44	Decrease	3.96	2024 ESV update had a decrease in the GMAV from 3,000 µg/L in 2021 to 1,070 µg/L in 2024. The decreased GMAV led to a decrease in SAV from 375 µg/L in 2021 to 175 µg/L in 2024. The SACR increased from 94.8 in 2021 to 122 in 2024. The decrease in SAV is the basis of the decreased ESV.

—: Dash indicates data gap; data not available.
ESV: Ecological screening level
GMAV: Genus mean acute values
SACR: Secondary acute chronic ration
SAF: Secondary acute factor
SAV: Secondary acute value
µg/L: Microgram per liter

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