Interim Chemical Action Plan for Per- and Polyfluorinated Alkyl Substances

Revised January 2019

Publication 18-04-005

Publication and Contact Information

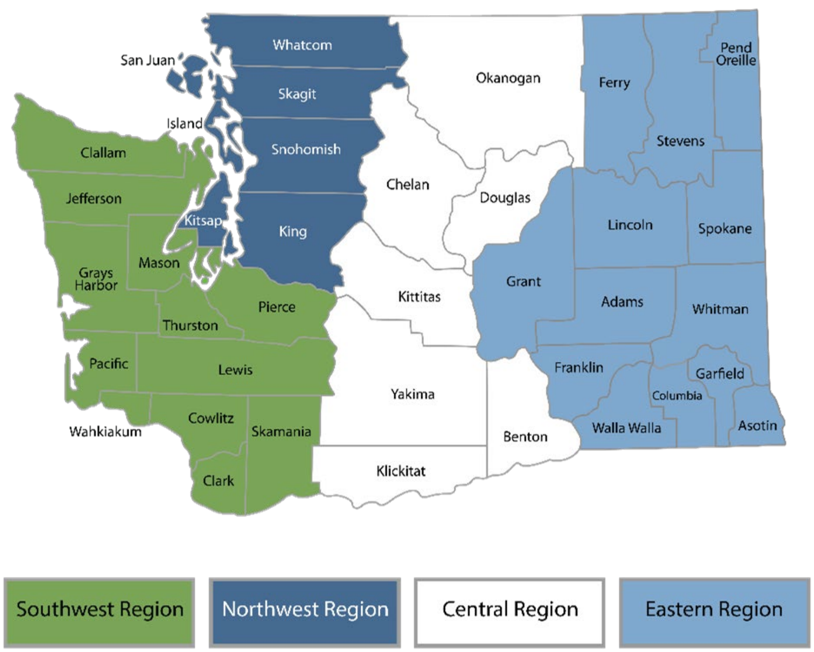
This document is available on the Department of Ecology's website at:
https://fortress.wa.gov/ecy/publications/summarypages/1804005.html

For more information contact:

Hazardous Waste and Toxics Reduction Program
P.O. Box 47600
Olympia, WA 98504-7600
Phone: 360-407-6700
Website: www.ecology.wa.gov

Department of Ecology's Regional Offices

Map of Counties Served



Region	Counties served	Mailing Address	Phone
Southwest	Clallam, Clark, Cowlitz, Grays Harbor, Jefferson, Mason, Lewis, Pacific, Pierce, Skamania, Thurston, Wahkiakum	PO Box 47775 Olympia, WA 98504	360-407-6300
Northwest	Island, King, Kitsap, San Juan, Skagit, Snohomish, Whatcom	3190 160th Ave SE Bellevue, WA 98008	425-649-7000
Central	Benton, Chelan, Douglas, Kittitas, Klickitat, Okanogan, Yakima	1250 W Alder St Union Gap, WA 98903	509-575-2490
Eastern	Adams, Asotin, Columbia, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman	4601 N Monroe Spokane, WA 99205	509-329-3400

Accommodation Requests: To request ADA accommodation including materials in a format for the visually impaired, call Ecology at 360-407-6700 or visit https://ecology.wa.gov/accessibility. People with impaired hearing may call Washington Relay Service at 711. People with speech disability may call TTY at 877-833-6341.

Table of Contents

List of Tables

Table of Figures

List of Abbreviations

AFFF – aqueous film forming foam

CAP – chemical action plan

EPA – U.S. Environmental Protection Agency

ng/L – nanograms per liter

PBT – persistent, bioaccumulative, toxic

PFAA – perfluorinated alkyl acid

PFCA - perfluorinated carboxylic acid

PFAS – per- and polyfluorinated alkyl substances

PFSA - perfluorinated sulfonic acid

FTSA - fluorotelomer sulfonic acid

RCW – revised code of Washington

UCMR3 – third unregulated contaminant monitoring rule

WAC – Washington administrative code

WWTP – waste water treatment plant

Abbreviations of Individual PFAS

6:2 FTS – 6:2 Fluorotelomer sulfonate

PFBS – Perfluorobutanesulfonic acid

PFDA – Perfluorodecanoic acid

PFDoDA – Perfluorododecanoic acid

PFHpA – Perfluoroheptanoic acid

PFHxA – Perfluorohexanoic acid

PFHxS – Perfluorohexane sulfonate

PFNA – Perfluorononanoic acid

PFOA – Perfluorooctanoic acid

PFOS – Perfluorooctane sulfonate

PFOSA – Perfluorooctanesulfonamide

PFUnDA – Perfluoroundecanoic acid

Executive Summary

PFAS (per- and polyfluorinated alkyl substances) are a group of over 4,700 synthetic organic chemicals. They are used in the manufacture of coatings, surface treatments, and specialty chemicals used in cookware, carpets, food packaging, clothing, cosmetics, and other common consumer products. PFAS also have many industrial applications and are an active ingredient in certain types of fire-fighting foams (aqueous film-forming foams, or AFFF). PFAS coatings resist oil, grease, and water. PFAS can withstand high temperatures, and survive highly corrosive environments.

Chemical Action Plans (CAPs) identify the potential health and environmental effects of persistent, bioaccumulative, and toxic chemicals, and recommend actions to reduce or eliminate those impacts. The Departments of Ecology and Health developed this Interim CAP to recommend immediate actions to address problems with PFAS. Development of the Final PFAS CAP will continue into 2019.

In March 2018, two laws passed in Washington that impact the use of PFAS in firefighting foam and food packaging. PFAS is defined in those laws as "a class of fluorinated organic chemicals containing at least one fully fluorinated carbon atom."

Why are we concerned about PFAS?

There is little toxicity or safety data for most of the PFAS in use. Of the few that have been evaluated, several are toxic in animal testing. Some have been linked to health problems in people.

They remain in the environment for a long time. Many PFAS are or transform into highly persistent perfluorinated chemicals in the environment. There are no natural processes that can break these substances down. As a result, exposures from these chemicals will continue to increase as long as they are produced. Exposures will continue for many decades after their phase-out.

Due to concerns about safety and persistence, EPA negotiated with 3M to voluntarily phase out production of perfluorooctane sulfonic acid (PFOS). 3M was the only US manufacturer of PFOS. EPA also asked eight major companies to phase out perfluorooctanoic acid (PFOA). Releases from past use will continue to contaminate soil, surface water, groundwater, fish, and other foods. Manufacturers in other countries still produce products with PFOA and PFOS and sell them in the U.S.

Ecology and Health are also concerned about "short-chain" PFAS that manufacturers use to replace "long-chain" PFAS like PFOS and PFOA. Some short-chain PFAS appear to be less bioaccumulative in people than long-chain compounds, but publicly available data on their hazards is limited to a small number of PFAS substances. Like long-chain PFAS, many of the short-chain substances are extremely persistent or degrade into extremely persistent forms.

Short-chain PFAS also tend to be more water soluble and more mobile than the long-chain substances. This means they can move more easily through soil to contaminate groundwater or surface water. They are hard to remove from drinking water. Without additional health and safety data, it is impossible for us to evaluate whether short-chain replacements are safe substitutes. If environmental exposures to short-chain PFAS are found to pose health risks to people or the environment, mitigation will be difficult and expensive.

PFAS Contamination in Washington

PFAS contamination has been found in drinking water in areas around Issaquah, Joint Base Lewis-McChord, Naval Air Station Whidbey Island, and Fairchild Air Force Base, including Airway Heights. PFOA and PFOS contamination exceeds the U.S. Environmental Protection Agency's (EPA) health advisory level.[1] The primary source of contamination at all of these areas is believed to be legacy PFAS-based firefighting foam.

Recommended Actions

1. Ensure drinking water is safe

Support State Board of Health rulemaking for limits on PFAS in Washington's drinking water supplies. Develop options for expanded drinking water testing for PFAS to include public water systems that have not yet been evaluated. Prioritize testing for public water systems at higher risk for contamination, such as those near airports or firefighter training centers.

2. Manage environmental PFAS contamination

Develop soil and groundwater cleanup levels to help determine when and where PFAS contamination should be addressed. Develop best practices for managing cleanups.

3. Reduce risks to drinking water from firefighting foam

Implement the new law that restricts the use of PFAS-containing foam for training and sale of PFAS-containing foam. Promote best management practices for use, storage, and disposal of AFFF to prevent further contamination. Encourage users to replace stockpiles of PFAS-containing firefighting foam with non-PFAS foam and to safely dispose of the PFAS foam.

4. Investigate other sources of PFAS

Identify other PFAS uses that are most likely to pose a risk to human health and the environment. Work with industry, the EPA, the U.S. Food and Drug Administration, and other states to identify and share data on uses, hazards, and risks of PFAS.

Support decision-making about significant sources of PFAS exposure by identifying safer alternatives to PFAS. Start with an alternatives assessment (required by the new law) to identify alternatives to PFAS in food packaging that are cost effective, readily available in sufficient quantity, meet or exceed performance in specific food packaging applications, and will not be tomorrow's problems.

---

[1]EPA lifetime health advisory level in drinking water is 70 nanograms per liter or parts per trillion (ppt) for PFOA and PFOS combined or for either separately (EPA 2016a; EPA 2016b).

Interim Chemical Action Plan

Introduction

In 2016, the Washington State Department of Ecology (Ecology) and Department of Health (Health) began work on a Chemical Action Plan (CAP) to address per- and polyfluorinated alkyl substances (PFAS). CAPs identify health and environmental threats of persistent, bioaccumulative, and toxic (PBT) chemicals on Washington's PBT list.[2] CAPs recommend actions to reduce or eliminate those impacts. CAPs consider a specific PBT or group of PBTs, their degradation products, and available substitutes.

PFAS describes a class of over 4,700 synthetic organic chemicals. PFAS are used in many products and manufacturing processes (OECD 2018a):

- Nonstick cookware.
- Grease and waterproof coatings on food packaging (such as popcorn bags, fast food wrappers, and takeout containers).
- Surfaces in food processing equipment (such as tubing in ice cream and soda dispensers).
- Waterproof textiles (shoes, clothing, upholstery, and mattresses).
- Stain- and water-resistant textiles (outdoor and upholstered furniture, carpets, and clothing).
- Coated paper products.
- Paints, cleaning products, and sealers where they help penetrate into rough surfaces or promote a smooth finish.
- Fire-fighting foam used to fight fuel-based fires.
- Engineered coatings used in semiconductor production.

PFAS are synthetic and not found naturally in the environment. PFAS contain at least one fully fluorinated carbon atom or a chain of carbon atoms completely surrounded by (bonded to) fluorine atoms, also called a perfluorinated chain (Buck 2011, CECBP 2015, ITRC 2017). Perfluorinated chains vary in chain length from a chain of two carbon atoms to large molecular weight polymers. The addition of non-fluorine chemical groups provide water or oil solubility, or help chemically bond them to other substances.

The carbon-fluorine bond is extremely strong and contributes to many of the unique properties of PFAS, including:

- Low surface energy (solids) and low surface tension (liquids).
- Resistance to corrosion and high temperatures.
- Low friction solids or lubricants.
- Grease-, oil-, water- and stain-resistance.

Early generation or "long-chain" PFAS are known PBTs. The most commonly studied and reported PFAS are perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS). PFOS and its salts were included on Ecology's original PBT list in 2006. PFOA and PFOS have

[2] Chapter 173-333 Washington Administrative Code (WAC).

been voluntarily withdrawn from the U.S. market. Production, use, and trade of long-chain PFAS, precursors, and treated articles still continues in other countries (ECHA 2017, EPA 2018b, FluoroCouncil 2014, Stockholm 2017).

Some long-chain PFAS are highly persistent in the environment and highly bioaccumulative in humans. They are readily absorbed following ingestion, resist metabolic breakdown, and are poorly excreted from the human body (ATSDR 2018). Several have been shown to be toxic in animal testing and are linked to health effects in human epidemiological studies (EPA 2016c; EPA 2016d; ATSDR 2018; NTP 2016; Johnson et al. 2014; Rappazzo et al. 2017). Past PFAS production, use, and trade have released these chemicals to the environment, leading to soil, surface water, and groundwater contamination.

Because of these concerns, manufacturers have been replacing long-chain PFAS with "short-chain" alternatives which behave similarly because they are structurally related compounds.The difference between long-chain and short-chain is the length of the fully fluorinated chain of carbon atoms.[3]They have the potential to break down into highly persistent perfluorinated compounds.

While there are a significant number of toxicology studies on a handful of short-chain chemicals, these include only a small fraction of the short-chain substances that may be of concern. For example, a 2018 OECD survey identified over 1,500 individual short-chain substances with three- to five-perfluorinated carbons that may have been on the commercial market (OECD 2018a, OECD 2018b). We have identified a published carcinogenicity study for only one of these substances, perfluorohexanoic acid (PFHxA). Reproductive and developmental effect studies are available to the general scientific community only for a handful of substances.

Since 2006, nearly 900 PFAS have been reviewed by the EPA's Toxic Substances Control Act new chemical review program. EPA conducts a review of new chemicals prior to manufacture or import into the U.S. Most of these PFAS were evaluated based on a limited set of toxicological data. The long-term effects of a mixture of short-chain PFAS, or the toxicity of PFAS in combination with natural and anthropogenic stressors are widely unknown (EPA 2018a).

When polyfluorinated product chemicals enter the environment, for example, from the use of firefighting foam (aqueous film forming foam, or AFFF), they may break down through many different pathways. A number of different daughter (transformation) products can be produced, and some of them can be long-lived (Barzen-Hanson et al. 2017, Yi et al. 2018). There is little published scientific information about the toxicity, persistence, or bioaccumulation of most of these breakdown products. More publicly accessible data are needed for Ecology and Health to assess the safety of short-chain replacement chemicals and breakdown products that can contaminate drinking water sources or fish and wildlife. Several short-chain PFAS have been identified in river, lake, and marine water samples, and in wastewater treatment plant effluent in Washington.

Like long-chain PFAS, many short-chain substances are extremely persistent or degrade into extremely persistent forms. Exposure could continue for many decades after their phase-out. The short-chain forms (perfluorinated carboxylic acids (PFCAs), perfluorinated sulfonic acids

---

[3] "Long-chain" PFAS refers to: Perfluorocarboxylic acids with chain lengths of seven carbons and higher, including PFOA and PFNA; Perfluoroalkyl sulfonates with chain lengths of six carbons and higher, including perfluorohexane sulfonic acid (PFHxS) and PFOS; and precursors that may be produced or present in products (OECD 2013).

(PFSAs) and fluorotelomer sulfonic acids (FTSAs)) are highly soluble in water and more mobile in soil than their long-chain counterparts, which means there is higher potential for groundwater contamination (Wang et al. 2015; Rankin et al. 2016). They are more difficult and more expensive to remove from water than long-chain perfluorinated alkyl acids (PFAAs), (Wang et al. 2015; Begley et al. 2005, Tittlemier et al. 2006, Rosati et al. 2007, Sinclair et al. 2007, Begley et al. 2008, Trier et al. 2011a, Trier et al. 2011b, Martinez-Moral and Tena 2012, Still et al. 2013). They are more likely to be taken up by plants from contaminated soil or irrigation water (Blaine et al. 2014; Brendel et al. 2018; Lee et al. 2014).

Some short-chain PFAS appear to be less bioaccumulative in people than long-chain compounds, but publicly available data on their hazards is limited to a small number of PFAS substances identified in products and environmental samples (OECD 2018a, Xiao 2017). Without additional health and safety data, it is impossible for us to evaluate whether short-chain replacements are safe substitutes for PFOA and PFOS (Barzen-Hansen et al. 2017, D'Agostino and Mabry 2014).

The implications of the short-chain PFAS replacements on human and environmental health are unknown/uncertain. If environmental exposures to short-chain PFAS are found to pose health risks to people or the environment, mitigation will be difficult and expensive. Therefore, the scope of this CAP will include the entire class of PFAS, degradation products, and available substitutes.

New PFAS Restrictions

In March 2018, two laws passed in Washington regarding the use of PFAS in firefighting foam and food packaging. PFAS is defined in the two laws as "a class of fluorinated organic chemicals containing at least one fully fluorinated carbon atom." Ecology is the lead agency for implementation of both laws and will incorporate the new duties into the CAP process where required or appropriate.

PFAS in Firefighting Foam

Chapter 70.75A Revised Code of Washington[4]

This law impacts the use and sale of firefighting foam and firefighting personal protective equipment. The highlights of the law are:

- After July 1, 2018, firefighting foam containing PFAS may not be used for training purposes.
- After July 1, 2018, manufacturers must notify purchasers of the presence of PFAS in firefighting personal protective equipment.
- After July 1, 2020, manufacture, distribution, and sale of firefighting foam containing PFAS is prohibited. This restriction does not apply to firefighting foam use by the military or at Federal Aviation Administration-certified airports, petroleum refineries and terminals, or large chemical plants.
- Ecology is directed to help other state agencies and local governments avoid purchasing firefighting foam that contain PFAS, and to give preference to firefighting personal protective equipment that does not contain PFAS.

[4] Link to Chapter 70.75A RCW http://app.leg.wa.gov/RCW/default.aspx?cite=70.75A

PFAS in Food Packaging

Chapter 70.95G Revised Code of Washington[5]

This law restricts the use of PFAS in specific applications of food packaging. Highlights of the law are:

- By January 2020, Ecology will publish the findings of an alternatives assessment that evaluates PFAS replacements for food packaging made from paper or other plant fibers. The alternatives assessment will follow the Interstate Chemicals Clearinghouse guidelines[6] and include an external peer review.
- After January 2022, PFAS may not be added to food packaging made from paper or other plant fibers if the alternatives assessment identifies multiple safer alternatives that meet certain requirements. If no safer alternatives are identified, Ecology will annually update the review.
- If safer alternatives are not identified by 2020, Ecology must review and report annually until safer alternatives are identified. The ban becomes effective two years after Ecology determines that safer alternatives exist.

PFAS Human Exposure and Health Concerns

Concerns about the possible public health consequences of PFAS exposure are growing as the body of research about toxicity and exposure expands.

Exposures

An ongoing nationwide survey of twelve PFAS compounds in blood serum indicates that almost everyone is exposed to some PFAS (CDC, 2017). People's exposure to PFOA and PFOS has been decreasing since the production of these chemicals in the U.S. has declined. PFOA, PFOS, and some other PFAS remain in people's bodies for many years after exposure (ATSDR 2018, Fromme 2009).

People's exposure to PFAS can come from:

- The food they eat (including breastmilk and formula for infants).
- The water they drink and use to prepare food and beverages.
- Use of consumer products that contain PFAS.
- Workplaces that manufacture PFAS compounds or treat products with PFAS.
- Contaminated soil, indoor dust, and air.

The relative contribution of these sources of exposure has not been studied in detail, although food has been found to be a significant exposure pathway in the general population (Trudel et al. 2008; ATSDR 2018; Lindstrom et al. 2011; Vestergren and Cousins 2009; Fromme et al. 2009). People with workplace exposure (Olsen et al. 2003, Olsen et al. 2007, Olsen and Zobel 2007, Emmett et al. 2006; Costa et al 2009; and Sakr et al. 2007), those who consume contaminated water (Emmett et al. 2006; MDH 2009; Steenland et al. 2009a; Steenland et al. 2009b), and

[5] Link to Chapter 70.95G RCW http://app.leg.wa.gov/RCW/default.aspx?cite=70.95G
[6] www.theic2.org/alternatives_assessment_guide (IC2 2017)

children who spend time on PFAS-treated carpet and furniture often have higher exposure from those specific sources (Harris et al. 2017; Trudel et al. 2008; Rappazzo et al. 2017).

Trudel et al. 2008 estimated relative contributions for major exposure pathways of PFOS and PFOA in a high-exposure scenario for adults (men and women). The exposure pathways included food and water ingestion, dust ingestion, and hand-to-mouth transfer from mill-treated carpets. For PFOA, the major exposure pathways were oral exposure resulting from:

- Migration from paper packaging and wrapping into food (representing 65 percent of the exposure pathway).
- General food and water ingestion (15 percent).
- Inhalation from impregnated clothes (15 percent).
- Dust ingestion (10 percent).

PFAS in Drinking Water

Neither Washington State nor the U.S. Environmental Protection Agency (EPA) have established enforceable drinking water standards for any PFAS. EPA's lifetime health advisory level in drinking water is 70 parts per trillion (or ppt) for PFOA and PFOS combined (EPA 2016a; EPA 2016b).

PFOA and PFOS have been detected in drinking water above the EPA drinking water health advisory level in or around these Washington locations:

- City of Issaquah.
- Joint Base Lewis-McChord.
- Naval Air Station Whidbey Island.
- Fairchild Air Force Base/City of Airway Heights.

The EPA health advisory does not include recommendations for other PFAS found in Washington's drinking water (such as those similar to PFOA and PFOS: perfluorohexane sulfonate (PFHxS) and perfluorononanoic acid (PFNA); or short-chain PFAS: perfluorobutanesulfonic acid (PFBS), PFHxA, or 6:2 fluorotelomer sulfonate (6:2 FTS)).

During 2013-2015, water samples from all 113 water systems serving more than 10,000 people and 19 smaller water systems in Washington were tested for 6 PFAS, as required by EPA's third Unregulated Contaminant Monitoring Rule (UCMR3). The UCMR survey showed that levels above the health advisory were not widespread in the tested public water systems, and most residents do not have PFAAs in their drinking water. Only three out of the 132 public water systems tested had detections above the minimum reporting limit:

- Issaquah water system (0.490 ug/L).
- City of Dupont water system (0.03 ug/L).
- Joint Base Lewis-McChord (0.051 ug/L).

The City of Dupont and Joint Base Lewis-McChord had detections for PFOA and PFOS below the EPA health advisory of 0.07 μg/L. In one of its wells, the City of Issaquah reported levels above the current EPA health advisory level for PFOA and PFOS combined. In response, the city installed a filtration system to remove PFAS.

Voluntary testing by the U.S. Department of Defense subsequently found PFOA and PFOS in groundwater at a number of military bases and surrounding areas (DOD 2017). The levels of PFOA and PFOS combined above the EPA health advisory level in on-base water systems at Joint Base Lewis-McChord; in both public and private water systems near Naval Air Station Whidbey Island; and in public and private water systems around Fairchild Air Force Base near Spokane. In response, the military has shut down some impacted wells on base, provided alternative water for drinking and cooking to residents who draw from affected wells, and is in the process of finding more permanent solutions such as installing filtration or connecting impacted residents to public water systems (EPA 2017, Carabajal 2017, NASWI 2016).

PFAS-based AFFF is believed to be the primary source of PFAS drinking water contamination in Washington. AFFF is directly released to the environment during firefighting training and emergencies. AFFF may have been used at airports, military bases, petroleum refineries, chemical facilities, manufacturing plants, large rail yards, local fire districts, and other sites where liquid-fuel fires were extinguished (Woodward, Chiang, Casson 2015). While AFFF is not considered a major use of PFAS, it is a dispersive release that has been implicated in many cases of groundwater contamination across the U.S. (Hu et al. 2016). As additional AFFF release sites are identified, it is likely that more contaminated aquifers will be discovered.

Eighty percent of Washington residents are served by large public water systems that have been tested for six PFAAs under the EPA UCMR3. However, there are nearly 4,000 Group A (large) and over 13,000 Group B (small) public water systems that have not been tested. In addition, about 15 percent of people in Washington are served by private drinking water wells – nearly all have not been tested.

PFAS in drinking water (PFOA, PFOS, PFHxS, and PFNA) can contribute significantly to body burden. Concentrations in blood serum are elevated in communities with PFAS-contaminated drinking water, compared to the general population (Emmett et al. 2006, MDH 2017, Hurley 2016, NHDHHS 2016). Interventions to identify and mitigate contaminated drinking water have been shown to be effective in reducing people's body burden of PFAS (MDH 2017). Public health agencies have focused on identifying and reducing exposure to long–chain PFAS as the key approach to reducing health risk.

Granulated activated carbon filters are effective for removing long-chain PFAS. Short-chain PFAS break through these filters faster than long-chain and require more frequent filter changes. It is therefore more expensive to remove short-chain PFAS from drinking water using these filters (AWWA 2016; Water Research Foundation 2016; Calgon Corporation 2017).

Health Effects

Exposure to certain PFAS produce harmful effects in laboratory animal research and have been linked to harmful effects in human epidemiological studies (EPA 2016c; EPA 2016d; ATSDR 2018; NTP 2016; Johnson et al. 2014; Rappazzo et al. 2017).

Most public health research has focused on PFOA and PFOS. In laboratory animals, these compounds have been found to:

- Cause liver toxicity and tumors.
- Alter lipid metabolism and serum lipid levels.

- Alter hormones and timing of sexual maturation.
- Cause changes in many organs including thyroid, kidney, liver, and reproductive tissue.
- Suppress immune response.
- Cause reproductive and developmental effects in laboratory animals.

Data from some, but not all, epidemiological studies suggest that exposure to PFOA and PFOS in humans:

- Increase cholesterol levels.
- Reduce birth weight.
- Reduce immune antibody response to childhood vaccines.
- May increase rates of some types of cancers, such as kidney and testicular cancer.

Some PFAS are known to bioaccumulate in people (examples include PFOA, PFOS, PFHxS, and PFNA). Bioaccumulation occurs because they are readily absorbed following ingestion, resist metabolic breakdown, and are poorly excreted from the human body (ATSDR 2018).

Some PFAS have been detected in blood serum of pregnant women, amniotic fluid, placental tissue, umbilical cord blood, and breast milk (examples include PFOA, PFOS, PFHxS, PFNA, and perfluorodecanoic acid (PFDA)) (ATSDR 2018, Frisbee et al. 2010, Morgenson et al. 2015). Thus, maternal transfer to the developing baby is a concern. The Department of Health supports action to identify and reduce people's exposure to PFAS in part to protect these sensitive developmental lifestages. In the meantime, Health also strongly encourages women to continue breastfeeding their children because of the many demonstrated health benefits of breastfeeding for both babies and mothers.

Manufacturers are moving away from highly bioaccumulative PFAS. Available data on replacements for PFOA and PFOS are limited to a few compounds. Studies show they are lower in toxicity and bioaccumulation. Understanding potential health risks and exposures to the variety of short-chain PFAS in our direct environment will require additional information on their fate, transport, exposure, and toxicity. Available studies indicate they are persistent, are soluble in water, and mobile in soil, and thus, likely to contaminate ground and surface water when released into the environment.

Short-chain PFAS replacements migrate more efficiently from treated food-contact paper to food than their long-chain chemical relatives (homologues) (Yuan et al. 2016). They are also more easily taken up from soil by certain food crops (Blaine et al. 2014; Lee et al. 2014; Brendel et al. 2018; Scher et al. 2018). Newer generation products may contain short-chain fluorotelomer alcohols as contaminants or degradation products. These chemicals become more volatile as the perfluorinated chain becomes shorter (Lei et al. 2004) so they are more likely to escape into indoor air from products. These exposure pathways need to be assessed for overall safety.

Environmental Cleanup of PFAS Contamination

Soil, groundwater (including some drinking water supplies), and surface water in parts of Washington are contaminated due to releases of PFAS (Hu et al. 2016, NASWI 2017, Carabajal 2017, Issaquah 2018, Ecology 2017). The most significant PFAS-related public health concern in Washington has been their discovery in public and private drinking water supplies.

PFOA and PFOS are soluble in water (EPA 2016a, EPA 2016b) and have been found to travel long distances (more than one mile) in groundwater (Woodward, Chiang, Casson 2015). Because they are stable in the environment, many PFAS in groundwater and soil may serve as sources of exposure to people for decades or centuries.

To reduce people's exposure, most public health actions to date have involved treating contaminated groundwater at the wellhead to remove contaminants or providing bottled water. In some cases, cleanup of PFAS-contaminated soil and groundwater upstream of drinking water wells may be an effective way to reduce people's exposure by lowering the concentrations of PFAS in drinking water, and to shorten the time that drinking water sources must be treated.

Available evidence suggests that drinking water contamination resulted from the use of fire-fighting foam (AFFF) that was sprayed on the ground and then migrated into groundwater aquifers (DOD 2017).

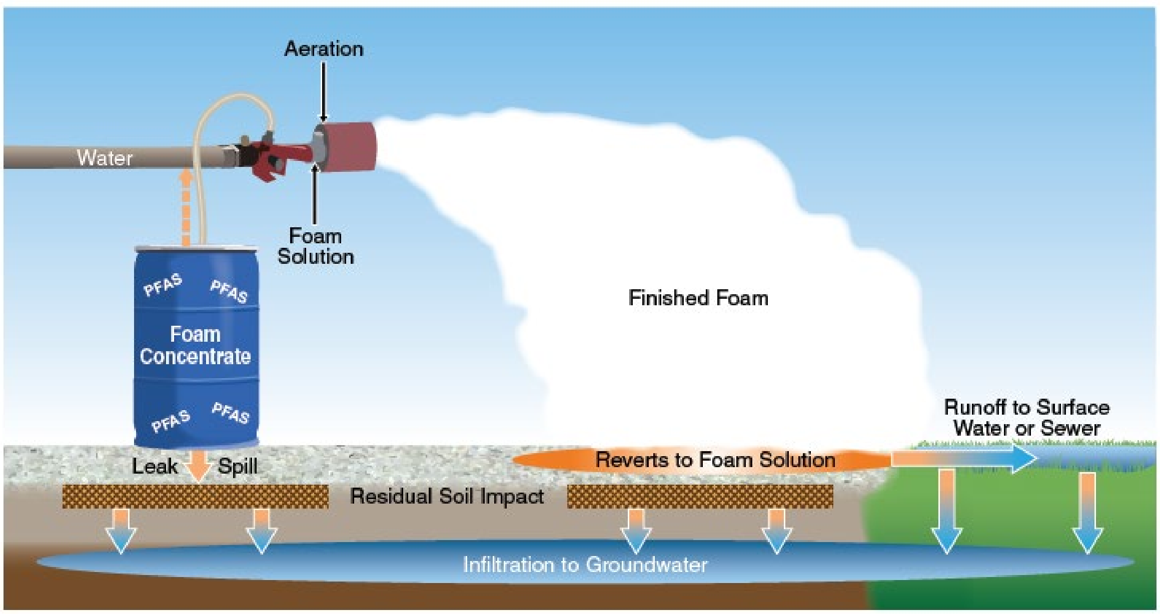


Figure 1. How a release of AFFF foam gets into groundwater.[7]

For a specific geographic area, answers to the following questions would help investigators determine whether cleanup is warranted and, if so, the best ways to clean up and prevent harmful exposure to AFFF-related PFAS contamination:

- Where was AFFF sprayed?
- When was it sprayed, and how often?
- What was the chemical composition of the AFFF, and were different formulations used at different times?
- What are the current concentrations of the various PFAS in soil and groundwater throughout the area?

[7] Source: ITRC, 2017 (adapted from original by J. Hale, Kleinfelder).

- How are these concentrations likely to change over time as the PFAS move through the soil and groundwater?
- What are the benefits and drawbacks of various options for reducing PFAS exposure?

Unfortunately, the locations, formulations, and frequency of use of AFFF have not been well documented. Further, groundwater plumes and soil containing PFAS may be spread over large areas, meaning that sufficient resources may not be available to adequately characterize the contamination and its future migration. These factors hamper our ability to identify the most appropriate ways to address the contamination over the long term.

Several cleanup technologies are under development, but further testing is needed to evaluate their effectiveness in different environments. Site-specific factors influence the effectiveness of potential options, and will have to be adequately characterized before selecting cleanup actions (NGWA 2017).

Important steps in addressing a contaminated area include identifying which chemicals should be included, whether or not exposure-reduction actions are warranted, and where they should be conducted. This is typically done by comparing the concentrations of the contaminants of concern throughout the environment to a level that is considered to be protective of human health and the environment. Concentrations equal to or higher than the protective level would likely trigger some type of action and those below the level generally would not. Depending on the situation and the government agency involved, the protective level may be called a cleanup level, remediation level, action level, screening level, or investigation level. Ecology is currently working to identify cleanup levels to clarify when concentrations of PFAS in the environment may be of public health concern and should be addressed.

PFAS in AFFF

PFOS-based firefighting foams were developed in the 1960s to extinguish high hazard flammable liquid fuel fires. After extinguishing the fire, a foam-surfactant film acts as both a radiation barrier and a vapor-sealant to prevent re-ignition or "burnback."

There are many different AFFF products which vary in chemical composition and contain mixtures of both documented and unidentified PFAS. Over the past decade, AFFF manufacturers have phased out long-chain PFAS and shifted to short-chain formulations. Non-fluorinated firefighting foam products are also available (KEMI 2015). At this time, non-fluorinated firefighting foams have not met Department of Defense specifications.

A multi-year research project on AFFF contamination at military sites was completed in 2017, funded by the Department of Defense (Field, Sedlak and Alvarez-Cohen 2017). Additional studies are underway to better understand subsurface fate and transport of AFFF chemicals, and to evaluate remediation options. The final Department of Defense project report summarizes current knowledge about contaminated sites (Field, Sedlak and Alvarez-Cohen 2017). Many of the results were separately published in the peer-reviewed literature. Key project findings were:

- AFFF formulations from suppliers contained PFAS ingredients that can degrade to long-chain PFAS. While long-chain AFFF products are not manufactured today, they were still in production within the last decade and likely remain in some AFFF stockpiles.

- Many AFFF products contain additional PFAS that are not detected by the drinking water test method recommended by the EPA, Method 537[8] (EPA 2009). As a result, significant PFAS content may simply go undetected without more extensive analytical testing work.
- Many AFFF products contain a dozen or more identifiable PFAS. Sophisticated forensic testing of AFFF products, contaminated soil, and contaminated groundwater were all reported to contain PFAS that cannot be identified even by advanced research analytical methods.
- PFAS in soil and groundwater degrade by different pathways, depending on local environmental conditions. A variety of degradate substances develop over periods of months. Many of these degradate substances have not been completely identified and their impacts on the environment, wildlife, or humans are not known.

Figure 2. Firefighters from the 916th Air Force Reserve Fire Protection Flight fight a fire during an exercise on a mock fuselage.[9]

[8] EPA Method 537 or subsets of Method 537 analytes have been used for most drinking water characterization studies, including EPA's Third Unregulated Contaminant Monitoring Rule (UCMR3) (EPA 2009, EPA 2017).
[9] Source: USAF photo by Tech. Sgt. Brian E. Christiansen.

Interim CAP Recommended Actions

Ecology and Health recommend the following immediate actions to reduce exposure to PFAS. Some of these actions are currently underway.

1 Ensure drinking water is safe

PFAS testing of public and private drinking water wells in Washington has confirmed the presence of PFOA and PFOS above EPA's health advisory level of 70 ppt (EPA 2017, Carabajal 2017, Hu et al. 2016, Issaquah 2018, NASWI 2016). This groundwater contamination is believed to have resulted from nearby use of AFFF.

Figure 3. The U.S. Air Force distributes water to Airway Heights residents after town water system is contaminated by PFAS.[10]

1.1 Support rulemaking for state drinking water standards

Support the State Board of Health rulemaking to establish a state drinking water standard or advisory level for PFAS. Implement state standards to address the PFAS of highest concern to Washington drinking water and bring PFAS contamination into a regulatory framework for drinking water cleanup and mitigation.

The EPA health advisory level of 70 ppt is a voluntary standard that applies to PFOA and PFOS. There are no EPA advisory levels for any other PFAS detected in community water supplies. Lack of health-based standards hampers cleanup decisions.

[10] Source: USAF photo by 2nd Lt. Kate Miranda.

In October 2017, the State Board of Health accepted a petition for rulemaking for PFAS in drinking water. Department of Health toxicologists and drinking water experts will provide technical assistance and support the State Board of Health throughout the rulemaking process. The cost of this support is $450,000 over two years, based on standard rulemaking assumptions.

1.2 Test drinking water wells

Expand voluntary testing for PFAS to include drinking water sources and PFAS chemicals that have not yet been evaluated. Prioritize water systems at high risk for contamination, such as those near airports or firefighter training centers, for early testing.

PFAS are not currently regulated in drinking water, and there is no requirement for PFAS testing under the federal Safe Drinking Water Act or state law. PFAS water contaminants are tasteless and odorless at levels that cause public health concerns. More testing will also help focus rulemaking on the forms of PFAS actually found in our water supplies.

Largely untested for PFAS are:

- Private wells, which serve 15 percent of Washington's population.
- Over 4,000 smaller Group A and 13,000 Group B public water systems,[11] which serve five percent of the state population.

Testing of up to 500 water samples is underway at Health, and is funded for $235,000. This includes costs of sample analysis and staff time to oversee testing and provide assistance to communities with drinking water contamination.

As part of the PFAS sampling project, the Department of Health's Office of Drinking Water notified all water systems that were potentially at risk. This included more than 300 Group A public and tribally owned water systems across the state. Many of these systems are made up of vulnerable/sensitive populations, including children, pregnant women, low-income, immigrant and refugee communities, or communities of color.

If a system finds high levels of PFAS, the Office of Drinking Water will ensure they provide public notice to their customers, including vulnerable/sensitive populations. The public notice will include what to do, what not to do, and the health effects of PFAS. If a system needs help communicating to customers, Office of Drinking Water will support them by providing resources (including translated materials) and assistance.

Office of Drinking Water will also inform the appropriate local health jurisdiction, and support their efforts to communicate public health messages to the community and those they regulate. This includes Group B water systems and private wells.

To test all public drinking water supplies, more funding would be required:

- A two-year effort to test 8,000 samples from all Group A public water systems would cost more than $2.6 million, including analytical costs of a commercial laboratory and a full-time staff person at Health.

[11] Group A public water systems serve more than 15 connections and more than 25 people for 60 or more days per year. Group B public water systems serve fewer than 15 connections and fewer than 25 people per day.

- A three-year effort to test 24,000 samples from all Group A and B public water systems would cost more than $8 million, including analytical costs and two full-time staff at Health.

1.3 Implement methods to reduce PFAS in drinking water

Encourage water systems to implement options to meet the EPA health advisory level for PFOA and PFOS of 70 ppt until state rulemaking is complete. Provide technical assistance to public water systems for talking to the public about contamination, mitigation options, and monitoring.

Water systems need advice and assistance from Health to understand the mitigation options and guide voluntary action on unregulated PFAS until the rulemaking for PFAS in drinking water is complete. Local health departments need outreach and guidance to support private and public water systems. Water systems facing PFAS contamination should thoroughly evaluate approaches to prevent potential exposures, including the use of alternative sources, blending sources, and other treatment options.

The costs of staff time to provide this assistance is estimated to be $30,000 to $60,000 per contaminated water system. Additional funding would be needed to support mitigation costs and source investigations in water systems with minimal resources.

2 Manage environmental PFAS contamination

Soil, groundwater, and surface water in parts of Washington are contaminated due to releases of PFAS. In the areas of greatest concern, where PFAS have been found in drinking water supplies, contamination appears to be related to the use of certain types of firefighting foam. The foam was sprayed onto the ground and moved downward, spreading through underlying aquifers. In some places, this contamination has the potential to harm people, and cleanup of PFAS in soil, groundwater, or both may be needed to reduce people's exposures and protect their health.

2.1 Develop PFAS cleanup levels for soil and groundwater

Set health-based cleanup levels for PFAS in soil and groundwater. Cleanup levels are designed to protect vulnerable populations from harmful exposures to chemicals in the environment. They help determine which geographic areas and environmental media (for example soil or groundwater) are contaminated enough to require further evaluation and, possibly, cleanup actions.

Currently, there are no federal or Washington State regulatory standards to determine whether a site with PFAS contamination requires cleanup, nor have best practices for conducting such a cleanup been established. Ecology has begun to develop cleanup levels for PFOA and PFOS, and this work will be informed by the findings of the State Board of Health and Department of Health as they consider establishing drinking water standards or advisories. As this work progresses, Ecology will provide information to interested parties about cleanup efforts.

An Ecology toxicologist would work for three months to develop PFAS cleanup levels at a cost of $43,000.

2.2 Identify methods to reduce exposure to contamination

Develop expertise and provide technical assistance and guidance to parties that address PFAS contamination and conduct cleanup actions. Provide technical assistance to help parties understand the advantages and disadvantages of the different options that are available or under development to reduce levels of PFAS in water and soil.

Estimation of cleanup costs is difficult due to the variation in environmental conditions from site to site, as well as the generally poor understanding of the distribution of the contamination resulting from inadequate site characterization that currently exists. Each contaminated area has unique characteristics and the selection of appropriate actions will need to be based on local conditions. Several methods are available or under development to reduce levels of PFAS in water and soil.

Ecology is collaborating with several parties in the City of Issaquah to better understand the sources, composition, and distribution of the PFAS contamination in soil and water. Evaluation of appropriate cleanup actions and their costs will be informed by this work. Public entities have the option to apply to Ecology for Remedial Action Grants to obtain funding from the Toxics Control Accounts authorized under the Model Toxics Control Act.

The following examples illustrate the variation in investigation and cleanup costs for several known areas with PFAS contamination:

- $1.37 million spent, so far, for investigation and cleanup efforts at Naval Air Station Whidbey Island (DOD 2017).
- $3.5 million with ongoing maintenance costs of $300,000 per year for a granular activated carbon system to treat groundwater at a site in Moose Creek, Alaska (Eielson Air Force Base 2015, Wang et al. 2017). This does not include investigation costs or bottled water for 9,000 residents.
- $10 million budgeted for temporary municipal and private residential water filtration systems and investigation into an alternate drinking water source in Hoosick Falls, New York (Wang et al. 2017).
- $49 million spent over 10 years on treatment of surface water, groundwater, sediment and soil at three sites in Minnesota (Wang et al. 2017).

3 Reduce risks to drinking water from firefighting foam

PFAS-containing AFFF is primarily used to fight fires at military sites, airports, refineries, industrial or chemical plants, rail transport of fuel and for training purposes. There are 700 fire districts, departments and stations across Washington. In response to concerns about the impact of PFAS-containing AFFF on drinking water, Washington State enacted Chapter 70.75A[12] that:

[12] Link to Chapter 70.75A RCW http://app.leg.wa.gov/RCW/default.aspx?cite=70.75A

- Prohibits the use of PFAS-containing firefighting foam in training exercises after July 2018.
- Prohibits sale and distribution of PFAS-containing firefighting foam after July 2020. The sale restriction does not apply to the military, Federal Aviation Administration-certified airports, petroleum refineries and terminals, or large chemical plants.
- Directs Ecology to help other state agencies and local governments avoid purchasing firefighting foam that contain PFAS.

Figure 4. A U.S. Air Force firefighter moves a 55-gallon drum of fire retardant foam. The unit switched all fire retardant foam to a more environmentally friendly foam.[13]

3.1 Implement AFFF notifications and restrictions

Develop outreach materials and provide technical assistance to foam manufacturers regarding the notification requirements and the ban on PFAS-containing AFFF sale and distribution required by Chapter 70.75A RCW. Provide technical assistance to manufacturers when certifications of compliance are requested to attest that firefighting foam does not contain PFAS.

Notify state, local governments, and other firefighting foam users of the prohibition on the use of PFAS-containing AFFF for training purposes. Provide technical assistance to state, local governments, and other jurisdictions to help them avoid the purchase of PFAS-containing firefighting foam. Develop a state procurement contract for state, local governments and other jurisdications to purchase PFAS-free AFFF alternatives.

The cost for Ecology staff to conduct outreach, technical assistance, compliance and enforcement will be higher in the first three years and then lower in later years. Staff efforts in the first three years will require several staff members working at a total cost of $63,000

[13] Source: USAF photo by Benjamin Wilson.

for the first three years plus laboratory costs of $11,600 for compliance testing of AFFF. Ongoing costs after those first three years will reduce to $18,000 per year for technical assistance, compliance and enforcement starting in July 2022.

3.2 Survey firefighting foam users to identify high-risk sites

Survey users of AFFF to identify where PFAS-containing AFFF was used repeatedly in training, used in large quantities during firefighting, or involved in spills. Use this information to identify areas at high risk for contamination and to prioritize funding for site-specific assessments and inform groundwater testing.

The estimated cost for Ecology staff to complete this survey is one employee working for three to six months at a cost of $32,000 (three months) to $64,000 (six months).

3.3 Develop outreach on responsible AFFF use

Develop and promote best management practices and related outreach materials for firefighting foam users to address the proper use, storage, and disposal of AFFF. Promote best management practices to reduce future environmental and human impacts from both PFAS-containing and PFAS-free firefighting foams.

The estimated cost for Ecology staff to develop and promote best management practices is one employee working for three to six months at a cost of $32,000 (three months) to $64,000 (six months).

3.4 Replace PFAS-containing AFFF in non-exempt uses

Develop outreach materials that encourage AFFF users to dispose of PFAS-containing foams and replace them with PFAS-free foams. Many facilities subject to Chapter 70.75A RCW may hold stockpiles of PFAS-containing AFFF.

Launch a pilot project to assist state, and local governments, airport, and fire districts with a focus on those in economically disadvantaged communities to dispose and replace PFAS-containing foams. Prioritize assistance to regular users of AFFF who do not have the resources to quickly fund replacements.

Disposing of PFAS-containing AFFF is estimated to cost up to $1,500 for disposal of 30 gallons of AFFF[14]. A pilot project could assist 80 to 150 AFFF users for a cost of $250,000. The pilot project requires one employee for six months to one year to provide technical assistance, best practices guidance, and disburse funding for waste designation, removal, and replacement of PFAS-containing AFFF. The total cost for that work could range from $64,000 (six months) to $127,000 (one year), plus the pilot project fund of $250,000.

[14] Requirements for the disposal of PFAS-containing AFFF would depend on the waste designation under the Dangerous Waste Regulations (WAC 173-303). Fluorinated firefighting foam would designate as a state-only dangerous waste if concentrations of halogenated organic carbons exceed 100 parts per million in the concentrate.

4 Investigate other potential sources of PFAS

Limited information is available on potential sources of PFAS in Washington State other than firefighting foams. More work is needed to understand the fate, transport, exposure and toxicological effects in humans and environmental impacts of replacement chemicals currently used in products or manufacturing. Where phase-out of PFAS is required or indicated, alternatives assessments are recommended to identify safer alternatives

In addition to the AFFF actions described earlier, other recently enacted PFAS requirements include:

- Require manufacturers to provide written notice to purchasers that firefighting personal protective equipment contains PFAS (Chapter 70.75A RCW).
- Conduct an alternatives assessment of PFAS-containing food packaging (Chapter 70.95G RCW).
- Prohibit PFAS in specific food packaging applications after January 2022 if the alternatives assessment identifies multiple safer alternatives that meet certain requirements (Chapter 70.95G RCW).

4.1 Identify sources of PFAS exposures and releases

Identify other potential industrial point sources of PFAS in the state. Review data from other states, including information about metal plating operations, product manufacturing, paper mills, tanneries, chemical identities and levels of PFAS at contaminated sites, and landfills. Consider outreach on best management practices for handling and disposing of PFAS-containing wastes.

Identify in products:

- Current uses of all PFAS.
- Remaining uses of legacy PFOA and PFOS.
- PFOA and PFOS precursors.

Conduct product testing and propose restrictions if necessary to halt import of PFOA and PFOS or their precursors in foreign-made products sold in the state.

Identify sources of PFAS exposure in the home. Carpets, textiles, cosmetics, waxes, polishes, and cleaning agents are possible sources of PFAS in the home. Identify the sources that present the greatest exposures to PFAS. Identify strategies to reduce these exposures, including alternatives assessments.

Identify PFAS releases to the environment from manufacturing in Washington state. Use this information to identify areas where there is a high risk of PFAS emissions to the environment and releases to drinking water.

This work will provide information and data to support recommendations in the Draft PFAS CAP on key sources that impact food, water and homes.

The estimated cost for Ecology to conduct this research is one staff person working half- to full-time for six months is $41,000 (half-time) to $82,000 (full-time).

4.2 Ensure firefighting personal protective equipment notifications

Develop outreach materials to manufacturers of firefighting personal protective equipment to inform them of the requirement to notify vendors of the presence of PFAS (Chapter 70.75A RCW). Provide technical assistance to state and local governments, and fire protection districts to give priority and preference to the purchase of personal protective equipment that does not contain PFAS. Provide technical assistance to manufacturers when certifications of compliance are requested to attest that firefighting personal protective equipment does not contain PFAS.

The estimated cost for Ecology to conduct this outreach and technical assistance is one staff person spending less than ten percent of their time for six months at a cost of $6,400.

4.3 Conduct alternative assessments

Complete an alternatives assessment of PFAS-containing food contact materials as required by Chapter 70.95G RCW. Alternative assessments follow the guidelines of the Interstate Chemicals Clearinghouse to evaluate hazards, exposure, performance, cost and availability of alternatives (IC2 2017). Additional alternatives assessments are recommended for uses of PFAS with the highest potential for human exposure which may include firefighting foam, cosmetics, and/or textiles.

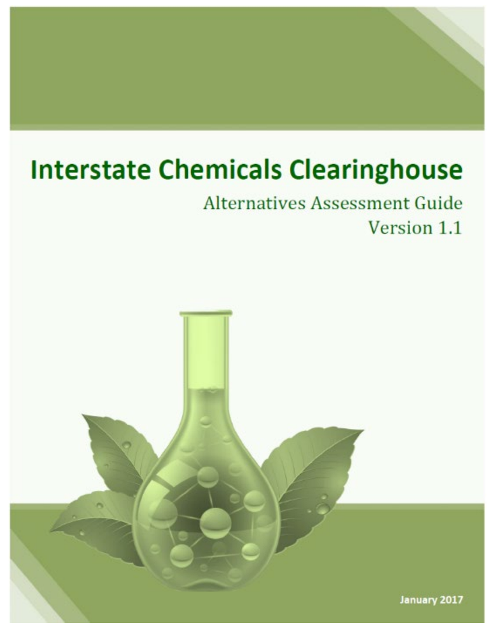


Figure 5. The Interstate Chemicals Clearinghouse Alternatives Assessment Guide.

There are a large number of short-chain PFAS in current use, which have replaced older generation PFOA, PFOS, and their related substances. Much of the short-chain safety and toxicity data submitted to federal authorities is not available to the public or state agencies. This hampers state efforts to assess whether replacement PFAS are regrettable substitutes for PFOA and PFOS. Ecology and Health would send Freedom of Information Act requests to EPA and FDA and attempt to partner with industry to arrange for alternatives assessments to confirm their safety.

Based on Ecology's experience, alternatives assessments can range in cost from $175,000 (less complex) to $400,000 (more complex), depending on the type and number of products. Alternatives assessments require a chemist to select priority product(s), scope the alternatives assessment, contract for an alternatives assessment, manage the contract, review, and comment on the draft alternatives assessment, and review and comment on the final alternatives assessment. Alternatives assessments are conducted by a contractor with agency oversight and take about 18 months to complete. Management of the alternatives assessment contract would require a chemist to spend six to twelve percent of his/her time over 2 years.

The cost of the food contact material alternatives assessment will include a $175,000 contract and $20,000 for a chemist's time over 2 years.

Estimates for contracting alternatives assessments on additional priority products over 2 years: $175,000 contract plus $20,000 staff time (less complex, six percent oversight effort) to $400,000 contract plus $40,000 staff time (more complex, twelve percent oversight effort).

Benefits of Implementing the Recommendations

Four broad categories of potential benefits are listed below. The general benefits in each category are identified for the recommended actions. A more detailed analysis of economic impacts from CAP recommendations will be provided in the Final PFAS CAP. It is not possible at this time to determine a monetary value for these benefits.

Human health benefits: reduced exposure to contaminated water and reduced potential for health effects. Data from a Minnesota study showed that people's PFAS levels declined steadily over time after filtration was installed to remove PFAS from community drinking water (MDH 2017). Testing water from small water systems and private wells supports health equity in that people have reduced exposure to contaminated water no matter what their water source is.

Ecological benefits: reduced drinking water and environmental contamination, reduced impacts on recreation and aesthetics, and improved ecosystem health.

Remediation benefits: reductions in future cleanup costs.

Amenity benefits: no identified improvements in taste, odor, or visibility.

Supplemental Information

Types of PFAS

Below is a classification hierarchy of environmentally relevant perfluoroalkyl and polyfluoroalkyl substances (PFAS). The two columns show a typical breakdown of types of PFAS in this class of chemicals, which include both polymers and non-polymer chemicals. [15]

Polymers are often used as linings for fluid pipes or tubing or as layers in laminated fabrics. A polymer is a chemical made of many repeating units. “Side-chain fluorinated polymers” consist of hydrocarbon backbones with polyfluoroalkyl side chains that stick out like teeth on a comb (FluoroCouncil, 2018).

Non-Polymers

Perfluoroalkyl Substances
Compounds for which all hydrogen atoms on all carbon atoms (except for carbon atoms associated with functional groups) have been replaced by fluorine atoms, such as:

- (Aliphatic) perfluorocarbons.
- Perfluoroalkyl acids.
- Perfluoroalkane sulfonyl fluorides.
- Perfluoroalkane sulfonamides.
- Perfluoroalkyl iodides.
- Perfluoroalkyl aldehydes.

Example uses: surfactants, manufacturing intermediates.

Polyfluoroalkyl Substances
Compounds for which all hydrogen atoms on at least one (but not all) carbon atoms have been replaced by fluorine atoms, such as:

- Perfluoroalkane sulfonamido derivatives.
- Fluorotelomer-based compounds.
- Semifluorinated *n*-alkanes and alkenes.

Example use: ski wax, water, oil, and stain repellency for textiles, leather, and food contact paper.

Polymers

Fluoropolymers
Carbon-only polymer backbone with fluorine atoms directly attached, such as:

- Polytetrafluoroethylene.
- Polyvinylidene fluoride.
- Polyvinyl fluoride.

Example uses: wire and cable linings, cookware, lubricants.

Perfluoropolyethers
Carbon and oxygen polymer backbone with fluorine atoms directly attached to carbon atoms, such as:

- Perfluoropolyethers.

Example use: functional fluids and surface protection products for stone, metal, glass, plastics, leather, and paper.

Side-chain Fluorinated Polymers
Variable composition non-fluorinated polymer backbone with fluorinated side chains, such as:

- Fluorinated acrylate and methacrylate polymers.
- Fluorinated urethane polymers.
- Fluorinated oxetane polymers.

Example use: water, oil, and stain repellency for textiles, leather, and food contact paper.

[15] Source: adapted from Buck et al. 2011.

Side-chain fluorinated polymers are primarily used for surface treatments of paper and packaging, textiles, upholstery, and carpeting (Buck et al. 2011). Perfluoropolyethers are also used for surface-treatments, but have many other specialized uses.

Non-polymeric PFAS are often used as additives to industrial or commercial formulated products, such as cleaners, polishes, paints, and sealers. Members of the non-polymer group include the fluorinated surfactants in aqueous film-forming foams (AFFF) used to fight high hazard liquid fuel fires.

Most PFAS are manufactured by one of two major processes: electrochemical fluorination or telomerization. Both processes produce many unintended by-products which may or may not be removed in subsequent processing. As a result, any single PFAS product may contain a complex mixture of related PFAS. These mixtures of target products, by-product substances, residuals, and contaminants complicate efforts to assess environmental and human health impacts.

Sources of Potential PFAS Release

PFAS may be released to the environment from:

- Use of PFAS-containing AFFF.
- Chemical manufacturing facilities that make PFAS (none are known to have existed in Washington).
- Manufacturing facilities that use PFAS during production, such as metal plating.
- Wastewater treatment plant (WWTP) effluent.
- Land application of biosolids from WWTPs.
- Landfill air emissions and leachate.
- Compost containing PFAS-treated food contact materials.
- Disposal of PFAS-containing consumer products outside of landfills and WWTPs.

PFAS are not known to have been manufactured in Washington but they may have been used in production of other products. The types of industries that might use PFAS or PFAS-containing products include:

- Car washes.
- Furniture.
- Metal fabricating and chrome plating.
- Rubber and plastics.
- Semiconductor and electronic production.
- Tanneries.
- Textile and paper mills.
- Manufacturing of high performance surfactants in polishes, waxes, paints, adhesives, and lubricants.

Two studies estimated global releases of PFAS from 1970-2002 (Paul et al. 2009, Prevedouros et al. 2006). PFAS emissions are reported to mostly occur during consumer product use and after disposal (Paul et al., 2009). PFAS emissions can also occur when treating a product, such as during treatment of carpet or apparel, and from product waste created during the treatment process. Based on Ecology estimates, the Washington proportion of those global estimates could represent 30 metric tons per year of legacy PFAS releases and emissions.

PFAS in Washington's Environment

In both urban and remote areas around the world, several PFAS have been found in water, soil, and air, as well as in the tissues of many types of animals.

Several PFAS have been detected in a variety of environmental media analyzed in Washington State: surface water, groundwater, WWTP effluent, freshwater and marine sediments, freshwater fish tissue, and osprey eggs.

PFOS, and to a lesser extent PFDA, perfluorododecanoic acid (PFDoDA), perfluoroundecanoic acid (PFUnDA), and perfluorooctanesulfonamide (PFOSA) were widespread in tissue of freshwater fish in Washington lakes (Ecology 2017; Ecology 2012; Ecology 2010). PFOS levels in fish from urban lakes were higher than levels the Department of Health developed to screen for human health concern for fish consumers. The number of fish tested was too small for the Department of Health to conduct a fish consumption advisory assessment.

PFOS and other long-chain PFAS were also detected in samples of osprey eggs taken from sites affected by urban sources and WWTP inputs (Ecology 2017; Ecology 2010b). The concentrations were lower than would affect offspring survival, but potentially high enough to reduce hatchability based on thresholds proposed by Newsted et al. (2005) and Molina et al. (2006). PFAS concentrations measured in osprey eggs collected in Washington in 2016 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 Washington samples near urban or WWTP sources (Ecology 2017).

Environmental monitoring in 2016 (Ecology 2017) suggested that PFAS levels in surface waters and WWTP effluent have decreased since the last round of sampling in 2008 (Ecology 2010). A general shift in PFAA make-up was evident in WWTP effluent samples, with short-chain PFAA compounds replacing PFOA as the most dominant compounds in effluent. PFAS concentrations in freshwater fish tissue and osprey eggs (primarily made up of PFOS) remained unchanged between 2008 and 2016. PFOS appears to be a relatively ubiquitous contaminant in Washington State aquatic biota.

PFAA compounds were found in marine surface water in the Puget Sound and in nearby Clayoquot and Barkley Sounds in British Columbia, Canada (Dinglasan-Panlilio et al. 2014). The highest concentrations were found in two urbanized sites draining to Puget Sound. Perfluoroheptanoic acid (PFHpA), PFOA, and PFOS were the most frequently detected compounds in the samples.

Data gaps in our understanding of PFAS contamination in Washington include a lack of monitoring of ambient groundwater and landfill leachate, assessing sources of PFAS in urban waterbodies, and testing PFAS beyond PFAAs. Some media types, such as biosolids and landfill leachate, have not been sampled in Washington.

The relative impacts of different sources of PFAS releases, like WWTP effluent or AFFF use, are not well characterized for Washington State. However, environmental monitoring in Washington shows that surface water PFAS concentrations are highest in waterbodies located in urban settings and where WWTP effluent makes up a significant portion of the flow or hydrologic dilution, suggesting WWTP effluent, stormwater, and AFFF are important pathways. Monitoring in the state has focused on releases of PFAS to surface water and the aquatic food chain. Background levels in soil or geographical distribution of PFAS in soils, groundwater, or air have not been investigated.

PFAS CAP Process

Ecology and Health develop CAPs in consultation with an advisory committee that represents business, local government, human health, environmental advocates, and other interested parties.

Table 1. PFAS CAP advisory committee

Type of group	Participating Agency
Advocacy	• Clean Production Action. • Green Science Policy Institute. • Institute of Neurotoxicology and Neurological Disorders. • Toxic–Free Future. • Zerowaste Washington.
Business	• Association of Washington Business. • Carpet and Rug Institute. • FluoroCouncil. • Outdoor Industry Association.
Governments	• Agency for Toxic Substances and Disease Registry. • City of Issaquah.Island County Public Health. • King County Department of Natural Resources. • Office of Governor Jay Inslee. • Port Gamble S'Klallam Tribe. • Port of Seattle.
Interested parties	• Naval Facilities Engineering Command Northwest. • Port of Seattle Firefighters. • University of Washington–Tacoma. • Washington Fire Chiefs Association. • Whidbey Island Water Systems Association. • Whitman College.

In 2017, PFAS CAP advisory committee meetings were facilitated by The William D. Ruckelshaus Center to foster stakeholder dialogue. Details about the PFAS CAP process and information from advisory committee meetings are posted at:
www.ezview.wa.gov/?alias=1962&pageid=37105
Development of this PFAS CAP is occurring in three phases. You are reading the Interim PFAS CAP developed during Phase 2.

Phase 1: Draft CAP findings

- Conduct research and discuss findings with advisory committee.
- Publish draft CAP documents for review and comment.
- Review comments and work with the advisory committee to make adjustments.

Table 2. Summary of Phase 1 CAP Activities

Timeframe	*Phase 1 Actvities*
August 2017	Advisory committee meeting
September 2017	Post draft CAP chapters
October 2017	Post draft sections
November 2017	Advisory committee meeting
December 2017	Advisory committee meeting

Phase 2: Publish Interim CAP recommendations

- Publish Interim PFAS CAP recommendations.
- Review comments with the advisory committee.
- Implement some urgent actions as resources are available.

Table 3. Summary of Phase 2 CAP Activities

Timeframe	*Phase 2 Actvities*
April 2018	Publish interim CAP
June 2018	Advisory committee webinar
August 2018	Publish updated interim CAP

Phase 3: Publish the Final PFAS CAP

- Meet with the advisory committee to discuss draft recommendations and the cost analysis of the recommendations.
- Develop the Draft PFAS CAP that details:
  - Concerns about PFAS use, including replacement PFAS chemistries used in place of PFOA and PFOS.
  - Exposures of concern to Washington residents and the environment.
  - Recommended actions to reduce exposures to PFAS, including safer alternatives to PFOA and PFOS.
  - A cost analysis of recommended actions.
  - Supplemental documents to cover physical and chemical properties, human health and environment exposures and data, and estimated uses and releases in Washington.
- Publish the Draft PFAS CAP.
- Hold a 90-day public review and comment period with two public meetings.
- Review comments with the advisory committee.

- Publish the Final PFAS CAP.

Table 4. Summary of Phase 3 CAP Activities

Timeframe	***Phase 3 Actvities***
October 2018	Advisory committee meeting
March 2019	Cost analysis webinar
Summer 2019	Publish draft CAP
Summer 2019	90-day public review and public meetings
Fall 2019	Advisory committee meeting
Winter 2019	Publish Final CAP

References

Agency for Toxic Substances and Disease Registry (ATSDR). 2018. "Toxicological Profile for Perfluoroalkyls, draft for public comment," August 2018. U.S. Department of Health and Human Services. https://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=1117&tid=237

American Water Works Association (AWWA). 2016. "Perfluorinated Compounds Treatment and Removal" www.awwa.org/Portals/0/files/resources/water%20knowledge/rc%20healtheffects/AWWAPFCFactSheetTreatmentandRemoval.pdf

Barzen-Hanson, K.A. et al. 2017. Discovery of 40 classes of per-and polyfluoroalkyl substances in historical aqueous film-forming foams (AFFFs) and AFFF-impacted groundwater. *Environmental science & technology* 51, no. 4 (2017): 2047-2057. DOI: 10.1021/acs.est.6b05843 https://pubs.acs.org/doi/abs/10.1021/acs.est.6b05843

Begley, T.H., et al., 2005. Perfluorochemicals: potential sources of and migration from food packaging. *Food Additives and Contaminants*, 2005. **22**(10): p. 1023-31. https://www.ncbi.nlm.nih.gov/pubmed/16227186

Begley, T.H., et al., 2008. Food migration of fluorochemical paper additives from food-contact paper into foods and food simulants. *Food Additives and Contaminants*, 2008. **25**: p. 384 - 390. https://www.ncbi.nlm.nih.gov/pubmed/18311629

Blaine, A.C. et al. 2014. Perfluoroalkyl acid uptake in lettuce (Lactuca sativa) and strawberry (Fragaria ananassa) irrigated with reclaimed water. *Environmental science & technology*, *48*(24), 14361-14368. https://www.ncbi.nlm.nih.gov/pubmed/25386873

Brendel, S. et al. 2018, Short-chain perfluoroalkyl acids: environmental concerns and a regulatory strategy under REACH. *Environmental Sciences Europe* (2018) 30:9 https://doi.org/10.1186/s12302-018-0134-4

Buck, R.C., et al. 2011. "Perfluoroalkyl and Polyfluoroalkyl Substances in the Environment: Terminology, Classification, and Origins," *Integrated Environmental Assessment Management*, Vol. 7, No. 4, July 2011, p. 513–41. https://www.ncbi.nlm.nih.gov/pubmed/21793199

Calgon Corporation. 2017. Rapid Small Scale Column Tests: Comparison of Various Granular Activated Carbons for the Removal of "Short Chain" Perfluorinated Compounds from Groundwater.

California Environmental Contaminant Biomonitoring Program (CECBP), 2015. "Potential Priority Chemicals: Perfluoroalkyl and Polyfluoroalkyl Substances (PFASs)," November 18, 2015, Meeting of the Scientific Guidance Panel, Biomonitoring California, November 2015. www.biomonitoring.ca.gov/sites/default/files/downloads/PotentialPriority_PFASs_111815.pdf

Carabajal, Shannon, 2017. “Air force, Airway Heights strike water agreement,” Fairchild Air Force Base, November 2017. www.afcec.af.mil/News/Article-Display/Article/1367923/air-force-airway-heights-strike-water-agreement/

Center for Disease Control (CDC), 2017. NHANES Fourth National Report on Human Exposure to Environmental Chemicals – Updated Tables, January 2017. U.S. Department of Health and Human Services. https://www.cdc.gov/exposurereport/pdf/fourthreport.pdf

Costa G, Sartori S, Consonni D. 2009. Thirty years of medical surveillance in perfluooctanoic acid production workers. *Journal of Occupational and Environmental Medicine* 51(3):364-372. https://www.ncbi.nlm.nih.gov/pubmed/19225424

D’Agostino, L.A. and S. A. Mabury. 2014. Identification of Novel Fluorinated Surfactants in Aqueous Film Forming Foams and Commercial Surfactant Concentrates. *Environmental Science & Technology*. Volume 48, p. 121−129 https://pubs.acs.org/doi/abs/10.1021/es403729e

Dinglasan-Panlilio, J.M. et al. 2014. Perfluorinated Compounds in the Surface Waters of Puget Sound, Washington and Clayoquot and Barkley Sounds, British Columbia, *Marine Pollution Bulletin,* Vol. 78, No. 1-2, January 2014, p. 173-180. https://www.ncbi.nlm.nih.gov/pubmed/24262211

Eielson Air Force Base. 2015 “Action Memorandum for a Time-Critical Removal Action of PFC-contaminated Water at Moose Creek, Alaska,” November 2015. http://alaskacollection.library.uaf.edu/eafbsc/cd0/Moose%20Creek%20PFCs%20Contamination%20Information%20Repository/07_Memorandums/Final%20Memo%20for%20Time-Critical%20Removal%20Action%20of%20PFCs_Moose%20Creek,%20Alaska_18Nov2015.pdf

Emmett, E. A., et al. 2006. “Community Exposure to Perfluorooctanoate: Relationships Between Serum Concentrations and Exposure Sources," *Journal of Occupational and Environmental Medicine*, Vol. 48, No. 8, August 2006, p. 759-770. https://www.ncbi.nlm.nih.gov/pubmed/16902368

Eriksson, U. et al., 2016. Comparison of PFASs contamination in the freshwater and terrestrial environments by analysis of eggs from osprey (Pandion haliaetus), tawny owl (Strix aluco), and common kestrel (Falco tinnunculus). *Environmental Research*, Vol. 149: 40-47. https://www.ncbi.nlm.nih.gov/pubmed/27174782

European Chemicals Agency (ECHA). 2017. *Annex XVII to REACH – Conditions of restriction: Perfluorooctanoic Acid (PFOA).* August 11, 2017. https://www.echa.europa.eu/documents/10162/7a04b630-e00a-a9c5-bc85-0de793f6643c

Field, J., Sedlak, D., Alvarez-Cohen, L. 2017. “Characterization of the Fate and Biotransformation of Fluorochemicals in AFFF-Contaminated Groundwater at Fire/Crash Testing Military Sites,” Oregon State University Corvallis, April 2017. http://www.dtic.mil/docs/citations/AD1037940

FluoroCouncil. 2014. Potential PFAS Producers. Submitted to the Persistent Organic Pollutants Review Committee (POPRC) of the Stockholm Convention, January 31, 2014.

http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC9/POPRC9Followup/AlternativesPFOSSubmission/tabid/3565/Default.aspx

FluoroCouncil. 2018. "Terminology," Website accessed March 1, 2018. fluorocouncil.com/fluorotechnology/terminology

Frisbee, S. J. et al. 2010. Perfluorooctanoic Acid, Perfluorooctanesulfonate, and Serum Lipids in Children and Adolescents: Results from the C8 Health Project, *Archives of Pediatrics & Adolescent Medicine*, Vol. 164, No. 9, September 2010, p. 860-869. https://www.ncbi.nlm.nih.gov/pubmed/20819969

Fromme, H. et al. 2009. Perfluorinated Compounds--Exposure Assessment for the General Population in Western Countries, *International Journal of Hygiene and Environmental Health*, Vol. 212, No. 3, May 2009, p. 239-270. https://www.ncbi.nlm.nih.gov/pubmed/18565792

Harris, M.H.et al. 2017. Predictors of Per- and Polyfluoroalkyl Substance (PFAS) Plasma Concentrations in 6–10 Year Old American Children. *Environmental Science & Technology*. 2017, 51(9):5193-5204. https://www.ncbi.nlm.nih.gov/pubmed/28325044

Hu, X.C. et al. 2016. Detection of Poly- and Perfluoroalkyl Substances (PFASs) in U.S. Drinking Water Linked to Industrial Sites, Military Fire Training Areas, and Wastewater Treatment Plants, *Environmental Science & Technology Letters*, Vol. 3, No. 10, August 2016, p. 344-350. pubs.acs.org/doi/pdfplus/10.1021/acs.estlett.6b00260

Hurley, S. et al. 2016. Preliminary Associations between the Detection of Perfluoroalkyl Acids (PFAAs) in Drinking Water and Serum Concentrations in a Sample of California Women, *Environmental Science & Technology Letters*, Vol. 3, No. 7, June 2016, p. 264–269. https://pubs.acs.org/doi/abs/10.1021/acs.estlett.6b00154

Interstate Chemicals Clearinghouse (IC2), 2017. *Interstate Chemicals Clearinghouse Alternatives Assessment Guide, Version 1.1.* http://theic2.org/alternatives_assessment_guide

Interstate Technology Regulatory Council (ITRC) 2017. Naming conventions and physical and chemical properties of per- and polyfluoroalkyl substances (PFAS) https://pfas-1.itrcweb.org/wp-content/uploads/2017/10/pfas_fact_sheet_naming_conventions_11_13_17.pdf

Interstate Technology & Regulatory Council (ITRC) 2018. Per- and Polyfluoroalkyl Substances (PFAS) Fact Sheets, https://pfas-1.itrcweb.org/fact-sheets

Issaquah, 2018. "PFCs," Washington. Website accessed March 1, 2018: http://issaquahwa.gov/PFCs

Johnson, P. I et al. 2014. The Navigation Guide - Evidence-based Medicine Meets Environmental Health: Systematic Review of Human Evidence for PFOA Effects on Fetal Growth, *Environmental Health Perspectives*, Vol. 122, No. 10, October 2014, p. 1028-1039. https://ehp.niehs.nih.gov/doi/10.1289/ehp.1307893

Lee, H., et al. 2014. Fate of polyfluoroalkyl phosphate diesters and their metabolites in biosolids-applied soil: biodegradation and plant uptake in greenhouse and field experiments. *Environmental Science & Technology*, 2014. **48**(1): p. 340-9. https://www.ncbi.nlm.nih.gov/pubmed/24308318

Lei, Y D et al. 2004. Determination of vapor pressures, octanol− air, and water− air partition coefficients for polyfluorinated sulfonamide, sulfonamidoethanols, and telomer alcohols. *Journal of Chemical & Engineering Data* 49, no. 4 (2004): 1013-1022. https://pubs.acs.org/doi/abs/10.1021/je049949h

Lindstrom, A.B., M.J. Strynar, and E.L. Libelo. 2011. Perfluorinated compounds: Past, present, and future. *Environmental Science & Technology*, vol. 45, 7954-7961. https://pubs.acs.org/doi/10.1021/es2011622

Martinez-Moral, M.P. and M.T. Tena. 2012. Determination of perfluorocompounds in popcorn packaging by pressurised liquid extraction and ultra-performance liquid chromatography-tandem mass spectrometry. *Talanta*, 2012. **101**: p. 104-9. https://www.ncbi.nlm.nih.gov/pubmed/23158298

Minnesota Department of Health (MDH). 2014. Environmental Public Health Tracking, 2009. East Metro perfluorochemical biomonitoring pilot project. Minnesota Department of Health, Minnesota Environment, Exposure and Health. May 2014. http://www.health.state.mn.us/divs/hpcd/tracking/biomonitoring/projects/pfcfinalrpt2009.pdf

Minnesota Department of Health (MDH). 2017. "Environmental Public Health Tracking and Biomonitoring, Report to the Legislature," March 2017. www.health.state.mn.us/divs/hpcd/tracking/pubs/2017legreport.pdf

Mogensen, U. B. et al. 2015. Breastfeeding as an Exposure Pathway for Perfluorinated Alkylates. *Environmental Science & Technology*, Vol. 49, No. 17, August 2015, p. 10466-10473. https://www.ncbi.nlm.nih.gov/pubmed/26291735

Molina, E.D. et al. 2006. "Effects of Air Cell Injection of Perfluorooctane Sulfonate Before Incubation on Development of the White Leghorn Chicken (Gallus domesticus) Embryo," *Environmental Toxicology and Chemistry*, Vol. 25, No. 1, January 2006, p. 227–232. https://www.ncbi.nlm.nih.gov/pubmed/16494246

National Ground Water Association (NGWA). 2017. "Groundwater and PFAS: State of Knowledge and Practice," Website accessed: December 1, 2017: www.ngwa.org/Media-Center/news/Pages/Groundwater-and-PFAS-State-of-Knowledge.aspx

National Toxicology Program (NTP). 2016. "Systematic Review of Immunotoxicity Associated with Exposure to Perfluorooctanoic acid (PFOA) or Perfluorooctane Sulfonate (PFOS)," U.S. Department of Health and Human Services, June 2016. https://ntp.niehs.nih.gov/ntp/about_ntp/monopeerrvw/2016/july/draftsystematicreviewimmunotoxicityassociatedpfoa_pfos_508.pdf

Naval Air Station Whidbey Island (NASWI), 2016. "PFAS Groundwater and Drinking Water Investigation," Website accessed: September 12, 2017: www.navfac.navy.mil/navfac_worldwide/atlantic/fecs/northwest/about_us/northwest_documents/environmental-restoration/pfas-groundwater-and-drinking-water-investigation.html

New Hampshire Department of Health and Human Services (NHDHHS). 2016. "Pease PFC Blood Testing Program: April 2015 – October 2015,", June 2016. https://www.dhhs.nh.gov/dphs/documents/pease-pfc-blood-testing.pdf

Newsted, J.L.et al. 2005. Avian Toxicity Reference Values for Perfluorooctane Sulfonate, *Environmental Science and Technology*, Vol. 39, No. 23, December 2005, p. 9357–9362. https://pubs.acs.org/doi/abs/10.1021/es050989v

Organisation for Economic Cooperation and Development (OECD), 2013. OECD/UNEP Global PFC Group, "Synthesis Paper on Per- and Polyfluorinated Chemicals (PFCs)," Environment, Health and Safety, Environment Directorate,. http://www.oecd.org/env/ehs/risk-management/PFC_FINAL-Web.pdf

Organisation for Economic Cooperation and Development (OECD) 2018a Toward a New Comprehensive Global Database of Per- and Polyfluoroalkyl Substances (PFASs). Summary Report on Updating the OECD 2007 List of Per- and Polyfluoroalkyl Substances (PFASs). Series on Risk Management No. 39. May 2018 http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV-JM-MONO(2018)7&doclanguage=en

Organisation for Economic Cooperation and Development (OECD) 2018b Global Database of Per- and Polyfluoroalkyl Substances (PFASs). global-database-of-per-and-polyfluoroalkyl-substances.xlsx. https://oecd.us18.list-manage.com/track/click?u=df91cd39c652d7be5118c17f8&id=aeb27a5bc4&e=f4502cfec2

Olsen G.W. et al. 2003. Epidemiologic assessment of worker serum perfluorooctanesulfonate (PFOS) and perfluorooctanoate (PFOA) concentrations and medical surveillance examinations. J *Occupational and Environmental Medicine* 45(3):260-270. https://www.ncbi.nlm.nih.gov/pubmed/12661183

Olsen G.W. et al. 2007. Half-life of serum elimination of perfluorooctanesulfonate, perfluorohexanesulfonate, and perfluorooctanoate in retired fluorochemical production workers. *Environmental Health Perspectives* 115:1298-1305. https://www.ncbi.nlm.nih.gov/pubmed/17805419

Olsen GW and Zobel LR. 2007. Assessment of lipid, hepatic, and thyroid parameters with serum perfluorooctanoate (PFOA) concentrations in fluorochemical production workers. *International Archives of Occupational and Environmental Health* 81:231-246. https://www.ncbi.nlm.nih.gov/pubmed/17605032

Paul, A.G., K.C. Jones, and A.J. Sweetman. 2008. "A First Global Production, Emission, and Environmental Inventory for Perfluorooctane Sulfonate," *Environmental Science & Technology*, Vol. 43, No. 2, December 2008, p. 386–392. https://pubs.acs.org/doi/abs/10.1021/es802216n

Prevedouros, K. et al.2006. "Sources, Fate and Transport of Perfluorocarboxylates," *Environmental Science & Technology*, Vol. 40, No. 1, January 2006, p. 32–44. https://pubs.acs.org/doi/abs/10.1021/es0512475

Rankin, K., et al., 2016. A North American and global survey of perfluoroalkyl substances in surface soils: Distribution patterns and mode of occurrence. *Chemosphere*, 2016. **161**: p. 333-341. https://www.ncbi.nlm.nih.gov/pubmed/27441993

Rappazzo, K.M., E. Coffman, E.P. Hines. 2017. "Exposure to Perfluorinated Alkyl Substances and Health Outcomes in Children: A Systematic Review of the Epidemiologic Literature," *International Journal of Environmental Research and Public Health*, Vol. 14, No. 7, June 2017, p. 691. https://www.ncbi.nlm.nih.gov/pubmed/28654008

Rosati, J.A., K.A. Krebs, and X. Liu, 2007. Emissions from cooking microwave popcorn. *Critical Reviews in Food Science and Nutrition*, 2007. **47**(8): p. 701-9. https://www.ncbi.nlm.nih.gov/pubmed/17987444

Sakr CJ et al. 2007. Cross-sectional study of lipids and liver enzymes related to a serum biomarker of exposure (ammonium perfluorooctanoate or APFO) as part of a general health survey in a cohort of occupationally exposed workers. *Journal of Occupational and Environmental Medicine* 49:1086-1096. https://www.ncbi.nlm.nih.gov/pubmed/18000414

Scher, D. P. et al. 2018. Occurrence of perfluoroalkyl substances (PFAS) in garden produce at homes with a history of PFAS-contaminated drinking water. *Chemosphere*, *196*, 548-555. https://www.ncbi.nlm.nih.gov/pubmed/29329087

Sinclair, E., et al., 2007. Quantitation of gas-phase perfluoroalkyl surfactants and fluorotelomer alcohols released from nonstick cookware and microwave popcorn bags. *Environmental Science & Technology*, 2007. **41**(4): p. 1180-5. https://www.ncbi.nlm.nih.gov/pubmed/17593716

Steenland K, et al. 2009a. Predictors of PFOA levels in a community surrounding a chemical plant. *Environmental Health Perspectives* 117(7):1083-1088. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2717134/

Steenland K, Tinker S, Frisbee S, et al. 2009b. Association of perfluorooctanoic acid and perfluorooctane sulfonate with serum lipids among adults living near a chemical plant. *American Journal of Epidemiology* 170(10):1268-1278. https://www.ncbi.nlm.nih.gov/pubmed/19846564

Still, M., et al. 2013. Impact of industrial production and packaging processes on the concentration of per- and polyfluorinated compounds in milk and dairy products. *Journal of Agricultural and Food Chemistry*, 2013. **61**(38): p. 9052-62. https://www.ncbi.nlm.nih.gov/pubmed/24000959

Stockholm Convention 2017. "The 16 new POPs, An Introduction to the Chemicals Added to the Stockholm Convention as Persistent Organic Pollutants by the Conference of the Parties," Stockholm Convention on Persistent Organic Pollutants (POPs), June 2017. http://chm.pops.int/Portals/0/download.aspx?d=UNEP-POPS-PUB-Brochure-16NewPOPs-201706.English.pdf

Swedish Chemicals Agency (KEMI) 2015b. "Survey of fire-fighting foam," No. PM 5/15, 2015. www.kemi.se/global/pm/2015/pm-5-15-survey-of-fire-fighting-foam.pdf

Tittlemier, S., K. Pepper, and L. Edwards, 2006. Concentrations of perfluorooctanesulfonamides in Canadian total diet study composite food samples collected between 1992 and 2004. *Journal of Agricultural and Food Chemistry*, 2006. **54**: p. 8385 - 8389. https://cdn-pubs.acs.org/doi/10.1021/jf061713p

Trier, X., K. Granby, and J.H. Christensen, 2011a. Polyfluorinated surfactants (PFS) in paper and board coatings for food packaging. *Environmental Science and Pollution Research International,,* 2011, **18**(7): p. 1108-20. https://www.ncbi.nlm.nih.gov/pubmed/21327544

Trier, X., N.J. Nielsen, and J.H. Christensen, 2011b. Structural isomers of polyfluorinated di- and tri-alkylated phosphate ester surfactants present in industrial blends and in microwave popcorn bags. *Environmental Science and Pollution Research International*, 2011. **18**(8): p. 1422-32. https://www.ncbi.nlm.nih.gov/pubmed/21487649

Trudel D et al. 2008. Estimating consumer exposure to PFOS and PFOA. *Risk analysis*: an official publication of the Society for Risk Analysis. 2008; 28(2):251–69. https://www.ncbi.nlm.nih.gov/pubmed/18419647

U.S. Department of Defense (DOD), "Aqueous Film Forming Foam Report to Congress," : Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics October 2017. http://www.denix.osd.mil/derp/home/documents/aqueous-film-forming-foam-report-to-congress/

U.S. Environmental Protection Agency (EPA). 2009. "Determination of Selected Perfluorinated Alkyl Acids in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS)," Version 1.1., September 2009. https://cfpub.epa.gov/si/si_public_record_report.cfm?direntryid=198984

U.S. Environmental Protection Agency (EPA). 2016a. "Drinking Water Health Advisory for Perfluorooctanoic Acid (PFOA),", Office of Water, May 2016, p. 103. epa.gov/sites/production/files/2016-05/documents/pfoa_health_advisory_final_508.pdf

U.S. Environmental Protection Agency (EPA. 2016b. "Drinking Water Health Advisory of Perfluoroctane Sulfonate (PFOS)," Office of Water, May 2016. epa.gov/sites/production/files/2016-05/documents/pfos_health_advisory_final_508.pdf

U.S. Environmental Protection Agency (EPA) 2016c. "Health Effects Support Document for Perfluorooctane Sulfonate (PFOS)," Office of Water, May 2016. epa.gov/sites/production/files/2016-05/documents/pfos_hesd_final_508.pdf

U.S. Environmental Protection Agency (EPA) 2016d. "Health Effects Support Document for Perfluorooctanoic Acid (PFOA),", Office of Water, May 2016. epa.gov/sites/production/files/2016-05/documents/pfoa_hesd_final_508.pdf

U.S. Environmental Protection Agency (EPA), 2017. "The Third Unregulated Contaminant Monitoring Rule (UCMR 3): Data Summary, January 2017,". epa.gov/dwucmr/data-summary-third-unregulated-contaminant-monitoring-rule

U.S. Environmental Protection Agency (EPA) 2018a. "New Chemicals Program Review of Alternatives for PFOA and Related Chemicals," Website accessed on 2/13/18: https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/new-chemicals-program-review-alternatives-pfoa-and

U.S. Environmental Protection Agency (EPA) 2018b. "Risk Management for Per- and Polyfluoroalkyl Substances (PFASs) under TSCA. PFOA Stewardship Program," Website accessed on 2/13/18: https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-management-and-polyfluoroalkyl-substances-pfass#tab-3

Vestergren R., and I.T. Cousins. 2009. Tracking the pathways of human exposure to perfluorocarboxylates. *Environmental Science & Technology,* vol. 43, 5565–5575. https://www.ncbi.nlm.nih.gov/pubmed/19731646

Wang, Z. et al. 2017."A Never-ending Story of Per- and Polyfluoroalkyl Substances (PFASs)?" *Environmental Science and Technology*, Vol. 51, No. 5, February 2017, p/ 2508-2518. https://pubs.acs.org/doi/abs/10.1021/acs.est.6b04806

Wang, Z., et al., 2015.Hazard assessment of fluorinated alternatives to long-chain perfluoroalkyl acids (PFAAs) and their precursors: status quo, ongoing challenges and possible solutions. *Environment International,* 2015. **75**: p. 172-9. https://www.ncbi.nlm.nih.gov/pubmed/25461427

Washington State Department of Ecology (Ecology). 2010. "Perfluorinated Compounds in Washington Rivers and Lakes,", No. 10–03–034, August 2010. https://fortress.wa.gov/ecy/publications/SummaryPages/1003034.html

Washington State Department of Ecology (Ecology). 2012. "PBTs Analyzed in Bottom Fish from Four Washington Rivers and Lakes: Hexabromocyclododecane, Tetrabromobisphenol A, Chlorinated Paraffins, Polybrominated Diphenylethers, Polychlorinated Naphthalenes, Perfluorinated Organic Compounds, Lead, and Cadmium," No. 12–03–042, October 2012. https://fortress.wa.gov/ecy/publications/SummaryPages/1203042.html

Washington State Department of Ecology (Ecology). 2017. "Survey of Per– and Poly–fluoroalkyl Substances in Rivers and Lakes, 2016,", No. 17–03–021, September 2017. https://fortress.wa.gov/ecy/publications/SummaryPages/1703021.html

Water Research Foundation 2016. "Treatment and Mitigation Strategies for Poly- and Perfluoroalkyl Substances," Web Report #4322, 2016. http://www.waterrf.org/PublicReportLibrary/4322.pdf

Woodward, D, D. Chiang, and R. Casson. 2015. Lessons Learned from Characterizing Several Dozen Sites Impacted by Perfluorinated Compounds. *Bioremediation and Sustainable Environmental Technologies—2015*, Proceedings of the Third International Symposium on Bioremediation and Sustainable Environmental Technologies, Miami, Florida, May 2015.

Xiao, Feng. 2017. Emerging poly- and perfluoroalkyl substances in the aquatic environment: A review of current literature. *Water Research*, Volume 124, 1 November 2017, Pages 482-495. https://doi.org/10.1016/j.watres.2017.07.024

Yi, S, et al. 2018. Biotransformation of AFFF Component 6: 2 Fluorotelomer Thioether Amido Sulfonate Generates 6: 2 Fluorotelomer Thioether Carboxylate under Sulfate-Reducing Conditions. *Environmental Science & Technology Letters* 5, no. 5 (2018): 283-288. https://pubs.acs.org/doi/10.1021/acs.estlett.8b00148

Yuan, G. et al. 2016. Ubiquitous occurrence of fluorotelomer alcohols in eco-friendly paper-made food-contact materials and their implication for human exposure. *Environmental science & Technology*, *50*(2), 942-950. https://www.ncbi.nlm.nih.gov/pubmed/26655429