Per- and Poly-Fluorinated Alkyl Substances Chemical Action Plan (PFAS CAP) – 2019 Updates

Updated Environment Chapter

In 2017, the Washington State departments of Ecology and Health shared draft PFAS CAP chapters with external parties for review and comment. Comments received are available online. This document is either an update of a 2017 draft or a new 'chapter.' Ecology and Health are sharing chapters with interested parties prior to the April 2019 PFAS CAP webinar (*previously planned for March*). Updates will be discussed during the April webinar. We expect to publish the entire Draft PFAS CAP around June 2019 followed by a 60-day comment period.

In April 2019, Ecology and Health will host a PFAS CAP webinar (*date not yet set*) to:

- Briefly review activities underway: firefighting foam, food packaging, drinking water.
- Review updated/new chapters – comments will be accepted on the updated chapters. Responses will be provided after the 2019 public comment period (summer 2019).
- Discuss preliminary recommendations – requesting comments and suggestions from interested parties – due a week after the webinar.
- Submit comments online.

Quick summary of PFAS CAP efforts:

- PFAS CAP Advisory Committee and interested parties met in 2016, 2017 and 2018.
- September 2017 Draft PFAS CAP chapters posted:

Intro/Scope	Environment
Biosolids	Health
Chemistry	Regulations
Ecological Toxicology	Uses/Sources

- March of 2018, Ecology and Health published the Interim PFAS CAP.
- The 2019 updated PFAS CAP "chapters" to be posted (in the order we expect to post on the PFAS CAP website):

Biosolids	*Analytical methods (new)*
Ecological Toxicology	Chemistry
Environment	*Fate and Transport (new)*
Regulations	*Economic analysis (new)*
Uses/Sources	*Preliminary Recommendations (new)*
Health	

Questions - contact Kara Steward at kara.steward@ecy.wa.gov.

This document is posted on the PFAS CAP Website - https://www.ezview.wa.gov/?alias=1962&pageid=37105

Appendix #: Environment

Abstract

Major environmental pathways of specific PFAS compounds released to the environment have been identified as stormwater, wastewater treatment plant (WWTP) effluent, discrete releases from direct product use (i.e., AFFF use), and atmospheric deposition. The relative importance of these pathways in Washington State is not well characterized; however, environmental monitoring and drinking water testing suggest that stormwater, WWTP effluent, and aqueous film-forming foam (AFFF) for firefighting use are primary ways specific PFAS, like perfluoroalkyl acids (PFAAs), are delivered to our waterbodies.

In Washington, PFAAs have been detected in surface waters, groundwater, WWTP effluent, freshwater and marine sediments, freshwater fish tissue, and osprey eggs. Other media types have not been sampled in Washington. Environmental monitoring in the state has shown that PFAA concentrations are highest in urban surface water and surface waters receiving minimally diluted WWTP effluent.

Perfluorooctane sulfonate (PFOS), and to a lesser extent, perfluorodecanoic acid (PFDA), perfluorododecanoic acid (PFDoA), perfluoroundecanoate (PFUnA), and perfluorooctanesulfonamide (PFOSA), were widespread in freshwater fish tissue of waterbodies in the state. PFOS was measured in urban lake fish tissue at levels that may trigger consumption advisories to protect human health. PFOS and long-chain PFAAs are also detected in osprey eggs, at concentrations lower than would affect offspring survival, but potentially high enough to reduce hatchability in samples from sites affected by urban sources and WWTP inputs.

Environmental concentrations of PFAAs in Washington State surface waters, WWTP effluent, and freshwater fish tissue sampled in 2016 were consistent with PFAS levels in other parts of the U.S. not impacted by PFAS manufacturing facilities. Osprey egg PFAS concentrations measured in 2016 were similar to recent findings in rural osprey eggs collected in Sweden, with the exception of higher concentrations found in the Washington samples near urban or WWTP sources.

Environmental monitoring in 2016 suggested that PFAA levels in surface waters and WWTP effluent have decreased since the last round of sampling in 2008. A general shift in PFAA compound make-up was evident in WWTP effluent samples, with short-chain PFAAs replacing perfluorooctanoic acid (PFOA) as the most dominant compounds in effluent. PFAS concentrations (primarily made up of PFOS) in freshwater fish tissue and osprey eggs have remained unchanged between 2008 and 2016. PFOS continues to be a ubiquitous contaminant in Washington State aquatic biota.

Data gaps in our understanding of PFAS contamination in Washington State's environment include a lack of monitoring ambient groundwater and landfill leachate, assessing sources of PFAS in urban waterbodies, and testing PFAS compounds beyond PFAAs.

1.0 Introduction

PFAS can be released to the environment as emissions during manufacturing, and during the use and disposal of consumer and industrial products containing PFAS (OECD, 2013). After products containing PFAS are used or disposed of, the PFAS are transported into and through the environment by pathways such as stormwater, discrete releases from product use, wastewater treatment plant (WWTP) effluent, land application of industrial sludges, landfill leachate, and atmospheric deposition. The Biosolids and Fate and Transport appendices provide additional details. A detailed synthesis of PFAS environmental fate and transport is provided by the Interstate Technology and Regulatory Council (ITRC 2018).

Washington State currently has no known PFAS manufacturing facilities. Therefore, most contamination in the state's environment likely comes from product manufacturing that involves the use of PFAS, product use and disposal, and atmospheric deposition. Currently, the relative importance of different environmental pathways for PFAS transport (for example, WWTP effluent, aqueous film forming foam (AFFF) use) is not well characterized for Washington State. However, environmental monitoring in Washington show that PFAA concentrations are highest in waterbodies located in urban settings and where WWTP effluent makes up a significant portion of the flow, or hydrologic dilution is minimal. This suggests WWTP effluent, stormwater, and AFFF use are important pathways. Monitoring in the state has focused on releases of PFAS to surface water and the aquatic food chain; the ambient concentrations of PFAS in soils, groundwater, or air have not been investigated.

2.0 PFAS in Washington's environment

The following sections discuss available PFAS data on environmental media collected in Washington State. Relatively few studies have been conducted on PFAS in Washington. PFAS analyses in Washington have generally been limited to the PFAA included in EPA Method 537 (refer to the 'Analytical Methods' chapter for more discussion on PFAS analytical methods). Additional PFAS compounds, including precursors that are known or have the potential to break down into PFAAs, were analyzed in surface water and WWTP effluent samples collected in 2016. Ecology studies discussed below have been conducted following the data quality and acceptance limits included in the EPA 537 method. Discussions of data quality can be found in individual references.

2.1 Air

Ecology did not identify any studies or analyses of PFAS compounds in Washington's air.

2.2 Soil

In 2014, one soil sample from the Moses Lake Port Aircraft Rescue and Firefighting School facility was analyzed for PFAAs and PFOSA, following a release of fire suppressant (Ecology, 2016a). This soil sample had an elevated concentration of PFOS, at 12,000 µg/g, followed by perfluoroundecanoic acid (PFUnDA) (1,100 µg/g), perfluorononanoic acid (PFNA) (120 µg/g),

and perfluorodecane sulfonate (PFDS) (110 µg/g) (*accessed from Ecology's Environmental Information Management Database on 8/30/2017* at: http://www.ecy.wa.gov/eim/). Other perfluoroalkyl acids were detected at levels less than 100 µg/g. Following this sampling event, the impacted soils were excavated and removed from the site for proper disposal.

2.3 Groundwater

Ecology did not identify any ambient groundwater monitoring for PFAS in Washington. However, PFAS have been detected in groundwater wells used for drinking water in several areas. The Health chapter describes this sampling in more detail.

2.4 Surface water

Ecology's 2008 Statewide Study: In 2008, Ecology carried out a study measuring PFAAs in a variety of environmental media throughout the state to determine their occurrence in freshwater systems (Ecology, 2010). This study collected freshwater from 14 waterbodies in the spring and fall for analysis of 11 PFAAs. All spring samples contained measurable concentrations of at least one of the target PFAAs, ranging in total perfluoroalkyl acids (summed concentration) (T-PFAAs[1]) from 1.11–185 ng/L (median = 7.5 ng/L). Fall samples contained detected PFAAs in all but two samples, ranging in T-PFAAs from <0.9–170 ng/L (median = 3.6 ng/L). The highest concentrations were found in sites receiving wastewater treatment plant effluent with limited dilution (West Medical Lake and South Fork Palouse River), followed by an urban lake (Lake Washington). The rest of the sites—mid-sized rivers draining a variety of land-use types—had T-PFAA concentrations of 1.0–10 ng/L.

Ecology's 2016 Statewide Study: Ecology conducted a second statewide study in 2016 to assess changes in concentrations and compound make-up following the 2008 survey (Ecology, 2017). Surface waters from 15 waterbodies were collected in the spring and fall for analysis of 12 PFAAs and 13 known or potential precursors to PFAAs[2]. Less than half of the surface water samples contained PFAS compounds, with 7 out of 15 sites containing at least one sample with PFAS detections. T-PFAA[3] concentrations ranged from <2–153 ng/L (median = <2 ng/L) in the spring and <2-170 ng/L (median = <2 ng/L) in the fall. Only heavily impacted waterbodies had detections—those with significant WWTP inputs or in urban areas. Detection frequencies and total concentrations were generally lower than those of surface water samples collected in 2008 at the same sites.

With the exception of West Medical Lake and South Fork Palouse River samples, surface water PFAA concentrations in 2016 were very similar to PFAA concentrations recently measured in other waterbodies lacking point sources collected throughout Michigan, Rhode Island, and New York (MDEQ, 2015; Zang et al., 2016). All surface water samples were 1–2 orders of magnitude

[1] Sum of detected perfluoroalkyl acid concentrations. Compounds analyzed: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFBS, PFHxS, PFOS, and PFDS.
[2] Precursors analyzed included polyfluorinated sulfonamides, fluorotelomer carboxylates (saturated and unsaturated), and fluorotelomer sulfonates.
[3] Sum of detected perfluoroalkyl acid concentrations. Compounds analyzed: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, and PFOS.

lower than levels found in surface water impacted by AFFF use or manufacturing facilities in the U.S. (Anderson et al., 2016; MDEQ, 2015; Newton et al., 2017).

Perfluoroalkyl acids were the primary compound type found in the surface waters. In addition to the PFAAs analyzed, 13 precursors that potentially break down into PFAAs were analyzed in the 30 surface water samples. The only precursor PFAS compounds detected were 8:2 fluorotelomer unsaturated carboxylic acid (8:2 FTUCA), 4:2 fluorotelomer sulfonate (4:2 FTS), and 6:2 fluorotelomer sulfonate (6:2 FTS), which were all detected only once at 1.02, 11.3, and 6.87 ng/L, making up 12 percent, 100 percent, and 100 percent of the total PFAS concentration, respectively. In the waterbodies impacted by WWTP effluent (West Medical Lake and South Fork Palouse River), perfluoropentanoic acid (PFPeA), PFOA, and PFHxA were the most dominant compounds, each contributing an average of 24 percent to 28 percent of the total PFAS concentration. The urban lakes were dominated by PFOS first, and then by the compounds seen in the WWTP-impacted sites.

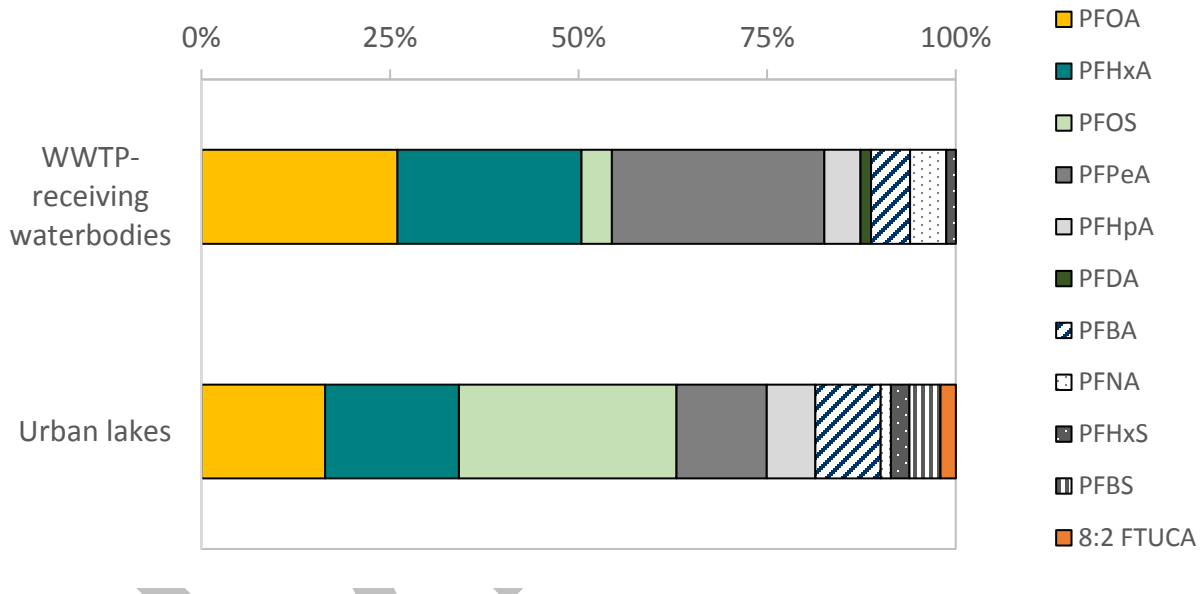

Figure 2. Average PFAS Compound Profiles in Two Types of Surface Waters Collected from Washington State Waterbodies in 2016. *WWTP-receiving waterbodies = South Fork Palouse River and West Medical Lake; Urban lakes = Angle, Meridian, and Washington Lakes.*

Local Source Control Monitoring: Ecology (2018) analyzed 12 PFAAs in stormwater of urban/industrial catchments in 2017 as part of a larger study to support Ecology's Local Source Control actions. Stormwater was collected twice from 7 commercial drainages in Clark County following spring storm events of >0.2" of rain. All 12 PFAAs were detected at nearly every site in the study. Stormwater T-PFAA[4] concentrations ranged from 31.9 to 114 ng/L. PFOS was

[4] Sum of detected perfluoroalkyl acid concentrations. Compounds analyzed: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, and PFOS.

measured in the highest concentrations (range: 3.8–71 ng/L), followed by perfluorohexane sulfonate (PFHxS) (range: 0.4–16.1 ng/L) and PFOA (range: 2.89–11.9 ng/L).

Puget Sound Study: Dinglasan-Panlilio et al. (2014) measured 14 PFAA compounds in surface water from seven sites in the Puget Sound area, as well as six sites in the nearby Clayoquot and Barkley Sounds in British Columbia, Canada. Samples were collected in spring, summer, and fall of 2009 and 2010, as well as winter 2011. At least one PFAA compound was detected in all samples analyzed. T-PFAA[5] concentrations ranged from 1.5–41 ng/L. The highest concentrations were found in two urbanized sites draining to Puget Sound (First Creek in Tacoma and Portage Bay in Seattle). T-PFAA concentrations in marine waters of the Puget Sound were lower than the urban freshwater sites and comparable to levels measured in the more remote sampling locations in Clayoquot and Barkley Sounds. Perfluoroheptanoic acid (PFHpA), PFOA, and PFOS were the most frequently detected compounds in the samples. Individual compound concentrations were not reported.

2.5 WWTP effluent

Statewide study, 2008: Ecology's 2008 PFAS survey analyzed 11 PFAAs in effluent of four WWTPs during the spring and fall (Ecology, 2010). All samples contained multiple compounds, with T-PFAAs[6] ranging 61–418 ng/L (median = 218 ng/L) in the spring and 73–188 ng/L (median = 140 ng/L) in the fall. PFOA, the dominant compound detected, contributed an average of 36 percent and 32 percent to the T-PFAA concentration in the spring and fall, respectively. In spring samples, perfluorohexanoic acid (PFHxA) was the next most-dominant compound (average of 28 percent contribution to T-PFAA concentration), followed by PFPeA (average of 10 percent). PFHxA and PFPeA had similar percent contributions in the fall samples (16–17 percent of the total).

Statewide study, 2016: Ecology collected effluent from 5 WWTPs in during the spring and fall of 2016 for analysis of 35 PFAS compounds (12 PFAAs and 23 known or potential precursor compounds[7]) (Ecology, 2016b and 2017). PFAS were detected in all WWTP effluent samples analyzed. Spring T-PFAA[8] concentrations ranged from 42.1 to 107 ng/L, with a median of 68.9 ng/L. Fall concentrations were similar, ranging in T-PFAAs from 41.8 to 125 ng/L, with a median of 71.4 ng/L. The PFAA concentrations from all WWTPs sampled were within the range found in other recent reports of municipal WWTP effluent in the U.S., but much lower than concentrations found in effluent samples that treat wastewater containing AFFF (Appleman et al., 2014; Houtz et al., 2016).

[5] Sum of detected perfluoroalkyl acid concentrations. Compounds analyzed: PFBA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFTrDA, PFTeDA, PFBS, PFHxS, PFOS, and PFDS.
[6] Sum of detected perfluoroalkyl acid concentrations. Compounds analyzed: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFBS, PFHxS, PFOS, and PFDS.
[7] Precursors analyzed included polyfluorinated sulfonamides, fluorotelomer carboxylates (saturated and unsaturated), fluorotelomer sulfonates, perfluoroalkyl phosphonates, and polyfluoroalkyl phosphates.
[8] Sum of detected perfluoroalkyl acid concentrations. Compounds analyzed: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, and PFOS.

PFAAs were the primary PFAS compound type found in the effluent samples. Only four of the precursor compounds were detected: PFOSA, bis(perfluorohexyl) phosphinate (6:6 PFPi), bis(1H,1H,2H,2H-perfluorooctyl) phosphate (6:2 diPAP), bis(1H,1H,2H,2H-perfluorodecyl) phosphate (8:2 diPAP), which ranged in concentration from 2.8 to 19.3 ng/L, contributing 6 percent–26 percent of the total PFAS concentration in individual samples. Overall, PFHxA was the most dominant compound in effluent samples (average contribution of 27 percent), followed by PFPeA (average of 22 percent), and PFOA (average of 16 percent). The low detection frequencies of precursor compounds seen in the Washington WWTP effluent was similar to the low number of precursors detected in effluent collected in California (Appleman et al., 2014).

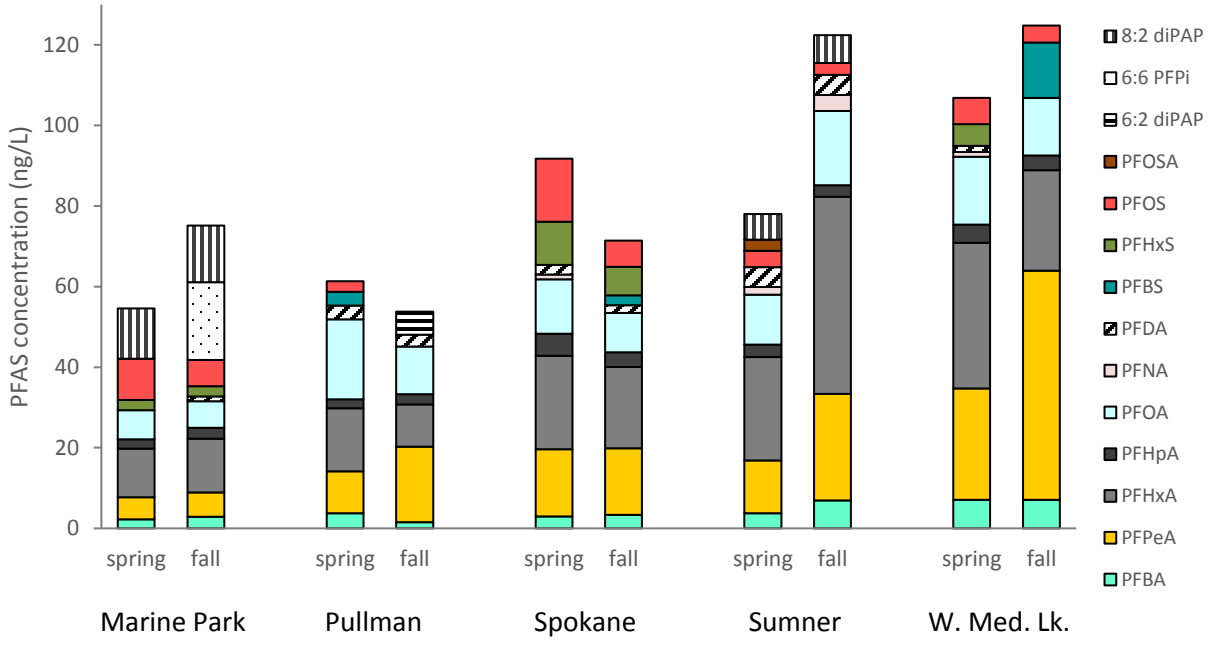

Figure 3. PFAS Concentrations (ng/L) in Wastewater Treatment Plant Effluent Samples Collected in 2016. ***Results below quantitation limits are excluded from figure.***

T-PFAA concentrations in effluent samples collected in 2016 were consistently lower than T-PFAA concentrations measured in 2008 by Ecology (2010) at the same WWTPs (Figure 4). A general shift in the composition of PFAS compounds was evident in the WWTP effluent samples as well, with the percent contribution of PFOA decreased in all samples, while the percent contribution of short-chain compounds increased: PFHxA, PFPeA, and perfluorobutanoic acid (PFBA).

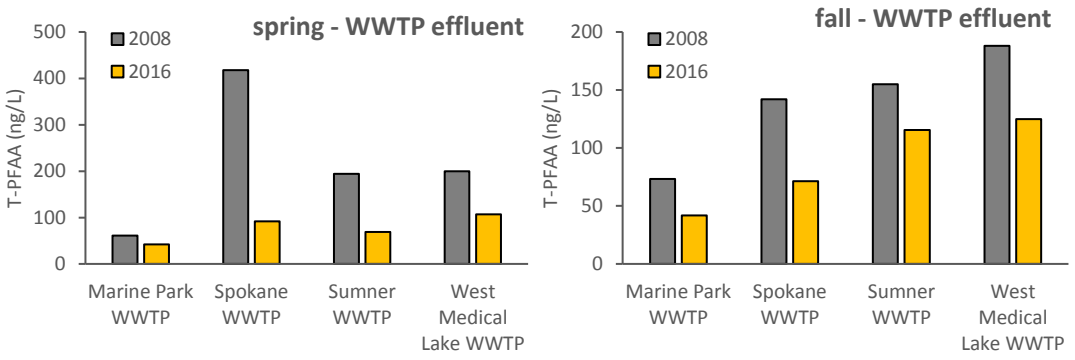

Figure 4. Total Perfluoroalkyl Acid (T-PFAA) Concentrations in Wastewater Treatment Plant Effluent Collected in 2008 (grey bars) and 2016 (orange bars).

Control of toxic chemicals in Puget Sound study, phase 3: Ecology and Herrera (2010) conducted a study to provide estimates of contaminant loadings to the Puget Sound. The study analyzed 12 PFAAs and PFOSA in effluent from 10 WWTPs during the winter and summer of 2009. All 10 WWTPs discharged treated effluent to Puget Sound tributaries. Six to ten of the PFAA compounds were detected in every sample. T-PFAA[9] concentrations ranged from 35.3–194 ng/L (median = 73.5 ng/L) in the winter and from 46.3–146 ng/L (median = 93 ng/L) in the summer.

PFHxA, PFNA, PFOS, and PFOA were present in the greatest concentrations and were detected in all samples. Loading estimates for T-PFAAs in the effluents were higher than estimated loadings of T-polychlorinated biphenyls, T-polybrominated diphenyls, and T-polycyclic aromatic hydrocarbons.

2.6 Sediments

2012 Sediment cores: In 2012, Ecology collected sediment cores from three freshwater lakes for analysis of 12 PFAAs and PFOSA (Ecology, 2013) (Figure 5). PFOS and long-chain PFAAs were the dominant compounds measured. T-PFAA[10] concentrations in the surface sediments ranged from 0.392 ng/g dw at the remote Deer Lake to 7.0 ng/g dw in West Medical Lake, which is impacted by WWTP effluent. The urban lake—Lake Stevens—had a surface T-PFAA concentration of 2.35 ng/g dw. T-PFAA concentrations increased from the 1980s to present in the West Medical Lake and Lake Stevens cores. Concentrations and detections were erratic in the rural Deer Lake core.

[9] Sum of detected perfluoroalkyl acid concentrations. Compounds analyzed: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, and PFOS.
[10] Sum of detected perfluoroalkyl acid concentrations. Compounds analyzed: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, and PFOS.

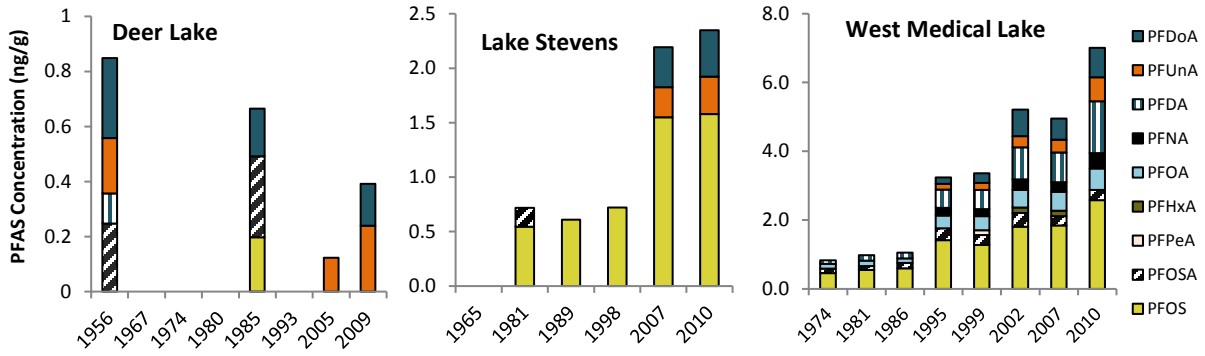

Figure 5. PFAS Concentrations (ng/g dw) in Sediment Core Samples Collected in Washington State in 2012.

Local Source Control monitoring: As part of Local Source Control monitoring, Ecology (2018) collected catch basin sediments over three sampling events in spring and early summer of 2017 for analysis of a suite of parameters that included 12 PFAAs. Sediments were collected from 7 urban/industrial catchments during dry-weather events. PFAAs were detected in all sediment samples analyzed. Sediment T-PFAA[11] concentrations ranged from 0.6 to 17.4 ng/g dw. The maximum concentration measured was of perfluorododecanoic acid (PFDoDA) (10.5 ng/g dw) and the maximum PFOS concentration was 9.68 ng/g dw. All other individual compound results were less than 5 ng/g dw.

Marine sediment: Ecology's Marine Sediment Monitoring Program collected sediments from Puget Sound urban bays in 2013 (Elliott Bay), 2014 (Commencement Bay) and 2015 (Bainbridge Basin) for analysis of 12 PFAAs and PFOSA. T-PFAA values were not reported. In Elliott Bay, PFOS was detected in 7 out of 30 stations, with detected concentrations ranging from 0.24–0.48 ng/g dw (Ecology, 2014). PFDA and PFUnDA were detected in one Elliott Bay station, at slightly lower levels. In Commencement Bay sediments, PFOA, PFOS, PFOSA, and PFDoDA were detected at concentrations ranging from 0.11 to 0.57 ng/g dw (accessed from Ecology's Environmental Information Management Database on 3/21/2017 at: http://www.ecy.wa.gov/eim/). Six out of 30 Commencement Bay stations (20 percent) contained one or more PFAS. In Bainbridge Basin, PFOS was detected in about half of the stations monitored (17 out of 33) and one station also contained detections of PFOSA and PFUnDA. Detected concentrations ranged from 0.11 to 1.6 ng/g dw (accessed from Ecology's Environmental Information Management Database on 3/21/2017 at: http://www.ecy.wa.gov/eim/). The highest concentration of PFOS (1.6 ng/g dw) was found in a sediment sample collected from Sinclair Inlet.

[11] Sum of detected perfluoroalkyl acid concentrations. Compounds analyzed: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, and PFOS.

2.7 Freshwater fish

Statewide study, 2008: Ecology collected freshwater fish from 7 waterbodies throughout the state in 2008 for analysis of 10 PFAAs (Ecology, 2010). A total of 11 different species were collected and analyzed as a total of 15 composite fillet samples and 15 composite liver samples. Of the PFAAs analyzed, only PFOS, PFDA, PFUnDA, and PFDoDA were detected and quantified. Quantitation limits were fairly high, ranging from 5–25 ng/g. PFOS was detected in 67 percent of the liver samples (10 out of 15) and 40 percent of fillet samples (6 out of 15). Concentrations of PFOS in liver samples ranged from <10–527 ng/g ww (median = 47.5 ng/g ww). Fillet samples had PFOS concentrations of <10-75.5 ng/g ww (median = < 10 ng/g ww). PFDoDA, PFUnDA, and PFDA were each detected once at concentrations of 21.0–46.1 ng/g ww in liver tissue and 5.5–7.5 ng/g ww in fillet tissue.

Statewide study, 2016: Ecology collected freshwater fish of various species from 11 waterbodies in Washington State in 2016 (Ecology, 2017) as part of the follow-up study to the 2008 sampling (Ecology, 2010). A total of 22 composite samples of freshwater fish fillet tissue and 22 composite liver tissue samples were analyzed for 12 PFAAs and PFOSA. Eighty-six percent of fillet samples contained at least one PFAS, while the detection frequency for liver samples was 100 percent. Fillet T-PFAA[12] concentrations ranged from <1–87.3 ng/g ww (median = 3.92 ng/g ww) and liver T-PFAS concentrations ranged 5.12 to 399 ng/g ww (median = 19.3 ng/g ww). PFOS was the dominant compound in all fillet samples, making up 62 percent–100 percent of the total concentration. PFAA concentrations in the Washington fish were generally much lower than concentrations found near point sources by recent U.S. and Canadian studies, and within the range seen in other waterbodies lacking point sources (MDEQ, 2015; Lanza et al., 2016; and Gewurtz et al., 2014).

PFOS concentrations in six of the fillet samples were above than the Washington Department of Health's (DOH's) provisional general population screening level for PFOS in edible fish tissue (23 ng/g). All six fillet samples above the provisional screening level were collected from urban lakes in Western Washington. Seven fillet samples were above DOH's provisional high consumer population screening level for PFOS in edible fish tissue (8 ng/g). Only one sample was above the provisional high consumer population screening level, but below the provisional general population screening level. This data was evaluated by DOH, but determined to have insufficient sample sizes for a fish advisory assessment.

[12] Sum of detected perfluoroalkyl acid concentrations. Compounds analyzed: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, and PFOS.

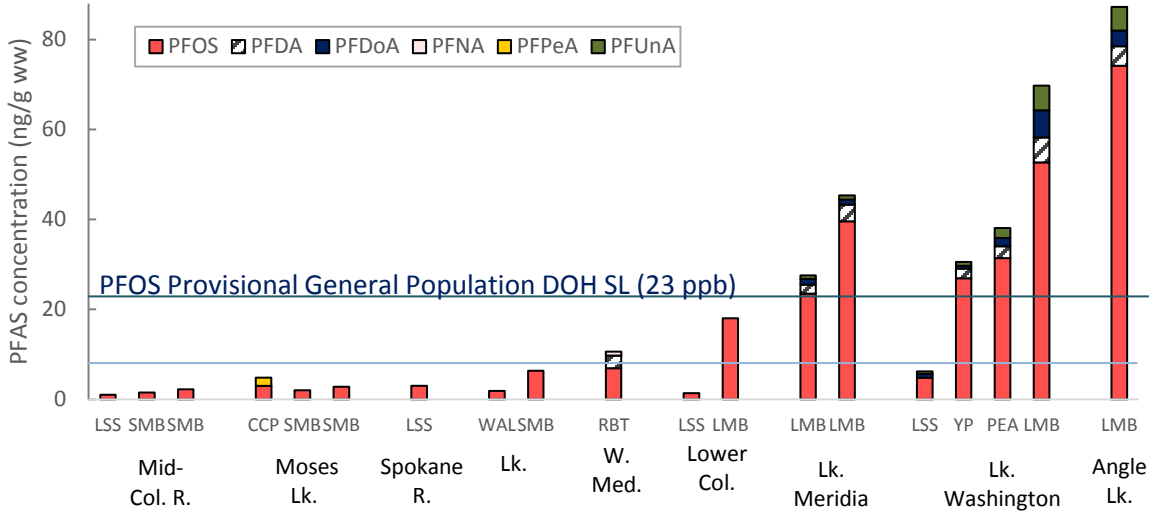

Figure 6. PFAA Concentrations (ng/g ww) of Freshwater Fish Fillet Samples Collected in Washington State in 2016.

Eleven freshwater fish tissue samples analyzed for PFAS in 2016 had paired species/waterbody data from 2008 (Figures 7 and 8). Of the eleven samples, a difference in quantitation limits hampered comparison in five paired fillet samples and three paired liver samples. The direction of change was mixed for fillet samples greater than the limit of quantitation (LOQ), showing no overall apparent pattern. No consistent increase or decrease over the time period was evident with liver samples, either, despite higher detection frequencies.

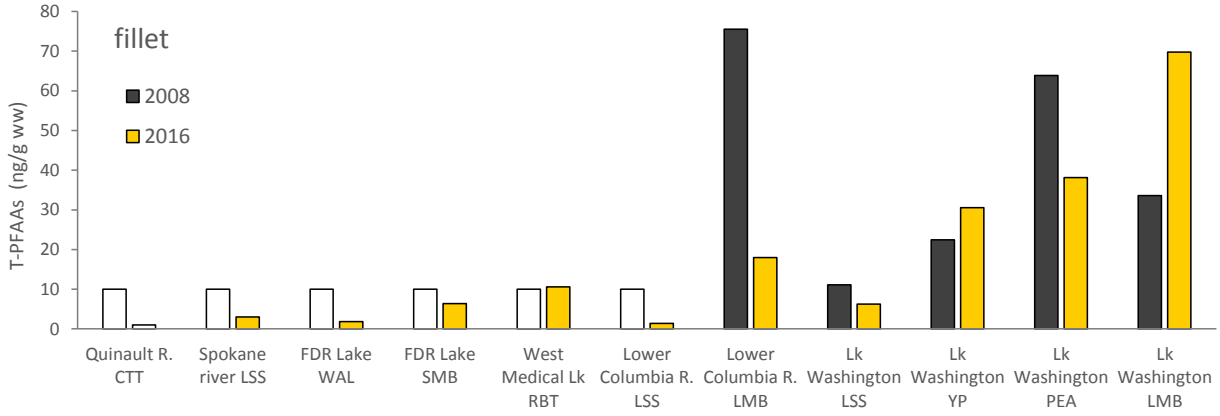

Figure 7. Total Perfluoroalkyl Acid (T-PFAA) Concentrations in Freshwater Fish Fillet Tissue Collected in 2008 (grey bars) and 2016 (yellow bars). *White bars indicate PFASs were not detected and the height of the bar represents the limit of quantitation.*

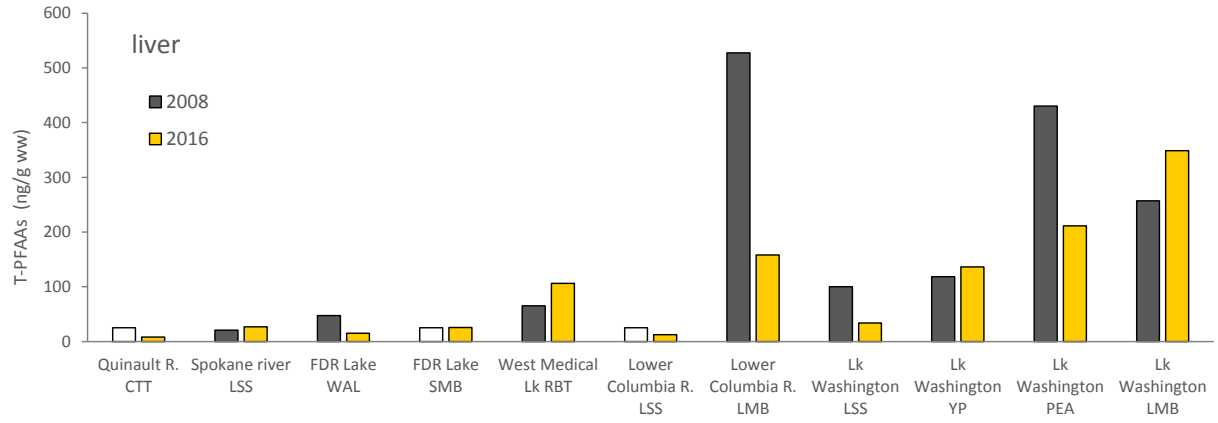

Figure 8. Total Perfluoroalkyl Acid (T-PFAA) Concentrations in Freshwater Fish Liver Tissue Collected in 2008 (grey bars) and 2016 (yellow bars). *White bars indicate PFASs were not detected at that concentration.*

PBT screening study, 2011: In 2011, Ecology collected common carp and largescale suckers from Lake Washington, lower Columbia River, Lake Spokane, and the lower Yakima River as part of a screening survey for PBTs (Ecology, 2012). All samples contained PFOS, at concentrations ranging from 2.1–19.8 ng/g wet weight (ww) in common carp fillet tissue and from 2.9–45.7 ng/g ww in whole body large-scale suckers. PFDA, PFUnDA, and PFDoDA were detected in approximately 80 percent of the samples, at lower concentrations than PFOS. Other PFAAs were detected infrequently or not at all. T-PFAA[13] concentrations across both species and sample types ranged from 2.1–91.9 ng/g ww, with the highest concentration in the Lake Washington largescale sucker whole body sample.

2.8 Osprey

Statewide study, 2008: Ecology collected eleven osprey eggs in 2008 from the Lower Columbia River and tested the inner contents (whole egg without shell) for 13 PFAAs (Ecology, 2010). Egg homogenates contained T-PFAA[14] concentrations ranging from 38–910 ng/g fresh weight (fw) (Ecology, 2010). Similar to fish tissue, PFOS was the dominant compound (range = 23.5–884 ng/g fw; median = 69.0 ng/g fw), followed by PFUnDA (range = 3.5–12.6 ng/g fresh weight (fw); median = 7.8) and PFDA (range = 2.0–10.2 ng/g fw; median = 5.8 ng/g fw). Other acids were detected less frequently and at low concentrations.

Statewide study, 2016: In 2016, Ecology collected osprey eggs from the Lower Columbia River, Lake Washington, and West Medical Lake (Ecology, 2017). A total of 11 osprey eggs were analyzed for 12 PFAAs and PFOSA. All eggs contained at least four PFAA compounds. T-

[13] Sum of detected perfluoroalkyl acid concentrations. Compounds analyzed: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, and PFOS.
[14] Sum of detected perfluoroalkyl acid concentrations. Compound analyzed: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, PFOS, and PFDS.

PFAA[15] concentrations ranged from 11.7 to 820 ng/g fw (median = 99.8 ng/g fw). The highest concentration was found in an osprey egg collected from Lake Washington. Two other elevated concentrations were measured in samples collected near WWTP inputs—along the Lower Columbia River and at West Medical Lake. Osprey egg concentrations were similar to recent findings in rural osprey eggs collected in Sweden (Eriksson et al., 2016), with the exception of higher concentrations found in the three Washington samples near urban or WWTP inputs.

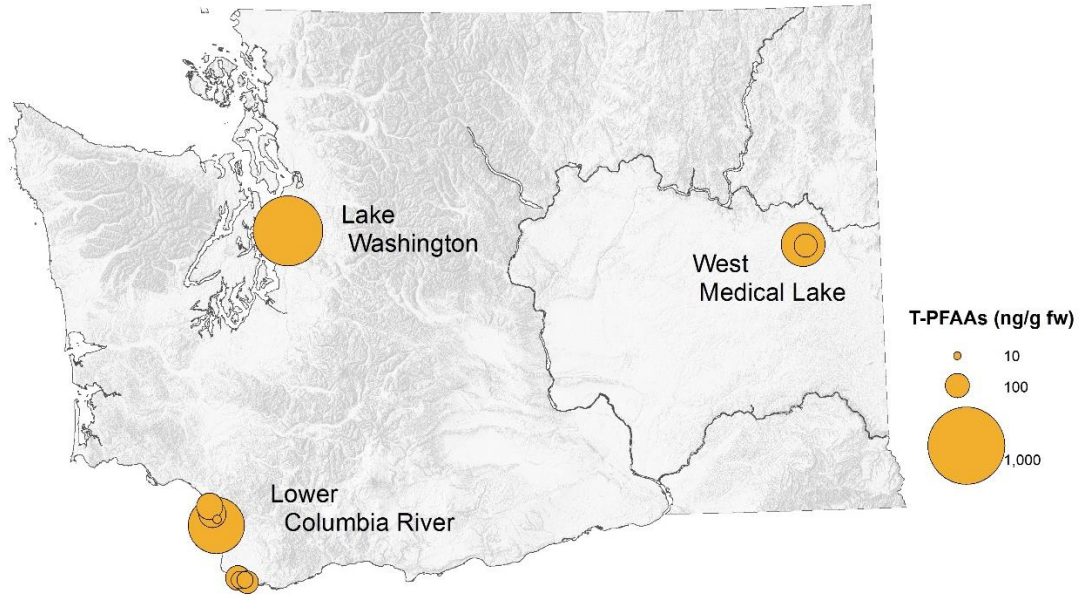

Figure 9. Total Perfluoroalkyl Acid Concentrations (ng/g fw) Measured in Osprey Eggs Collected in 2016.

PFOS made up 69 percent to 94 percent of the PFAA burden in the osprey eggs (median concentration = 92.5 ng/g fw; range = 9.08–675 ng/g fw). PFDA, PFDoDA, and PFUnDA were also detected in every sample, each making up less than 10 percent of the total PFAS concentration. Almost all of the PFAS contamination in osprey eggs was from long-chain compounds, but the short-chain PFPeA was detected in three samples – all from Lower Columbia River nests. However, PFPeA concentrations were quite low, at 0.45–1.83 ng/g fw, and made up less than 2 percent of the total.

None of the osprey eggs analyzed for this study had PFOS concentrations exceeding a Practical No Effects Concentration of 1,000 ng/g for offspring survival in a top avian predator (Newsted et al., 2005). PFOS concentrations in five of the samples were above a Lowest Observable Adverse Effect (LOAE) level of 100 ng/g ww for reduced hatchability based on injections in chicken embryos (Molina et al., 2006). These five samples were collected from Lake Washington, West Medical Lake, and Lower Columbia River downstream of the Willamette River confluence. This LOAE value of 100 ng/g is more conservative, as chicken embryos are more sensitive than

[15] Sum of detected perfluoroalkyl acid concentrations. Compounds analyzed: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFBS, PFHxS, PFOS, and PFOSA.

wildlife species and another study found higher values for reduced hatchability (Peden-Adams et al., 2009).

No consistent change in concentration levels or compound make up was evident between osprey eggs collected along the Lower Columbia River in 2008 and 2016 (Figure 10).

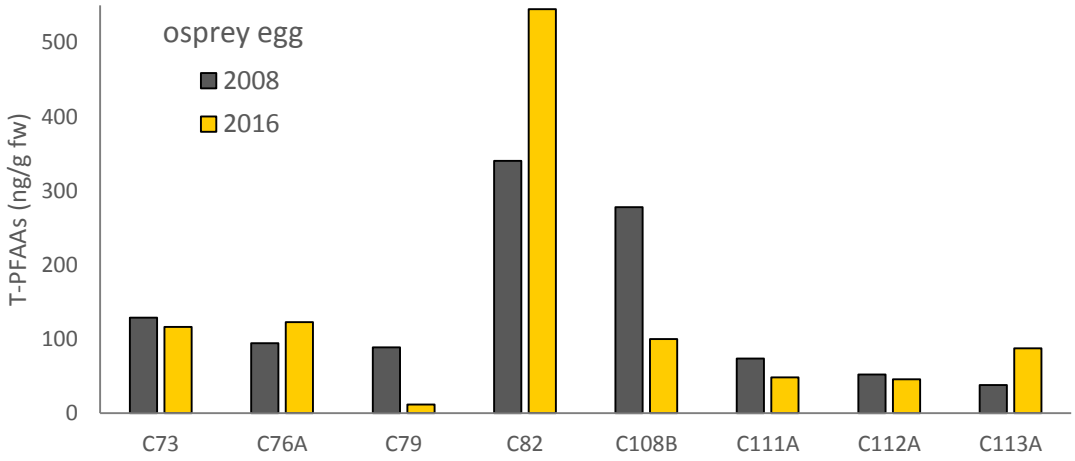

Figure 10. Total Perfluoroalkyl Acid (T-PFAA) Concentrations in Osprey Eggs Collected from the Lower Columbia River in 2008 (grey bars) and 2016 (yellow bars).

3.0 Wildlife studies outside of Washington

PFAS have been detected throughout the world in wildlife types that haven't been sampled in Washington State, with PFOS generally detected at the highest frequency and in the greatest amounts. Giesy and Kannan (2001) were the first to report detectable levels of PFOS in a wide range of biota, including species such as bald eagles, polar bears, and seals. Their study included PFOS detections in wildlife from urbanized centers in North America to remote regions of the Arctic and North Pacific Oceans. Literature reviews done in the mid-2000s confirmed PFOS contamination at all levels at the food chain, and particularly elevated levels in fish-eating animals living near industrialized areas (Houde et al., 2006; Lau et al., 2007). Other perfluoroalkyl sulfonates, long-chain perfluoroalkyl carboxylates, and PFOSA were detected in wildlife such as fish, amphibians, seabirds, and marine mammals (reviewed by Houde et al., 2006). A more recent review by Houde et al. (2011) concluded that PFOS and long-chain PFCAs continue to be widespread in invertebrates, fish, reptiles, aquatic birds, and marine mammals throughout the globe (Houde et al., 2011).

4.0 Environmental data gaps in Washington

Washington State is lacking data in some key areas for characterizing PFAS contamination in the environment, such as monitoring of ambient groundwater and landfill leachate, source assessments of PFAS in urban waterbodies, and testing PFAS compounds beyond PFAAs. With

the exception of drinking water wells and military base investigations, no ambient groundwater studies have been conducted in Washington State. Around the U.S., PFAA compounds have been found at high concentrations in groundwater near areas of repeated AFFF use, such as airports, oil and gas sites, firefighter training areas, and military bases (Cousins, 2016), but levels of concern may be present in groundwater of other land uses as well.

Environmental monitoring identified Washington State urban lakes as sites of elevated PFAA contamination relative to other waterbody types. The source of this contamination is not fully understood. Research on PFAA contamination in urban waterbodies has suggested sources related to traffic or automobile/railway transportation may be important (Kim and Kannan, 2007; Zushi and Masunaga, 2009), as well as the transfer of indoor air PFAS loads to the outdoor environment (Gewurtz et al., 2009). An assessment of industrial users of PFAS-containing products in Washington State may also contribute to our understanding of sources in the environment.

Recent research using new analytical methods has identified novel PFAS compounds—such as perfluoro-1-butane-sulfonamide (FBSA) and polyfluoroalkyl ether sulfonic acid (F-53B)—in wildlife, though levels have generally been lower than PFOS (Chu et al., 2016; Shi et al., 2015; Baygi et al., 2016). Other novel PFAS, such as cyclic perfluoroalkyl acids and fluorosurfactants, have been found to accumulate in fish from waterbodies directly impacted by AFFF use (Wang et al., 2016; Munoz et al., 2017). Recent research has identified hundreds of new PFAS, many of which have been identified in the aquatic environment (Xiao, 2017). Aside from a limited list of precursor compounds measured in surface waters and WWTP effluent in 2016, none of these emerging PFAS compounds have been analyzed in Washington State samples.

5.0 Washington environmental concentrations data table

Table 1. PFAS Concentration Ranges in Washington State Environmental Media. *Median concentrations included in parentheses, when available).*

Sample Matrix	Sample Type	Collection Year	Units	n	# PFAA compounds analyzed	T-PFAAs	PFBA	PFPeA	PFHxA	PFHpA	PFBS	Ref.
Surface water	Spring	2008	ng/L	14	11	**1.1-185 (7.5)**	<0.1-**3.6**	<0.1-**26.5**	<1.0-**10.5**	<1.0-**28**	<0.1-**0.6**	Ecology, 2010
Surface water	Fall	2008	ng/L	14	11	<0.9-**170 (3.6)**	<0.1-**5.5**	<0.5-**32**	<0.1-**37**	<0.9-**22**	<0.1-**2.0**	Ecology, 2010
Surface water (fresh and marine)	Spring/summer/ fall/winter mean	2009-2010	ng/L	13	14	**1.5-40**	NR	---	NR	NR	NR	Dinglasan-Panlilio et al., 2014
Surface water	Spring	2016	ng/L	15	12	<2-**153** (<2)	<1.0-**13**	<1.0-**29**	<1.0-**33**	<1.0-**13**	<2.0-**2.1**	Ecology, 2017
Surface water	Fall	2016	ng/L	15	12	<2-**170** (<2)	<1.0-**12**	<1.0-**39**	<1.0-**32.5**	<1.0-**13**	<2.0-**13**	Ecology, 2017
WWTP effluent	Spring	2008	ng/L	4	11	**61-418 (218)**	**0.7-3.3**	**3.8-31**	**14.5-141**	**4.1-35**	<0.1-**1.5**	Ecology, 2010
WWTP effluent	Fall	2008	ng/L	4	11	**73-188 (140)**	**1.9-5.4**	**13-47**	**11-30**	<3.5-**13**	<0.5-**6.6**	Ecology, 2010
WWTP effluent	Summer	2009	ng/L	10	12	**46-146 (93)**	<1.0-**4.9**	<1.0-**18**	**9.6-44**	**3.4-9.7**	<2.0-**18**	Ecology and Herrera, 2010
WWTP effluent	Winter	2009	ng/L	10	12	**35-194 (73.5)**	<1.0-**3.6**	<1.5-**16**	**11-52**	**2.1-10**	<2.0	Ecology and Herrera, 2010
WWTP effluent	Spring	2016	ng/L	5	12	**42-107 (69)**	**2.2-7.1**	**5.5-28**	**12-36**	**2.2-5.5**	<2-**3.4**	Ecology, 2017
WWTP effluent	Fall	2016	ng/L	5	12	**42-125 (71)**	**1.6-7.1**	**6.1-57**	**10.5-49**	**2.6-3.7**	<2.0-**14**	Ecology, 2017
Sediment	Freshwater (0-2 cm)	2013	ng/g dw	3	12	**0.4-7.0 (2.35)**	<0.2	<0.2	<0.2	<0.2	<0.4	Ecology, 2013
Sediment	Marine (0-3 cm)	2013-2015	ng/g dw	101	12	---	<0.1	<0.1	<0.1	<0.1	<0.2	EIM database*
Freshwater fish	Fillet - mult. sp.	2008	ng/g ww	15	10	<10-**76** (<10)	---	---	<5.0	<5.0	<5.0	Ecology, 2010
Freshwater fish	Liver - mult. sp.	2008	ng/g ww	15	10	<25-**527** (**48**)	---	---	<10.0	<10.0	<10.0	Ecology, 2010
Freshwater fish	Fillet - CC	2011	ng/g ww	4	12	**2.1-21.5 (12)**	<LOQ	<LOQ	<LOQ	<0.3	<LOQ	Ecology, 2012
Freshwater fish	Whole body - LSS	2011	ng/g ww	4	12	**3.3-92 (23)**	<LOQ	<LOQ	<LOQ	<0.2-**0.6**	<LOQ	Ecology, 2012
Freshwater fish	Fillet - mult. sp.	2016	ng/g ww	22	12	<1-**87 (3.9)**	<0.5	<0.5-**1.8**	<0.5	<0.5	<1.0	Ecology, 2017
Freshwater fish	Liver - mult. sp.	2016	ng/g ww	22	12	**5.1-394 (20)**	<1.0	<0.5-<2.9	<0.5-**2.5**	<0.5-**1.1**	<0.9-**6.2**	Ecology, 2017
Osprey	Egg	2008	ng/g fw	11	13	**37.5-910 (91)**	<0.5	<0.5	<0.5-**0.8**	<0.5-**0.8**	<0.5	Ecology, 2010
Osprey	Egg	2016	ng/g fw	11	12	**12-820 (100)**	<0.5	<0.4-**1.8**	<0.5	<0.5	<1.0	Ecology, 2017

* *accessed from Ecology's Environmental Information Management Database on 3/21/2017 at*: http://www.ecy.wa.gov/eim/

Sample Matrix	Sample Type	Collection Year	Units	n	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFHxS	PFOS	PFDS	PFOSA	Ref.
Surface water	Spring	2008	ng/L	14	<1.0-**96**	<0.1-**17**	<0.1-**4.9**	---	---	<1.0-**3.3**	<0.1-**6.5**	<1.0	---	Ecology, 2010
Surface water	Fall	2008	ng/L	14	<0.5-**48**	<0.5-**7.0**	<0.1-**3.8**	---	---	<0.5-**4.5**	<0.5-**7.6**	<0.1-**1.3**	---	Ecology, 2010
Surface water (fresh and marine)	Spring/summer/ fall/winter mean	2009-2010	ng/L	13	NR	NR	NR	NR	NR	NR	NR	NR	---	Dinglasan-Panlilio et al., 2014
Surface water	Spring	2016	ng/L	15	<1.0-**42.5**	<1.0-**5.2**	<1.0-**1.9**	<1.0-<1.2	<1.0-<1.2	<2.0-**5.3**	<2.0-**9.2**	---	<1.0-<2.6	Ecology, 2017
Surface water	Fall	2016	ng/L	15	<1.0-**55**	<1.0-**5.8**	<1.0-**3.2**	<1.0-<1.1	<1.0-<1.1	<2.0-**3.0**	<2.0-**12.5**	----	<1.0-<1.2	Ecology, 2017
WWTP effluent	Spring	2008	ng/L	4	**16.5-128**	**3.6-18**	**3.6-13**	---	---	**1.3-16**	**3.9-31**	<0.1	---	Ecology, 2010
WWTP effluent	Fall	2008	ng/L	4	**22-63**	**5.7-14**	**3.7-13**	---	---	**2.2-12**	**9.4-18**	<0.1-<0.5	---	Ecology, 2010
WWTP effluent	Summer	2009	ng/L	10	**11-52.5**	**3.3-29**	**1.5-10**	<1.0	<1.0	<2.0-**8.3**	<2.0-**55**	---	<2.5	Ecology and Herrera, 2010
WWTP effluent	Winter	2009	ng/L	10	**11-70**	**1.4-134**	**1.4-7.9**	<1.0	<1.0	<1.9-**6.9**	<2.0-**19.5**	---	<1.0-**2.0**	Ecology and Herrera, 2010
WWTP effluent	Spring	2016	ng/L	5	**7.2-20**	<1.0-**1.9**	<1.0-**4.9**	<1.0	<1.0	<2.0-**11**	**2.6-16**	---	<2.5-**2.8**	Ecology, 2017
WWTP effluent	Fall	2016	ng/L	5	**6.6-18**	<1.0-**4.0**	<1.0-**5.0**	<1.0	<1.0	<2.0-**7.1**	<2.0-**6.5**	---	<1.0	Ecology, 2017
Sediment	Freshwater (0-2 cm)	2013	ng/g dw	3	<0.1-**0.6**	<0.1-0.4	<0.1-**1.5**	**0.2-0.7**	**0.2-0.9**	<0.4	<0.2-**2.6**	---	<0.1-**0.3**	Ecology, 2013
Sediment	Marine (0-3 cm)	2013-2015	ng/g dw	101	<0.1-**0.21**	<0.1	<0.1-**0.14**	<0.1-**0.2**	<0.1-**0.2**	<0.2	<0.2-**1.6**	---	<0.1-**0.3**	EIM database*
Freshwater fish	Fillet - mult. sp.	2008	ng/g ww	15	<5.0	<5.0	<5.0-**7.5**	<5.0-**7.2**	<5	<5.0	<10.0-**76**	---	---	Ecology, 2010
Freshwater fish	Liver - mult. sp.	2008	ng/g ww	15	<10.0	<10.0	<21.0-**25**	<10.0-**46**	<10.0-**21**	<10.0	<10.0-**527**	---	---	Ecology, 2010
Freshwater fish	Fillet - CC	2011	ng/g ww	4	<0.25	<0.3	<0.25-**1.2**	<0.25-**1.3**	<0.3-**1.8**	<LOQ	**2.1 - 20**	---	<0.4	Ecology, 2012
Freshwater fish	Whole body - LSS	2011	ng/g ww	4	<0.2-**0.8**	<0.2-**1.6**	**0.3-10**	<0.24-**20**	<0.2-**9.5**	<LOQ	**2.9 - 46**	---	<0.3-**3.4**	Ecology, 2012
Freshwater fish	Fillet - mult. sp.	2016	ng/g ww	22	<0.5	<0.5-**0.9**	<0.5-**5.5**	<0.5-5.5	<0.5-**6.0**	<1.0	<1.0-**74**	---	<0.5	Ecology, 2017
Freshwater fish	Liver - mult. sp.	2016	ng/g ww	22	<0.7	<0.5-**7.3**	<0.5-**20**	<0.5-26	<0.5-**17**	<1	**1.4-336**	---	<0.5-**4.9**	Ecology, 2017
Osprey	Egg	2008	ng/g fw	11	<0.2-<1.0	<0.5-**6.4**	**2.0-10**	**3.5-13**	<5.0-**11**	<0.5-**1.8**	**24-884**	<1.0-**5.8**	---	Ecology, 2010
Osprey	Egg	2016	ng/g fw	11	<0.5	<0.5-**5.7**	**1.0-47**	**1.1-45**	**0.6-47**	<1.0	**9.1-675**	---	<0.5	Ecology, 2017

* *accessed from Ecology's Environmental Information Management Database on 3/21/2017 at*: http://www.ecy.wa.gov/eim/

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List of chemicals discussed

These are the chemical acronyms and names used in this chapter.

Acronym	Chemical Name
4:2 FTS	4:2 fluorotelomer sulfonate
6:2 FTS	6:2 fluorotelomer sulfonate
8:2 FTUCA	8:2 fluorotelomer unsaturated carboxylic acid
FBSA	perfluoro-1-butane-sulfonamide
PFAA	perfluoroalkyl acid
PFAS	per- and poly-fluorinated alkyl substances
PFBA	perfluorobutanoic acid
PFBS	perfluorobutane sulfonate
PFDA	perfluorodecanoic acid
PFDoA	perfluorododecanoic acid
PFDoDA	perfluorododecanoic acid
PFDS	perfluorodecane sulfonate
PFHpA	perfluoroheptanoic acid
PFHxA	perfluorohexanoic acid
PFHxS	perfluorohexane sulfonate
PFNA	perfluorononanoic acid
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonate
PFOSA	perfluorooctanesulfonamide
PFPeA	perfluoropentanoic acid
PFTeDA	perfluorotetradecanoic acid
PFTrDA	perfluorotridecanoate
PFUnA	perfluoroundecanoate
PFUnDA	perfluoroundecanoic acid
T-PFAA	total perfluoroalkyl acid (summed concentration)