November 2017 DRAFT Per- and Poly-Fluorinated Alkyl Substances Chemical Action Plan (PFAS CAP)

The Washington State departments of Ecology and Health prepared additional sections for the draft PFAS CAP for external review. This section describes the potential risk that PFAS pose to ecological receptors. This material may be modified in response to comments and the content re-organized for the draft Interim PFAS CAP.

The 2017 Draft Interim PFAS CAP includes:

- Health, Environment, Chemistry, Regulations – posted online 09/20/2017
- Uses, Intro – posted online 10/05/2017
- Sections on Ecological Receptors and Biosolids - posted online 11/08/2017

The draft chapters and sections may include cross-references to other sections/chapters in the Draft Interim PFAS CAP or notes where additional information will be provided in a later draft.

Ecology and Health are asking interested parties to provide feedback on these draft documents by **November 17, 2017.**

Submit comments, suggestions, and questions to Kara Steward at kara.steward@ecy.wa.gov

The Draft Interim PFAS CAP documents are posted at https://www.ezview.wa.gov/?alias=1962&pageid=37105 (at the bottom of the webpage).

Per- and Polyfluoroalkyl Substances (PFAS): Persistence, Bioaccumulation, Toxicokinetics, and Toxicological Response for Ecological Receptors

1.0 Purpose, Applicability, and Terminology

This document summarizes the potential risk that per- and poly-fluoroalkyl substances (PFAS) pose to ecological receptors. A list of acronyms used is provided at the end of this document.

PFAS terminology proposed by Buck, et al. (2011) is used in this document. Aimed more at wildlife studies (Reiner and Place 2015), PFAS includes perfluoroalkyl acids (PFAA) which, in turn, include perfluoroalkyl carboxylic acids (PFCA) and perfluoroalkyl sulfonic acids (PFSA). Use of the terms, perfluoroalkyl contaminant (PFC) (Kelly, et al. 2009) and polyfluoroalkyl substance (PFS) (Houde, et al. 2006), appears to denote PFAS. Other PFAS terms are introduced throughout this chapter.

2.0 Summarizing Ecological Risk

The potential risk chemicals pose to ecological receptors is dependent on:

- Distribution of the chemical in the environment
- Persistence of the chemical in the environment
- Persistence and bioaccumulation of the chemical within the organism
- Toxicokinetics[1], and
- Resulting toxicological response of the organism to the chemical

Distribution and persistence of PFAS in the environment have been described in an earlier chapter of the CAP. As a result, the foci of this document will be on the persistence and bioaccumulation within organisms, toxicokinetics, and the resulting toxicological responses of the organism to PFAS compounds.

2.1 Assessing Ecological Risk Based on Grouping (Short vs. Long-Chain PFAS)

An early step in the assessment of evaluating the potential risk of PFAS is to group the short- and long-chain substances based on the number of associated perfluorinated carbons.

[1] Toxicokinetics is the determination of the fate of the chemical administered to a living organism (i.e. where does it move within the organism). The term includes the basic kinetics concepts of absorption, distribution, metabolism, and excretion (ADME) of chemicals.

Short-Chain PFAS

Short-chain PFAS contain up to five perfluorinated carbons terminating with a sulfonate group, or up to six perfluorinated carbons terminating with a carboxyl group. While resistant to degradation, these substances do not appear to be highly bioaccumulative or to have significant toxicological effects on ecological receptors (IMAP 2017a, 2017b, and 2017c; USEPA 2017). These short-chain substances include:

- Short-chain PFCAs and their direct precursors
- Direct and indirect precursors of PFBS[2], and
- Short-chain polyfluoroalkyl acrylic polymer[3] based on 6:2 fluorotelomer chemistry (Methacrylate Polymer), intermediates and degradation products

Additional literature suggests that:

- 6:2 FTOH, 6:2 FTAC, and 6:2 FTMAC (considered short-chain PFAS) would not meet the criteria for persistence, bioaccumulation, or toxicity based on the Stockholm Convention on Persistent Organic Pollutants (Ramboll Environ. 2016), and
- Research findings suggest (see Table 1 below) that biomagnification and bioaccumulation increase as the number of fluorinated carbons also increase (Conder, et al. 2007).

Table 1: Example of the bioaccumulation potential of some PFAS, as related to the number of fluorinated carbons comprising each compounds molecular structure (Conder, et al. 2007).

# Fluorinated Carbons	Compound	Frequency of Detection	BAV/BCF Significant Values (L/Kg)	Biomagnification	Bioaccumulative
Perfluoroalkyl Sulfonates					
4	PFBS	Not detected	< 1	No	No
6	PFHxS	Detected in some wildlife	10	No	No
8	PFOS	Detected in most wildlife	18 - 11000	Possibly	Yes
Perfluorocarboxylates					
4 - 6	PFPn, PFHx, PFHp	Not detected or infrequently detected	< 1	No	No

[2] The degradation of PFBS is very slow compared with its rate of formation from degradation of the precursors and PFBS will be the final degradant from multiple precursors. Therefore, the amount of PFBS in the environment (general or local) is expected to be higher than that of any of the precursors. It is therefore assumed for the purposes of the cited (IMAP) assessment that the primary risk posed by the chemicals in this group results from the release of PFBS to the environment.

[3] Polymers may be precursors to short-chain substances, but they are not themselves short-chain substances. The side chains may be based on short-chain monomers.

# Fluorinated Carbons	Compound	Frequency of Detection	BAV/BCF Significant Values (L/Kg)	Biomagnification	Bioaccumulative
7	PFO	Detected in some wildlife	2 – 570	No	No
8 – 13	PFN, PFD, PFU, PFDo, PFTri, PFT	Detected in most wildlife	100 - 23000	Possibly	Possibly

Long-Chain PFAS

Long-chain PFAS contain six or more perfluorinated carbons terminating with a carboxylate, sulfonate, or sulfonyl fluoride group. These chemicals also resist degradation. However, in contrast to the short-chain substances, long-chain PFAS tend to be both bioaccumulative and produce adverse toxicological effects to both upland and aquatic ecological receptors even at relatively low contaminant levels (IMAP 2017d, 2017e, 2017f, and 2017g). These long-chain substances include:

- PFHxS and related perfluoroalkylcyclohexane sulfonates
- PFOA and its direct precursors
- PFOS and its direct precursors, and
- Direct precursors to:
    - PFHpS
    - PFHxS
    - PFPeS

Additional literature suggests that long chain PFAS refer to the following (OECD 2015):

- PFCAs with 7 and more perfluoroalkyl carbons, such as:
    - PFOA or C_8 PFCA; with 8 carbons, and
    - PFNA or C_9 PFCA; with 9 carbons
- PFSAs with 6 and more perfluoroalkyl carbons, such as:
    - PFHxS or C_6 PFSA; with 6 perfluoroalkyl carbons, and
    - PFOS or C_8 PFSA; with 8 perfluoroalkyl carbons
- Precursors that have the potential to transform to long-chain PFCAs or PFSAs in the environment or biota, such as PASF- and FT based substances

Summary

It is important to note that there appears to be very limited research available on short-chain PFAS. However, the information presented above indicates the potential risk of these short-chain substances (e.g., PFBS, PFPn, PFHx, PFHp) is less than that of the long-chain substances (e.g., PFOA, PFOS) to both aquatic and upland ecological receptors. As a result, this review will focus on evaluating the potential risks of long-chain PFAS on ecological receptors.

2.2 PFAS Representative Substances

As mentioned earlier, the potential risk for ecological receptors is much greater for the general class of chemicals known as long-chain PFAS. It is important to note that most of the information presented in this review is derived from the most extensively produced of the long-chain PFAS – i.e., PFOA and PFOS. The rationale for using these two specific chemicals as representative of the general class of long-chain PFAS chemicals is:

- PFOA and PFOS are the most widely studied of the long-chain PFAS
- These chemicals are structurally related, in that one of the defining characteristics that differentiates the chemicals within this class from other classes is chain length (or number of carbon atoms in the molecule)
- The carbon-fluorine bonds are among the strongest in organic chemistry which renders them practically non-biodegradable and persistent in the environment (Key, et al. 1997; Presher, et al. 1985; Lau, et al. 2007), including their presence and persistence in:
    - Water
    - Soil and sediment
    - Ambient air
    - Humans and laboratory animals, and
    - Aquatic, benthic, and upland wildlife
- The toxicokinetics and toxicological response for these chemicals appears closely related depending on species observed (Lau, et al. 2007; Kelly, et al. 2009; Lindstrom, et al. 2011; White, et al. 2011).

3.0 Persistence and Bioaccumulation within the Organism

Fluorine atoms are substituted for the hydrogen atoms that compose part of the hydrocarbon backbone in PFAS compounds. The fluorine-carbon bonds are stronger than the hydrogen-carbon bonds they replace, conferring extremely high chemical and thermal stability on these substances and is manifested in high environmental persistence. In addition, some long-chain PFAS bioaccumulate in the environment and can also undergo biomagnification (Li 2008; Stahl, et al. 2009).

The anions of PFOA, PFNA, and PFDA have been detected in a variety of wildlife across the globe. Detection of chemicals in wildlife does not necessarily imply high bioaccumulation potential for any specific chemical, but does comprise a standard element of many environmental monitoring programs. The large number of biota samples collected that contain quantifiable amounts of PFCAs, the ongoing scientific discourse regarding the high persistence and long-range fate and transport of PFCAs, and perceived similarities with perfluorinated sulfonates (including PFOS) have prompted concerns regarding the bioaccumulation potential

of PFCAs (Conder, et al. 2008). PFOS is reported to have a very low Henry's law constant[4], indicating aquatic environments may be a significant sink for PFOS with a potential for bioaccumulation in fish (Boudreau, et al. 2003).

PFOS and longer chain PFCAs (> C8) bioaccumulate and persist in protein-rich compartments of fish and birds, and in marine mammal tissues, such as carcass, blood, and liver. PFOS has been the most frequently detected PFAA in zooplankton and invertebrate studies. However, most studies showed concentrations of PFOS and other PFAAs very close to the limits of detection (Reiner and Place 2015). Available evidence shows the likely potential for bioaccumulation or biomagnification in marine or terrestrial species (USEPA 2009). Concentrations of PFOA/PFOS in plants vary greatly, depending on the concentrations applied to the soil, as well and soil-to-plant uptake factors. The uptake and storage of these substances in the vegetative parts of the plants appear to be greater than the transfer to the storage organs within the plants (Stahl, et al. 2009). PFAA studies of birds benefit from having species in nearly every region of the planet, including both aquatic and terrestrial ecosystems, representing a broad range of PFAA sources. The majority of studies focus on birds coming from the Arctic, North America, and Europe, while there are limited studies from the Southern Hemisphere (Antarctica and the Southern Ocean). Initial studies focused on PFOS and PFOA, but the number of PFAAs examined has recently expanded to precursor compounds, PFCAs, and PFSAs (Reiner and Place 2015).

In an earthworm study on bioaccumulation of PFAAs, the highest BAF (139 g soil dry wt. / g worm dry wt.) was observed for PFHxS in a soil contaminated with firefighting foam (Rich, et al. 2015). BAFs increased with chain length for PFCAs but decreased with chain length for PFSAs (Rich, et al. 2015). The unexpected finding for PFSAs may relate to decreased bioavailability. Overall, results from this study indicated that PFAA bioaccumulation into earthworms depends on soil concentrations, soil characteristics, analyte, and duration of exposure, and that accumulation into earthworms may be a potential route of entry of PFAAs into terrestrial foodwebs (Rich, et al. 2015).

Bioaccumulation is generally apparent for a variety of long-chain PFAS compounds in both terrestrial and aquatic wildlife. However, as shown in Table 2, BAF values in aquatic biota vary by specific compound, species, and tissue.

Table 2: BAF Values for Aquatic Biota.[5]

PFAS	Species	Tissue	BAF (L/Kg)	Reference
PFOS	Bluegill	Fillet	2700	MPCA 2013
PFOS	Carp	Fillet	1237	MPCA 2013
PFOS	Freshwater Drum	Fillet	3077	MPCA 2013
PFOS	Smallmouth Bass	Fillet	2845	MPCA 2013
PFOS	White Bass	Fillet	4618	MPCA 2013

[4] Henry's law constant refers to the ratio of a chemical concentration in the air to its concentration in water. Henry's law constant can vary significantly with temperature for some hazardous substances (Ecology 2007).
[5] Typically, a BAF is calculated as: Chemical concentration in the organism / Chemical concentration in the matrix. A higher BAF indicates more contaminant accumulates within the organism, relative to the environmental matrix.

PFAS	Species	Tissue	BAF (L/Kg)	Reference
PFOS	Common Shiner	Liver	6300 – 125000	Moody, et al. 2002
PFOS	Rainbow Trout	Carcass	690	ECCC 2017
PFOS	Rainbow Trout	Blood	3100	ECCC 2017
PFOS	Rainbow Trout	Liver	2900	ECCC 2017
PFOS	Phytoplankton	Whole unit	169	Loi, et al. 2011
PFOS	Lake Trout	Whole unit	31623	De Silva, et al. 2011
PFOA	Phytoplankton	Whole unit	292	Loi, et al. 2011
PFOA	Lake Trout	Whole unit	126	De Silva, et al. 2011
PFOA	Rainbow Trout	Blood	27	OECD 2008
PFOA	Rainbow Trout	Liver	8	OECD 2008
PFOA	Rainbow Trout	Whole unit	4	OECD 2008
PFHxS	Phytoplankton	Whole unit	58	Loi, et al. 2011
PFNA	Phytoplankton	Whole unit	1650	Loi, et al. 2011
PFDA	Phytoplankton	Whole unit	765	Loi, et al. 2011
PFECHS	Lake Trout	Whole unit	631	De Silva, et al. 2011
PFUnDA	Phytoplankton	Whole unit	4510	Loi, et al. 2011

In summary, persistence and bioaccumulation within the organism appear to be dependent on chain length. PFAS that contain six or more perfluorinated carbons have the potential to bioaccumulate within ecological receptors. It is apparent that wildlife from around the world are exposed to PFAAs. There is a tendency for animals living closer to industrialized regions to have higher concentrations of PFAAs compared to those living in more remote locations. The main compound found in most wildlife species is PFOS. However, especially in the more recent studies, the long chain PFCAs are frequently being detected and measured (Reiner and Place 2015).

4.0 Toxicokinetics and Toxicological Response

The toxicokinetic properties and toxicological responses of PFOS and PFOA have been studied in some detail. While there appears to be more literature available for aquatic than upland receptors, enough information is available for both to summarize the fate, as well as possible adverse effects, of these contaminants. In particular, animal studies with both PFOS and PFOA have shown that they are well-absorbed orally, but poorly eliminated; they are not metabolized, and undergo extensive re-uptake from enterohepatic circulation[6] (Lau, et al. 2007).

Conder, et al. (2008) have noted that the principal repository of bioaccumulated PFCA and PFSA in organisms is not lipid but protein. Although a portion of these chemicals is hydrophobic and may interact with lipids, the presence of the carboxylate or sulfonate functional group imparts high hydrophilicity, thereby making the molecule partly lipophilic and partly hydrophilic. Several

[6] Enterohepatic circulation refers to the circulation of the chemical from the liver to the bile, followed by entry into the small intestine, absorption by the enterocyte (intestinal absorptive cells) and then transport back to the liver.

studies have suggested that PFAAs are proteinophilic. For example, PFO in both rats and humans was strongly associated with serum albumin and other cytosolic proteins, and the proteinophilic nature of this class of chemicals has been hypothesized for the longer-chain PFAS (seven to eight fluorinated carbons). In support of this hypothesis, PFD (nine fluorinated carbons) has been shown to be more potent than PFO in binding to avian and carp serum proteins (Conder, et al. 2008).

In contrast to the protein binding ability of the chemicals with longer fluorinated carbon chains, the shorter perfluorinated compounds (PFSA and PFCA with four and three fluorinated carbons, respectively) were found to be 1-2 orders of magnitude less proteinophilic (Conder, et al. 2008). However, in general, studies continue to show that PFAAs are proteinophilic. For example, the tissue distribution of PFOA is undoubtedly dictated to some extent by its ability to bind avidly to plasma and other proteins (Kennedy, et al. 2004).

Comparing adverse effects among studies can be confounded by differences in genetics (e.g. species, gender), as well as differences in dose regimen (e.g. spacing, magnitude, duration, and route of administration). However, if the toxic mechanism is conserved, and some measure of the tissue concentration (i.e., dosimetry) at the biological target can be determined, then it is expected that this dosimetric anchor would be conserved across studies. Careful consideration of toxicokinetics is therefore required in order to link chemical exposure to toxicity (Wambaugh 2015). As a result, the tables presented later in this chapter illustrate effects associated with chemical concentrations in water (aquatic species) or chemical dose (upland species), rather than use for regulatory purposes.

Ecological Receptors in the Aquatic Environment

Aquatic plant studies have detected toxicological effects in microalgae (Latala, et al. 2009) and green algae (Ding, et al. 2012) for a variety of endpoints, including physiology, membrane potential, and growth rate (Rodea-Palomares, et al. 2015; Mhadhbi, et al. 2012). PFOS has been shown to be moderately toxic to aquatic invertebrates with acute toxicity values (48 and 96 hr. LC50) in the range of 10-300 mg/L, while PFOA has been shown to be only slightly toxic to aquatic invertebrates, with toxicity values in the range of 100-1000 mg/L (Li 2008). Boudreau, et al. (2003) indicates that PFOS is acutely toxic to freshwater organisms at or near 100 mg/L. Chronic toxicity would be expected to occur at lower concentrations.

Several toxicological effects have been tabulated for PFOA and PFOS in aquatic biota (Table 3). A variety of endpoints and effect concentrations are listed. As expected, gene expression effects occur at low concentrations (e.g., Cheng, et al. 2012; Spachmo and Arukwe 2012), relative to concentrations linked with deficits in apical endpoints (e.g., growth, survival, reproduction).

Table 3: Toxicological effects of PFOA and PFOS in aquatic species.

Chemical	Species	Matrix[7]	Concentration (ug/L)	Effect	Reference
PFOA	Blue-Green Algae	FW	5000 (LOEC)	Physiology/Membrane Potential	Rodea-Palomares, et al. 2015
PFOA	Atlantic salmon	FW	100 (LOEC)	Genetics/Bone Development	Spachmo and Arukwe 2012
PFOA	Sea urchin	SW	20000 (LOEC)	Growth/Length	Mhadhbi, et al. 2012
PFOA	Mysid	SW	7800 (EC10)	Mortality	Mhadhbi, et al. 2012
PFOS	Mysid	SW	530 (LOEC)	Survival	Drottar and Krueger 2000
PFOS	African Clawed frog	FW	0.1 (LOEC)	Genetics/Up-regulation of thyroid hormone regulated genes	Cheng, et al. 2012
PFOS	Water flea	FW	312.5 (LOEC)	Reproduction	Ji, et al. 2008
PFOS	Fathead minnow	FW	3300 (NOEC)	Survival	Drottar and Krueger 2000
PFOS	Algae	SW	12200 (EC10)	Population/Growth rate	Mhadhbi, et al. 2012
PFOS	Mysid	SW	3200 (EC10)	Mortality	Mhadhbi, et al. 2012
PFOS	Sea Urchin	SW	2000 (EC10)	Growth/Length (EC10)	Mhadhbi, et al. 2012

Freshwater biota: PFOA concentrations were observed in the following order in the tissues of rainbow trout (*Oncorhynchus mykiss*): blood > kidney > liver > gall bladder > gonads > adipose > muscle tissue, at average water exposure concentrations between 0.014 and 1.7 µg/L (Martin, et al. 2003). PFAAs also were detectable in the gills, suggesting that this was the site of uptake, depuration, or both, as has been determined for other xenobiotics[8] (Martin, et al. 2003). In addition, it was found that PFAS inhibited growth and had detrimental effects on photosynthesis on green algae (*P. subcapitata*, *S. capricornutum* and *C. vulgaris*) (Ding, et al. 2012; Boudreau, et al. 2003), as well as the floating macrophyte, *L. gibba* (Boudreau, et al. 2003).

Marine Environment: PFCs in arctic marine areas were found in tissue/fluids of fish, seaducks, and beluga whales (Kelly, et al. 2009). PFOA, PFNA, PFDA, and Perfluoroundecanoic acid (PFUnA) were commonly detected in sediments and macroalgae. PFOS and C_7 – C_{14} PFCAs were routinely detected in fish, seaduck, and beluga whale samples (Kelly, et al. 2009). High PFS concentrations have been detected in dolphin plasma and tissue samples in which PFOS, C_8 and C_{10} – PFCAs predominated in most matrices (Houde, et al. 2006). In addition, a preliminary screening of PFOS and related compounds has been performed in liver samples of fish, birds, and marine mammals from Greenland and the Faroe Islands (Bossi, et al. 2005). PFOS was the predominant fluorochemical in the biota analyzed, followed by PFOSA. Biomagnification of PFOS along the marine food chain showed shorthorn sculpin < ringed seal < polar bear. The greatest concentration of PFOS was found in the liver of polar bears (mean: 1285 ng/g wet weight, n = 2) (Bossi, et al. 2005).

[7] Matrix (FW = Freshwater, SW = Saltwater)

[8] Xenobiotics are chemical substances found within an organism that are neither naturally produced by the organism nor expected to be present within the organism.

Ecological Receptors in the Upland Environment

Upland Plants: Standard terrestrial plant test species are often used to evaluate the effect of contaminants on native wild plant species (USEPA 2012). For example, effects of PFAS on growth and reproduction have been studied in lettuce, pak choi, and cucumber (Li, et al. 2009; Ding, et al. 2012). There were no obvious effects on seed germination for the species. However, based on EC_{10}, EC_{50}, and NOECs, the five day root elongation sensitivity of test plants to both PFOS and PFOA was in the order of lettuce > pak choi > cucumber (Li, et al. 2009). In addition, another study evaluated the toxicity effects of seven PFCs in a five day test on root elongation of lettuce (*L. sativa*) (PFBA; 2,2,3,3,4,4,5,5 Octafluoro-1-pentanol; PFOA; PFNA; PFDA; PFUnA; PFDoA) (Ding, et al. 2012). This study indicated that the toxic effects of the seven PFCs increased with increasing fluorinated carbon chain length. It should be noted that extrapolating effects of PFAS on these test species to upland plants introduces additional uncertainty into an assessment of wild native plant species.

Upland Wildlife (and surrogate species): Limited information is available on the toxicokinetics and toxicological properties of PFOS and PFOA on upland wildlife receptors. Because few studies have determined safe exposure levels (NOAELs) for situations in which wildlife have been exposed over an entire lifespan or several generations, chronic exposures to a particular chemical are often estimated from toxicity studies conducted on a surrogate species. In many cases, the only available information is from studies on a laboratory species (primarily rats and mice) (Sample, et al. 1996). While not ideal, these surrogate species do provide valuable information.

A study was performed exploring the induction of liver tumors in Wistor rats for several chemicals, including PFOA (Abdellatif, et al. 1990). This study indicated that PFOA caused a 24-fold increase in the peroxisomal β-oxidation of fatty acids, but only about a 2-fold increase in catalase activity. These results suggest that PFOA has a promoting action on liver carcinogenesis.

In other laboratory studies, exposure to PFOA significantly increased offspring relative liver weights in all treatment groups in a full gestation study, and offspring of PFOA-treated dams exhibited significantly stunted mammary epithelial growth, as assessed by developmental scoring (Macon, et al. 2011). Evaluation of internal dosimetry in offspring revealed that PFOA concentrations remained elevated in liver and serum for up to 6 weeks and that brain concentrations were low and undetectable after 4 weeks. Additionally, in wild-type mice, concentrations of PFOA measured in the serum and liver were directly correlated with increasing dose to the animal, while the livers had ultrastructural changes induced by PFOA (Wolf, et al. 2008).

Reproductive and developmental effects are presented for several PFAS in terrestrial species, as shown in Table 4. Again, a variety of endpoints and dose levels are listed. Most of these data are for surrogate test animals, which imperfectly represent wildlife species.

Table 4: Reproductive and developmental effects of selected PFAS compounds in upland and surrogate species (data reported in Stahl, et al. 2011) [NR = Not Reported].

Chemical	Species	Dose (mg/kg – BW/day)	Gestation Day (day)	Effect	Reference
PFOS	Rats	1 – 10	6 – 15	Decrease body mass and lens abnormalities	Gortner 1980
PFOS	Quail	10 – 150 mg/kg feed	NR	Decrease viability of the 14 day old progeny; slight increase in incidences of small testes, however spermatogenesis and fertility were not affected	Newsted, et al. 2007
PFOS	Rabbits	0.1 – 3.75	6 – 20	Decrease in weight gain of the maternal animal; decreased birth weight and delayed ossification	Case, et al. 2001
PFOS	Leghorn chickens	1 – 5 mg/kg egg	Before incubation	No effect on hatching rate; increase spleen mass; right wings shorter; frequent occurrence of brain asymmetry; decrease immunoglobulin; increase plasma lysozyme activity; increase liver mass; increase body weight	Peden-Adams, et al. 2009
PFOA	Rats	1 – 30	NR	Decrease body weight; increase liver and kidney mass; decrease birth weight; delayed puberty; increase mortality rate after weaning	Butenhoff, et al. 2004a, 2004b
PFOA	Mice	1 – 40	During gestation	Liver enlargement; decrease in full term gestation, viable fetuses, fetus weight and postnatal viability; growth deficit; delayed opening of eyes; accelerated sexual maturity of male progeny	Lau, et al. 2006
PFOA	Chickens	5 – 40 mg/kg egg	Before incubation	Impaired hatching rate; high prevalence of splayed legs; chicks with partial or complete loss of yellow pigment in the down	Yanai, et al. 2008
PFBA	Mice	35 – 350	1 – 17	No adverse effects on survival rate of progeny or their postnatal growth; delayed opening of eyes; delayed onset of puberty; at the highest dosage: loss of complete litter	Das, et al. 2008
PFDA	Mice	0.25 to 32	10 – 13	Decrease in weight gain of maternal animal at high doses, fetal body weight reduced a low doses, no malformations observed	Harris and Birnbaum 1989
PFDA	Mice	0.03 – 12.8	6 – 15	Decrease in weight gain of maternal animal at high doses, fetal body weight reduced a low doses, no malformations observed	Harris and Birnbaum 1989

5.0 Summary

A distinction between effects of short-chain PFAS vs. long-chain PFAS in aquatic and terrestrial receptors is described in reviews by the Australian National Industrial Chemicals Notification and Assessment Scheme (IMAP 2017a, 2017b, and 2017c vs. IMAP 2017d, 2017e, 2017f, and 2017g, respectively), the Environmental Protection Agency (USEPA 2017), and the Organisation for Economic Cooperation and Development (OECD 2015). Both short and long-chain PFAS are

environmentally persistent. However, in contrast to short-chain PFAS, long-chain PFAS tends to bioaccumulate within ecological receptors, often eliciting adverse toxicological effects. Furthermore, it is also clear that the estimation of potential risks to receptors is dose dependent. As a result, the amount of contaminant in environmental matrices (e.g., soil, sediment, surface water), as well as those concentrations in dietary prey items, will ultimately contribute to ecological risk.

6.0 References

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7.0 Acronyms

General Terms:

BAF	Bioaccumulation Factor
BCF	Bioconcentration Factor
CAP	Chemical Action Plan
$EC_{(...)}$	Percent effect concentration
LOAEL	Lowest observed adverse effects level
LOEC	Lowest observed effects concentration
MTCA	Model Toxics Control Act
NOAEL	No observed adverse effects level
NOEC	No observed effects concentration
SMS	Sediment Management Standards

PFAS Related Terms:

6:2 FTAC	6 + 2 Fluorotelomer acrylate
6:2 FTMAC	6 + 2 Fluorotelomer methacrylate
6:2 FTOH	6 + 2 Fluorotelomer alcohol
8:2 FTOH	8 + 2 Fluorotelomer alcohol
FT	Fluorotelomer
PASF	Perfluoroalkane sulfonyl fluoride
PFAA	Perfluoroalkyl acid
PFAC	Perfluoroalkyl carboxylate

PFAS	Per- and Polyfluoroalkyl substances
PFBA	Perfluorobutanoic acid
PFBS	Perfluorobutane sulfonate
PFC	Perfluoroalkyl contaminants
PFCA	Perfluorinated carboxylates
PFD	Perfluorodecanoate
PFDA	Perfluorodecanoic acid
PFDo	Perfluorododecanoate
PFDoA	Perfluorododecanoic acid
PFECHS	Perfluoroethylcyclohexanesulfonate
PFHp	Perfluoroheptanoate
PFHpS	Perfluoroheptanesulfonate
PFHx	Perfluorohexanoate
PFHxA	Perfluorohexanoic acid
PFHxS	Perfluorohexane sulfonate
PFN	Perfluorononanoate
PFNA	Perfluorononanoic acid
PFO	Perfluorooctanoate
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonate
PFOSA	Perfluorooctane sulfonamide
PFPeS	Perfluoropetanesulfonate
PFPn	Perfluoropentanoate
PFS	Perfluoroalkyl substance
PFSA	Perfluoroalkyl sulfonic acid
PFT	Perfluorotetradecanoate
PFTri	Perfluorotridecanoate
PFU	Perfluoroundecanoate
PFUnA/PFUnDA	Perfluoroundecanoic acid