Airway Heights

Spokane County | Washington

INFORMATION TO PROTECT OUR COMMUNITIES

Per- and Polyfluoroalkyl Substances (PFAS) Exposure Assessment

REPORT

National Center
for Environmental Health
Agency for Toxic Substances
and Disease Registry

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About ATSDR

The Agency for Toxic Substances and Disease Registry (ATSDR) is a federal public health agency of the U.S. Department of Health and Human Services (HHS). ATSDR works with other agencies and state, tribal and local governments to protect communities from harmful health effects related to exposure to natural and manmade hazardous substances. For more information about ATSDR, visit https://www.atsdr.cdc.gov/.

Abbreviations

9Cl-PF3ONS	9-chlorohexadecafluoro-3-oxanone-1-sulfonic acid
11Cl-PF3OUdS	11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid
AFFF	aqueous film forming foam, also known as “A triple F”
ATSDR	Agency for Toxic Substances and Disease Registry
CDC	Centers for Disease Control and Prevention
DONA	4,8-dioxa-3H-perfluorononanoic acid
EA	exposure assessment
EPA	U.S. Environmental Protection Agency
EtFOSAA	N-ethyl perfluorooctanesulfonamidoacetic acid
FOD	frequency of detection
FtS 4:2	fluorotelomer sulfonic acid 4:2
FtS 6:2	fluorotelomer sulfonic acid 6:2
FtS 8:2	fluorotelomer sulfonic acid 8:2
HA	health advisory
HFPO-DA (GenX)	hexafluoropropylene oxide dimer acid
LOD	limit of detection
MeFOSAA	N-methyl perfluorooctanesulfonamidoacetic acid
µg/L, or ug/L	micrograms per liter (same as parts per billion or 1,000 parts per trillion)
ng/g	nanograms per gram (same as parts per billion or micrograms per kilogram)
NHANES	National Health and Nutrition Examination Survey
N-EtFOSA	N-ethyl perfluorooctanesulfonamide
N-EtFOSE	N-ethyl perfluorooctanesulfonamidoethanol
N-MeFOSA	N-methyl perfluorooctanesulfonamide
N-MeFOSE	N-methyl perfluorooctanesulfonamidoethanol
n-PFOA	linear isomer of PFOA
n-PFOS	linear isomer of PFOS
PFAS	per- and polyfluoroalkyl substances
PFBA	perfluorobutanoic acid
PFBS	perfluorobutane sulfonic acid
PFDA	perfluorodecanoic acid
PFDoA	perfluorododecanoic acid
PFDS	perfluorodecane sulfonic acid
PFDoS	perfluorododecanesulfonate
PFHpA	perfluoroheptanoic acid
PFHpS	perfluoroheptane sulfonic acid
PFHxA	perfluorohexanoic acid
PFHxS	perfluorohexane sulfonic acid
PFNA	perfluorononanoic acid
PFNS	perfluorononane sulfonic acid
PFOA	perfluorooctanoic acid

PFOS	perfluorooctane sulfonic acid
PFOSA	perfluorooctanesulfonamide
PFPeA	perfluoropentanoic acid
PFPeS	perfluoropentane sulfonic acid
PFTA	perfluorotetradecanoic acid
PFTrA	perfluorotridecanoic acid
PFUnA	perfluoroundecanoic acid
ppt	parts per trillion (same as 1 nanogram per liter)
Sb-PFOA	branched isomers of PFOA
Sm-PFOS	branched isomers of PFOS

Executive Summary

Background and Purpose

PFAS (or per- and polyfluoroalkyl substances) are a family of synthetic chemicals that have been used in industry and consumer products since the 1950s. There are thousands of different PFAS. This assessment discusses some of the most commonly studied PFAS, including perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), perfluorohexane sulfonic acid (PFHxS), perfluorononanoic acid (PFNA), perfluorodecanoic acid (PFDA), perfluoroundecanoic acid (PFUnA), and N-methyl perfluorooctanesulfonamidoacetic acid (MeFOSAA).

PFAS do not occur naturally but are widespread in the environment. They have been found in soil, water, air, and animal and plant life. Most PFAS (including PFOA, PFOS, PFHxS, and PFNA) are very resistant to breaking down or degrading into other PFAS that do not degrade further. Certain PFAS will therefore remain in the environment indefinitely. Major exposure routes for PFAS include drinking contaminated water and eating contaminated food, but exposure can also occur through other routes (e.g., ingestion of contaminated dust). Once PFAS enter people's bodies, some of them (including PFOA, PFOS, PFHxS, and PFNA) can remain in the body for long periods and can still be measured in the blood years after exposure. Most people in the United States have been exposed to PFAS. At least one PFAS was detected in more than 99% of NHANES samples collected for the 1999-2000 survey cycle.

The Centers for Disease Control and Prevention (CDC) and the Agency for Toxic Substances and Disease Registry (ATSDR) are conducting exposure assessments (EAs) in communities that were known to have PFAS in their drinking water and are near current or former military bases. This report shares results from the City of Airway Heights in Spokane County, Washington, near Fairchild Air Force Base (the Base). When all EAs are complete, ATSDR will prepare a report describing the results across all sites.

Possibly as early as the 1970s, the Base used aqueous film forming foam (AFFF) containing PFAS for its firefighter training. Over time, the PFAS from the AFFF entered the ground, moved into the groundwater to offsite locations, and affected nearby municipal wells. PFAS were first detected in the Airway Heights municipal wells in May 2017. Airway Heights authorities immediately removed the contaminated drinking water wells from service and provided bottled water to residents until drinking water could be obtained from the uncontaminated water supply in the City of Spokane. In June 2017, the City of Airway Heights declared the water safe to drink. Since 2017, Airway Heights has reactivated some of its drinking water wells with treatment systems to remove PFAS. Based on the information ATSDR has reviewed, the City of Airway Heights public drinking water supply currently meets the U.S. Environmental Protection Agency's (EPA) 2016 health advisory (HA) and state public health guidelines for PFAS in drinking water. ATSDR does not recommend that community members who get drinking water from the City of Airway Heights' public water supply use alternative sources of water.

This EA assessed PFAS levels in the blood and urine of Airway Heights residents living near Fairchild Air Force Base. Test results were compared to PFAS levels in a nationally representative sample. Tap water and indoor dust samples from a subset of households were analyzed for PFAS. These EA results will help participants and their communities better understand their PFAS exposure, allow ATSDR to provide recommendations to reduce exposure, and inform public health efforts related to protecting communities from sources of PFAS other than contaminated drinking water supplies.

ATSDR will use the data collected from this and other EAs to help inform future studies of PFAS water contamination.

Exposure Assessment Activities

ATSDR invited all Airway Heights residents who met eligibility criteria to participate in this EA. To be eligible to participate, household residents must have (1) received drinking water from the City of Airway Heights Water Department and lived west of Hayford Road for at least 1 year before June 8, 2017 (these residents have the greatest likelihood of past exposures to PFAS via the public drinking water supplies), (2) been greater than three years old at the time of sample collection, and (3) not been anemic or had a bleeding disorder that would prevent giving a blood sample.

In November 2019, 333 people (286 adults and 47 children) from 168 households participated in the EA sample collection event. ATSDR performed the following tasks:

- administered exposure history questionnaires to all participants
- collected blood and urine samples from most participants
- collected tap water and dust samples from the homes of 19 randomly selected participants
- tested for 7 PFAS in blood, 14 in urine, 18 in water, and 33 in dust[1]
- measured PFHxS, PFOS, PFOA, PFNA, PFDA, and PFUnA across all media
- mailed individual biological and environmental results to participants in May 2020

This report summarizes community PFAS blood levels, measured in serum, for the group of Airway Heights residents. In this report, when we write blood levels of PFAS, we are referring to the measurement of PFAS in the serum fraction of the blood. This report also summarizes urine sample results from a subset of participants and presents results from the dust and tap water samples. Finally, the relationships between blood results and the environmental sampling data are explored. The Airway Heights blood and urine results are compared to a nationally representative sample of the US population. Specifically, ATSDR compared Airway Heights data to those collected by CDC as part of its National Health and Nutrition Examination Survey (NHANES). The NHANES survey collects blood and urine samples from a representative sample of the civilian non-institutionalized U.S. population and tests them for chemicals, including PFAS. PFAS levels reported by NHANES are also shown by age, race/ethnicity, sex, number of years living in the community, drinking water consumption patterns, and other exposure parameters.

The samples were collected and analyzed in strict accordance with ATSDR's *Exposure Assessment Protocol: Biological and Environmental Sampling of PFAS* (EA protocol) to ensure their quality. This EA was designed to estimate geometric mean concentrations of PFOS in blood for the sampling frame (area west of Hayford Road served by the City of Airway Heights' municipal water supply) population, with a precision goal of at least 15%. The precision is a measure of how wide the confidence interval is around the estimated geometric mean. ATSDR met this goal for PFOS, and precision for all PFAS measured in this EA ranged from approximately 4% to 38%. ATSDR also calculated geometric means that were adjusted to the age distribution of the sampling frame population to correct for participation bias and to provide an estimate that is more generalizable to the sampling frame community. ATSDR also calculated geometric means that were adjusted to the national age distribution for comparison with the 2015–2016 NHANES survey. To assess possible relationships between blood levels and various demographic and exposure variables, ATSDR used statistical models. Univariate statistics, which evaluate one variable

[1] The laboratory reports branched and linear isomers of PFOA and PFOS in blood and urine. ATSDR reports on the sum of the individual isomer concentrations of PFOA and PFOS.

at a time, were used as a tool to examine the data broadly and find patterns within the data. Multivariate statistics and regression modeling were used to simultaneously account for multiple variables and to control for potential confounding factors.[2]

Spokane County Community-Wide Findings

Finding 1. Average blood levels of PFHxS, PFOS, PFOA, PFNA, and PFDA in Airway Heights EA site participants are higher than national levels.

Geometric means (i.e., averages) for PFHxS, PFOS, PFOA, PFNA, and PFDA blood levels were statistically higher ($p<0.05$) in Spokane County EA participants when compared to CDC's NHANES (2015–2016) testing, which was limited to people over 12 years old. The statistically higher blood PFAS levels were observed for both unadjusted geometric means for all EA participants and geometric means adjusted to the age distribution of the U.S. population from NHANES 2015–2016.

Of the PFAS analyzed in blood, PFHxS had the largest elevations when compared to national levels. The age-adjusted geometric mean blood PFHxS level among all EA participants was 56 times higher than the national geometric mean. Blood PFHxS levels were above the national geometric mean and above the NHANES 95th percentile for 99% of the Spokane County EA participants. Compared to national levels, the age-adjusted geometric mean blood levels among EA participants were 8.3 times higher for PFOS, 5.7 times higher for PFOA, 1.2 times higher for PFNA, and 1.3 times higher for PFDA.

PFUnA and MeFOSAA were detected in fewer than 60% of the EA participant samples; due to the large percentage of samples below the limit of detection, geometric means were not calculated.

Finding 2. Elevated blood levels of PFHxS, PFOS, and PFOA may be associated with past drinking water contamination.

Three PFAS (PFHxS, PFOS, and PFOA) with statistically elevated blood levels compared to national geometric means were detected in Airway Heights drinking water in 2017. We do not know if contamination began earlier because no data are available before 2017. The maximum concentrations observed in active drinking water wells in Airway Heights were 1,500 parts per trillion (ppt) for PFHxS, 1,200 ppt for PFOS, and 320 ppt for PFOA. In June 2017, Airway Heights changed water sources, which reduced its PFAS levels below EPA health advisory levels (70 ppt for PFOA and PFOS combined). Before 2016, PFAS-containing AFFF were primarily formulated with PFOS but also contained various PFAS precursors that could break down in the environment into other PFAS, such as PFHxS, which could explain the elevated blood PFHxS levels. PFHxS, PFOS, and PFOA have long biological half-lives (2.1 to 35 years). There were 2 years and 5 months between when Airway Heights changed water sources to reduce exposure to contaminated drinking water and collection of biological samples during the EA. Because of the long half-lives of PFHxS, PFOS, and PFOA, past drinking water exposures may have contributed to the EA participants' blood levels. PFHxS has the longest estimated half-life of the three compounds (up to 35 years), which may be why it exceeded the NHANES 2015-2016 geometric mean by the largest margin.

PFHxS, PFOS, and PFOA were highly correlated in Airway Heights residents' blood (Pearson correlation coefficient, *r*, between 0.91 and 0.96). This means that typically, residents who had elevated blood PFHxS levels also had elevated blood PFOS and blood PFOA levels. This correlation suggests a common

[2] A confounding variable is a factor that may distort or mask the relationship between a potential predictor and measure of exposure.

exposure source, such as the Airway Heights public water supply (prior to June 8, 2017), though other sources of exposure may also have contributed to the observed blood levels.

Additional observations from the multivariate analyses support the finding that past exposure to contaminated drinking water may also have contributed to the elevated blood levels.

- First, a consistent and statistically significant predictor of participant blood levels for PFHxS, PFOS, and PFOA was how long the resident had lived in Airway Heights during the past 20 years. Those who lived in the area longest likely drank, in total, a larger volume of contaminated water. For every year a participant reported having lived in Airway Heights, there was an increase in blood levels of PFHxS by 7.2%, PFOS by 5.6%, and PFOA by 3.9%.
- Second, adults who used at least one filter or treatment device had statistically lower blood levels of PFHxS (28%), PFOS (29%), and PFOA (27%) when compared to those who did not have a filter.
- Third, adults who reported mainly drinking tap water at home on average had statistically higher blood levels of PFHxS (29%) and PFOS (25%) when compared to those who reported mainly drinking bottled water.

PFNA and PFDA blood levels in Spokane County EA participants were also statistically elevated compared to the U.S. population. Blood levels for these PFAS were not as closely correlated to blood levels for the other three PFAS (PFHxS, PFOS, and PFOA). This suggests that drinking water contamination may not have been as strong a predictor of exposure for PFNA and PFDA.

Finding 3. Age, sex, race and ethnicity, stain-resistant product use, blood donation frequency, fast food consumption, and child births were associated with some PFAS blood levels.

PFAS blood levels varied with different demographic and exposure characteristics of the participant population. The following relationships were statistically significant in multivariate analyses in the Spokane County EA data set in adult participants (and are consistent with those reported in other non-ATSDR PFAS studies, except where noted below for fast food consumption):

- Blood levels of PFHxS, PFOS, and PFOA were higher in older participants. Blood levels of these compounds increased by 1.1% to 1.8% for every year of participant age.
- Males had higher blood levels of PFNA than females. Blood levels in adult males were 77% higher for PFNA.
- On average, adult participants who identified as non-White or Hispanic had higher blood PFNA (37%) and PFDA (33%) levels than adult participants who identified as White and non-Hispanic.
- Only 24 participants reported ever using stain resistant products, and most of these reported their frequency of use as “rarely.” Participants who reported ever using stain-resistant products had 26% higher blood levels of PFDA than those who reported never using these products. Because of the small sample size for people who ever used stain resistant products, these results should be interpreted with caution.
- Only 17 participants reported donating blood at least once or more a year. Participants who reported donating blood at least once or more a year had lower blood levels of PFHxS (67%), PFOA (60%), and PFNA (49%) than adult participants who reported never or rarely donating blood. Because of the small sample size for people who reported donating blood once or more a year, these results should be interpreted with caution.

- Participants who reported more fast food consumption had lower PFHxS, PFOS, PFOA, PFNA, and PFDA blood levels. Participants who reported eating fast food a few times per month on average had lower blood PFHxS (43%), PFOS (41%), PFOA (36%), and PFNA (24%) levels compared to participants who reported eating fast food a few times per year or less. This effect was stronger for participants who reported eating fast food three times per week or more. This finding differs from other studies and may be due to differences in diet and lifestyle correlated with fast food consumption. This finding does not mean that eating more fast food will reduce exposure to PFAS.
- Female participants' blood levels for some PFAS decreased with increasing number of children they had given birth to. This effect was observed for blood levels of PFHxS (11.7% reduction in blood levels per child), PFOS (9.3% per child), PFOA (13.7% per child), and PFNA (8.1% per child).

Two associations were observed in children (<18 years), though many variables could not be examined because of the small number of child participants (n=47). Because of the small sample size, results should be interpreted with caution. Specifically, children who were breastfed had 59% higher blood levels of PFNA than non-breastfed children. Second, children who drank formula prepared with tap water had significantly higher serum levels of PFHxS (2.2% per month on formula) and PFOS (1.5% per month on formula) than children who never drank formula prepared with tap water. Infants born to mothers exposed to PFAS can be exposed in utero and while breastfeeding. However, based on current science, the benefits of breastfeeding outweigh the risks for infants exposed to PFAS in breast milk. The final report on all EA sites will include a more robust analysis of children.

Finding 4. Only two PFAS were detected in urine.

ATSDR analyzed 34 (10%) of the urine samples collected. Only perfluorobutanoic acid (PFBA) and PFHxS were detected; they were detected in 53% and 26%, respectively, of the 34 samples analyzed. ATSDR did not analyze all participants' urine samples because none of the species were detected in more than 60% of the samples analyzed.

Finding 5. All Airway Heights tap water samples collected during the EA in 2019 met the EPA's HA and Washington state public health guidelines for PFAS in drinking water.

This is based on 19 unfiltered and 7 filtered tap water samples collected in 19 households during the EA.

Finding 6. Patterns and levels of dust contamination measured in participating EA households are comparable to those reported in selected U.S. studies.

Among the PFAS detected most frequently in household dust samples, PFOS, PFOA, and PFHxA were measured at the highest concentrations. No nationally representative comparison values are available, but geometric mean and median concentrations for PFAS measured in dust collected in a small subset of participating households (n=19) were within the range of levels reported in a few published studies of other U.S. communities (with or without known PFAS contamination). None of the PFAS measured in this EA's household dust samples were statistically correlated with the same PFAS measured in participants' blood. The final report on all EA sites will include a more robust comparison of PFAS measured in dust and blood.

Limitations

There are several limitations associated with this assessment.

- The EA participant sample may not be representative of the community. All households in the study area were invited to participate, and 7% participated in the EA. Participant characteristics

were different than those of the area's overall population. Participants were older and more likely to identify as White. ATSDR addressed some of these differences by calculating geometric mean estimates that were adjusted to the age distribution of the community.

- Measurement of blood, urine, and environmental PFAS concentrations for EA participants may improve the understanding of exposure in this community but will not provide information about all sources of exposure. Additionally, identifying every potential confounding exposure is not possible.
- There are challenges in measurement of trace levels of PFBA in urine, including selectivity of the analytical instrumentation and potential for external contamination. Therefore, we advise caution when interpreting the PFBA results in urine.
- Multivariate regression models did not explain a large portion of the variability in participants' blood PFAS levels (R-squared or R^2, a measure of model goodness-of-fit, ranged between 0.30 and 0.40). This means that other factors not identified could influence the relationships reported in this assessment (see "Statistical Analysis" section for details).
- This study did not directly assess participants' tap water consumption prior to the reduction of PFAS in the municipal water system.
- This EA was not designed to investigate health outcomes. Without additional information about exposure-response relationships, the results of this EA cannot be used to assess current or past health problems or predict the future occurrence of disease. PFAS found in a person's blood or urine means that exposure has occurred. The presence of PFAS in blood or urine does not tell us how, where, when, or for how long a person was exposed to PFAS. Exposure to PFAS does not mean adverse health effects will result, either now or in the future.
- The dust results are exploratory and should be interpreted with caution. They are based on a limited set of samples, and in some cases those samples are based on a small sample mass.

Recommendations

This PFAS EA provides evidence that past exposures to PFAS in drinking water have impacted the levels of PFAS in people's bodies. These PFAS are eliminated from the body over a long period of time. This allowed ATSDR to measure PFAS even though exposures through drinking water were mitigated, or lowered, years ago.

Although the exposure contribution from PFAS in public drinking water in Airway Heights has been mitigated, there are actions community members and city officials can take to further reduce exposures to PFAS and protect public health.

Based on the PFAS drinking water test results from the City of Airway Heights' municipal water system, ATSDR does not recommend an alternate source of drinking water at this time.

1. What the City of Airway Heights can/should do:
    a. Operators of the municipal water system should continue to monitor concentrations of PFAS in drinking water delivered to the Airway Heights community to ensure that concentrations of PFAS remain below the EPA's HA and Washington state health guidelines for specific PFAS in drinking water. Results of PFAS monitoring should be shared with community members through appropriate communication channels (Consumer Confidence Reports: http://www.cawh.org/departments/public-works/water-reports).

b. All treatment systems to remove PFAS from the public drinking water in Airway Heights should be maintained appropriately to ensure that PFAS concentrations remain below the EPA's HA and Washington state health guidelines for specific PFAS in drinking water.

2. What community members can/should do:
   a. Become familiar with Consumer Confidence Reports (http://www.cawh.org/departments/public-works/water-reports) for information on the City of Airway Heights' water quality.
   b. Private well owners living in the area affected by PFAS should consider having their wells tested for PFAS if testing has not been conducted before. To learn more about testing wells for PFAS visit: https://ecology.wa.gov/Water-Shorelines/Water-supply/Wells/Testing-drinking-water. Global public health organization NSF International has developed a test method to verify a water filter's ability to reduce PFOA and PFOS to below the health advisory levels set by the EPA. NSF International-approved devices can be found at: https://info.nsf.org/Certified/DWTU/. Click on "reduction devices" at the bottom of the page for PFOA and PFOS.
   c. Nursing mothers should continue breastfeeding. Based on current science, the known benefits of breastfeeding outweigh the potential risks for infants exposed to PFAS in breast milk.
   d. When possible, eliminate or decrease potential exposure to PFAS in consumer products, such as stain-resistant products and food packaging materials. To learn more, visit: https://www.fda.gov/food/chemical-contaminants-food/questions-and-answers-pfas-food.
   e. Pay attention to advisories about food consumption, such as local fish advisories.
   f. Discuss any health concerns or symptoms with your health care provider. Share results of PFAS blood testing with your health care provider and make them aware of ATSDR resources for clinicians (https://www.atsdr.cdc.gov/pfas/resources/info-for-health-professionals.html). Follow the advice of your health care provider and the recommendations for checkups, vaccinations, and health screening tests.
   g. At this time, ATSDR does not have plans to conduct additional blood testing for PFAS or recommend PFAS EA participants get individually retested for PFAS in blood.
      - The biological half-lives of many of the PFAS measured in people's blood are long. PFHxS, in particular, has one of the longest half-lives–some estimates range in the decades. This means that PFAS blood levels are not expected to change significantly in the near term, even if exposure stops. Additionally, it is unclear what an individual's PFAS test results mean in terms of possible health effects.

      For the general population, blood tests for PFAS are most useful when they are part of a scientific investigation like the EA. Test results tell you how much of each PFAS is in your blood, but it is unclear what the results mean in terms of possible health effects. In addition, blood testing for PFAS is not a routine test offered by most doctors or health departments. If you are concerned about the effect of PFAS on your health, talk to your health care provider and make them aware of ATSDR resources for clinicians (https://www.atsdr.cdc.gov/pfas/resources/info-for-health-professionals.html).
   h. Follow the advice of your child's health care provider and the recommendations for well child checkups, vaccinations, and recommended health screening tests. Consult https://health.gov/myhealthfinder to help identify those vaccinations and tests.

i. For additional information about environmental exposures and children's health, contact the Pediatric Environmental Health Specialty Units, a nationwide network of experts in reproductive and children's environmental health (https://www.pehsu.net/).

For More Information

If you have questions or comments or want more information on the Spokane County (Airway Heights) EA site, call 800-CDC-INFO or email pfas@cdc.gov. For more information on the work CDC/ATSDR is doing to address PFAS exposure, visit ATSDR's PFAS website: https://www.atsdr.cdc.gov/pfas/. For other EA or PFAS-related questions, email pfas@cdc.gov.

Background and Purpose

The Centers for Disease Control and Prevention (CDC) and the Agency for Toxic Substances and Disease Registry (ATSDR) are conducting exposure assessments (EAs) in communities near current or former military bases that are known to have had per- and polyfluoroalkyl substances (PFAS) in their drinking water. One of these communities is the City of Airway Heights in Spokane County, Washington. This report summarizes the findings of the Spokane County EA. When all EAs are complete, ATSDR will prepare a report describing the results across all sites.

EA participants were recruited among Airway Heights residents living near the Fairchild Air Force Base, west of Hayford Road, who received drinking water from the Airway Heights Water Department that had PFAS levels above state or federal guidelines. For more information and a map of the area see the "Methods" section of the report.

The EA involved collecting responses to exposure history questionnaires, biological samples (blood and urine), and environmental samples (tap water and household dust). ATSDR collected biological samples and administered questionnaires at the Airway Heights Community Center in Airway Heights between November 4 and November 14, 2019. During the same time frame, ATSDR also took water and dust samples in a subset of randomly chosen participant homes.

The results of the EA

- tell us the amount of PFAS in the blood of individual participants and the Airway Heights community and how these levels compare to the general U.S. population,
- tell us the amount of PFAS in the urine of a subset of individual participants and the EA community and how these levels compare to the general U.S. population,
- provide a better understanding of environmental factors that affect PFAS exposure,
- provide information that may be used to stop or reduce PFAS exposure,
- produce information that public health professionals can use to help communities affected by PFAS, and
- inform future studies looking at the effect of PFAS exposure on human health.

The EA does not look at what types of health problems are associated with exposure and is not meant to determine if PFAS levels in blood or urine are risk factors for illness now or later in life. Additionally, the EA does not tell us exactly how or where people were exposed or when or how long PFAS exposure lasted.

ATSDR's *Exposure Assessment Protocol: Biological and Environmental Sampling of PFAS,* termed the PFAS EA Protocol [ATSDR 2019a], provides additional background, describes the criteria for selecting communities for the EAs, and highlights the procedures ATSDR used in conducting the EAs.

What Are PFAS?

Human exposure to PFAS is a growing environmental health concern. PFAS are synthetic chemicals used in many industries and consumer products since the 1950s. They have been used in nonstick cookware; water-repellent clothing; stain-resistant fabrics and carpets; cosmetics; firefighting foams; and products that resist grease, water, and oil [Buck et al. 2011; Gluge et al. 2020; Wang et al. 2017]. Exposure to PFAS has been associated with increased cholesterol, decreased vaccine response in children, changes in

liver enzymes, small decreases in infant birth weights, increased risk of high blood pressure or pre-eclampsia in pregnant women, and increased risk of kidney and testicular cancer [ATSDR 2021].

There are thousands of different PFAS. This assessment discusses some of the most commonly studied PFAS, which include perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), perfluorohexane sulfonic acid (PFHxS), perfluorononanoic acid (PFNA), perfluorodecanoic acid (PFDA), and perfluoroundecanoic acid (PFUnA). The manufacture and import of PFOA, precursor chemicals that can break down to PFOA, and related higher homologue chemicals, have been mostly phased out in the United States. However, existing stocks of PFOA might still be used, and there might be PFOA in some imported articles. PFOS manufacture in the United States has not been reported to the EPA since 2002; however, there are some limited ongoing uses of PFOS. These PFAS with long perfluoroalkyl chains are no longer produced in the United States because of concerns over their high persistence, tendency to bioaccumulate, and potential risks to human health and the environment. Other countries may still manufacture and use them, but U.S. manufacturers have replaced these compounds with shorter chained PFAS, or chemicals with alternative chemistries, such as GenX (HFPO-DA) which typically have shorter biological half-lives. Some of the PFAS discussed in this report, such as N-methyl perfluorooctanesulfonamidoacetic acid (MeFOSAA), are considered precursors that can degrade in the environment or in people to other PFAS [ATSDR 2021; Wang et al. 2017].

PFAS do not occur naturally but are widespread in the environment. PFAS can be released into the environment during their production, use, or disposal. PFAS have been found in air, water, soil, sediment, animal and plant life, and air. Most PFAS (including PFOA, PFOS, PFHxS, and PFNA) are either very resistant to breaking down or degrade into other PFAS that do not degrade further. Certain PFAS will therefore remain in the environment indefinitely. Most people in the United States have been exposed to PFAS. At least one PFAS was detected in more than 99% of NHANES samples (1999-2000 survey cycle) [Calafat et al. 2007a]. Exposure can occur via contaminated drinking water for which ingestion is believed to be the primary exposure route. Studies have shown that showering, bathing, and swimming in water containing PFAS at levels seen in Spokane County are not expected to be an important contributor to PFAS exposure relative to the contribution from drinking water [Sunderland 2019].

ATSDR's PFAS EAs focused on communities with known exposures via contaminated drinking water. However, residents may have had additional exposures to PFAS, such as the following [Sunderland 2019]:

- eating food packaged in materials containing PFAS (e.g., popcorn bags, fast food containers, pizza boxes)
- eating fish or shellfish caught in PFAS-contaminated waters
- using consumer products such as stain-resistant carpeting and water-repellent clothing
- eating garden vegetables grown with PFAS-contaminated water or soil
- accidentally swallowing PFAS-contaminated soil
- drinking infant formula mixed with PFAS-contaminated water
- consuming breastmilk from women exposed to PFAS
- gestational exposure to PFAS
- working in industries that manufacture, process, or use products containing PFAS
- background exposure to PFAS due to their ubiquitous nature

ATSDR asked study participants about these types of potential exposures to evaluate whether these exposures might influence PFAS levels in the EA communities.

After PFAS enter the human body, some PFAS can remain there for a long time. Some studies estimate that the half-life of PFHxS is between 4.7 and 35 years [ATSDR 2021]. Half-life estimates range from 3.3 to 27 years for PFOS and from 2.1 to 10.1 years for PFOA [ATSDR 2021].

The body of science about PFAS exposure and health effects is growing rapidly. Some, but not all, scientific studies have shown that exposure to certain PFAS may be linked to harmful health effects. While this EA does not examine specific health outcomes associated with PFAS exposure, EA findings might help inform future studies on how PFAS exposure affects human health.

Why Spokane County?

Airway Heights, in Spokane County, was one of several sites located near military installations with identified PFAS drinking water contamination from use of products such as aqueous film forming foam (AFFF). When selecting EA sites, ATSDR considered the extent of PFOA and PFOS contamination in drinking water supplies, the duration over which exposure may have occurred, and the number of potentially affected residents.[3]

PFAS and precursors that degrade to other compounds measured in this EA were used in historical AFFF formulations. Two types of PFAS-containing AFFF were manufactured before 2016 [ITRC 2020]. Both formulations contained PFAS or PFAS precursors, the use of which resulted in the release of PFOS, PFHxS, PFOA, and PFHxA into the environment. Possibly as early as the 1970s, the Fairchild Air Force Base used AFFF containing PFAS for its firefighter training [AFCEC 2015]. Over time, the PFAS from the AFFF moved off site in groundwater and contaminated nearby municipal wells.

When PFAS first entered Airway Heights' public water system is not known. These substances were first detected in the city's water in May 2017, through testing conducted by the Air Force. This sampling was conducted following site inspections at the Base that found PFAS contamination in local groundwater. At that time, drinking water provided by the Airway Heights Water Department came from three groundwater wells and a connection with the City of Spokane. Air Force testing indicated that all of Airway Heights' three active drinking water wells were contaminated with PFAS. The highest sampling result from an active well was 1,520 parts per trillion (ppt) for the sum of PFOA (320 ppt) and PFOS (1,200 ppt). PFHxS was also detected in this well at a concentration of 1,500 ppt. PFAS were not detected in the City of Spokane's drinking water source.

The levels measured in 2017 by the Air Force were above EPA's HA for the sum of PFOA and PFOS levels in drinking water (70 ppt). To reduce concentrations of PFOA and PFOS in drinking water, the Airway Heights Water Department immediately removed the contaminated drinking water supply wells from service, flushed the water lines, placed temporary restrictions on use of water for drinking and cooking, and distributed bottled water to residents. The City of Airway Heights also secured an alternate source of uncontaminated drinking water through interconnections with the City of Spokane. In June 2017, the City declared the water safe to drink. In 2018, the City of Airway Heights installed granular activated

[3] PFHxS data were not available for all sites evaluated so were not considered in the site selection process even though water contaminated by AFFF often has higher concentrations of PFHxS than PFOA or PFOS.

carbon (GAC) treatment on one of its wells, and now this well is only used to meet peak demands during summer months.

The information available to ATSDR indicates that in 2019, the public drinking water supplies in the cities of Airway Heights and Spokane met or were below the EPA's HA and Washington state action levels[4] for PFAS in drinking water.

Methods

ATSDR's PFAS EA protocol [ATSDR 2019a] details the approaches used to recruit participants, collect samples, administer exposure history questionnaires, and evaluate data. This section briefly describes how those methods were applied to the Spokane County EA.

Sampling Frame

This EA targeted a specific geographic area, called the sampling frame or sampling area. The sampling frame for this EA was the part of Airway Heights that lies west of Hayford Road, where the highest PFAS contamination levels in tap water likely occurred (see Figure 1). Based on a review of Airway Heights land parcel data, ATSDR determined that 2,516 households in the sampling frame were connected to the city's water supply. These households formed the sampling frame from which households were invited to participate. Households with private wells were not invited to participate. Private well owners living in the area affected by PFAS should consider having their wells tested for PFAS if testing has not been conducted before. To learn more about testing wells for PFAS visit: https://ecology.wa.gov/Water-Shorelines/Water-supply/Wells/Testing-drinking-water.

Participant Eligibility

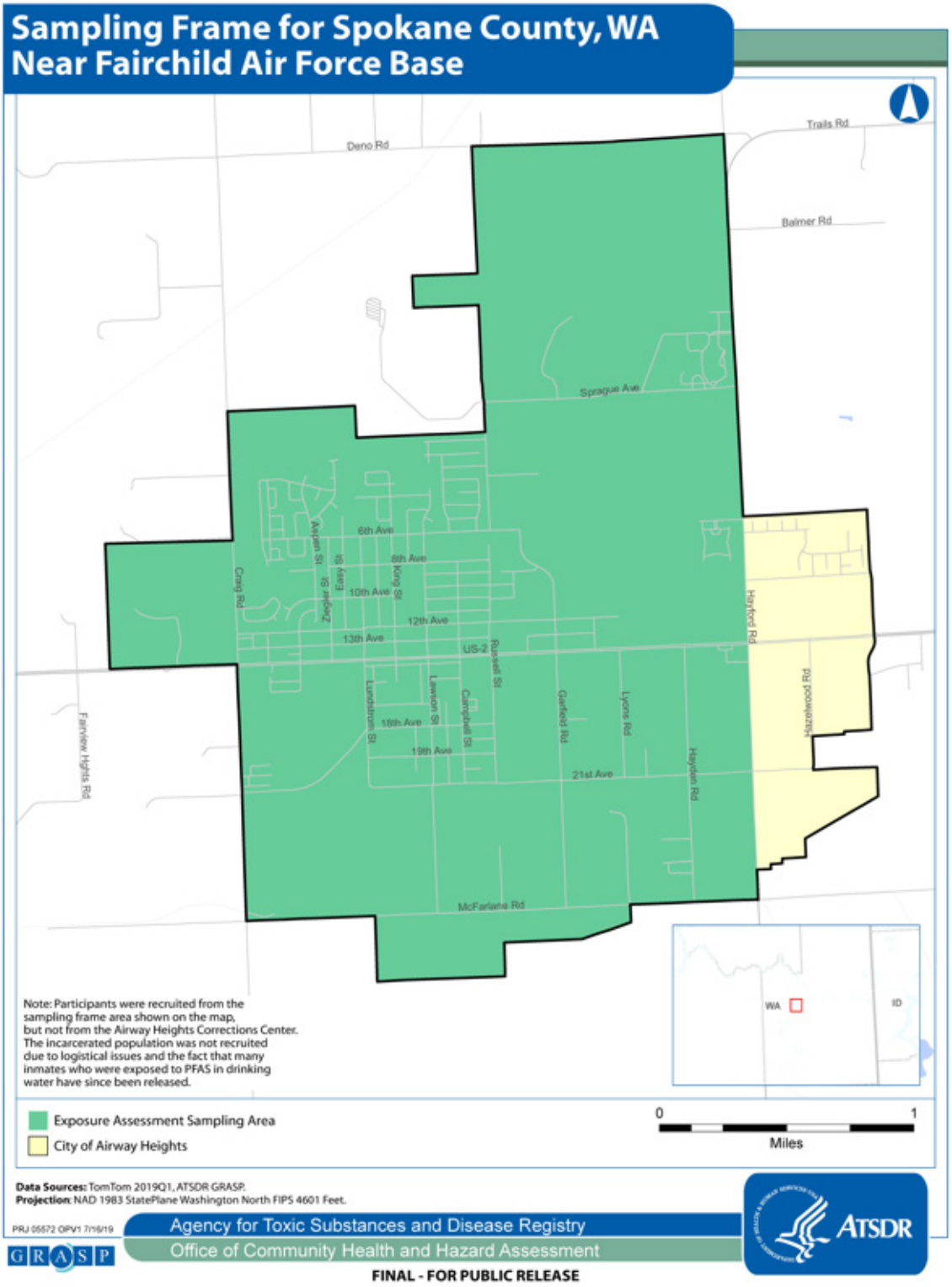
Airway Heights residents who met the following criteria were eligible to participate in the EA:

- Lived within the sampling frame (served by Airway Heights Water Department and west of Hayford Road) for at least one year before June 8, 2017, which is when the City of Airway Heights Water Department reduced PFAS drinking water concentrations below EPA's health advisory.
- Were at least 3 years old at the time of recruitment. This age criterion was used because national reference values are not available for children under the age of three.
- Did not have bleeding disorders and were not anemic, unless they confirmed with their doctor the ability to safely provide a blood sample.

People potentially exposed to PFAS occupationally such as firefighters, active-duty military, and veterans, were able to participate if they met the three eligibility criteria. Participants did not receive incentives and paid no costs to participate.

[4] The State of Washington Board of Health adopted a new rule (effective January 1, 2022) that includes state action levels (SAL) for five PFAS found in Washington state drinking water (PFOA, PFOS, PFHxS, PFNA, PFBS).

Figure 1. Sampling frame for Spokane County Exposure Assessment



Participant Recruitment

ATSDR invited all 2,516 households in the sampling frame to participate. All households were chosen to attempt to achieve the protocol recruitment target of 395 participants. All members of each household who met eligibility criteria were invited to participate.

Recruitment was done through mailings, phone calls, and in-person visits to households that had not been reached by phone. Each household for which ATSDR had a phone number received a minimum of three recruitment call attempts. In each attempt, ATSDR called all working phone numbers (cellphone and landline) associated with a household. For calls that went to voicemail, ATSDR staff left messages encouraging residents to call back to schedule appointments. Door-to-door recruitment occurred after each household had received an initial outreach letter and at least one recruitment call attempt. After recruitment, 391 residents from 194 households scheduled appointments for biological sampling and questionnaire completion.

ATSDR attempted to recruit approximately 10% of participating households for environmental sampling (i.e., 20 households from which at least one person had scheduled an appointment at the time environmental recruitment calls were made). ATSDR invited 39 households in two waves of recruitment. In total, ATSDR scheduled 20 environmental sampling appointments.

Data Collection and Analysis

The Spokane County EA involved collection of three types of data: questionnaires, biological samples (blood and urine), and environmental samples (tap water and household dust). The ATSDR project team collected biological samples and administered questionnaires at the Airway Heights Community Center in Airway Heights between November 4 and November 14, 2019. During the same time frame, ATSDR collected environmental samples in a subset of randomly chosen participant homes. All data met the stringent quality control requirements for sample collection and analysis.

Before any data collection, ATSDR obtained written consent from the participants. The purpose of the consent process was to ensure participants were fully aware of the purpose of the EA, sample collection procedures, benefits and risks of participating, and privacy protections. Copies of consent forms are included in the PFAS EA Protocol.

ATSDR project staff handled all data collected in accordance with the *Standard Operating Procedures of PFAS Exposure Assessment Data Management* [ATSDR 2019b]. These procedures have very strict requirements for handling any personally identifiable information. ATSDR project staff protected this information to the extent required by federal and Washington law. All signed consent forms were mailed to and are securely archived at ATSDR headquarters. Questionnaire data were collected using dedicated encrypted laptops with no internet access, and these data were transferred at program completion to ATSDR's secure data network. All information provided by participants was kept confidential, and no personally identifiable information appears in any of ATSDR's public reports for this site.

Table 1, at the end of this section, provides more details on the number of participants enrolled and the final number of samples collected during this EA. Table 2 lists the PFAS measured in the EA's biological and environmental samples.

Biological Sampling and Questionnaire Administration

Of the 391 residents who scheduled data collection appointments, 349 (89%) participated in the EA. ATSDR administered exposure history questionnaires to these 349 individuals: 302 adults 18 and older, and 47 children between the ages of 3 and 17. ATSDR used one questionnaire for adults and another for children. Both addressed topics relevant to PFAS exposure, such as residential and work histories, drinking water habits, and use of PFAS-containing consumer products.

Phlebotomists collected blood samples from all 349 participants. ATSDR processed the blood samples in the field, aliquoting the serum portion of the blood.

After the sampling was complete and upon further review of each participant's residential history, ATSDR determined that 16 participants had not lived in the sampling frame for at least one full year before June 8, 2017, and therefore were not eligible for the study. Questionnaire and biological data for these participants were excluded from the data evaluation, but ATSDR sent them their individual results. This means that a total of 333 blood samples (286 adults and 47 children) were considered in the community exposure summary. These samples were collected from participants residing in 168 unique households. This represents a household participation rate of 6.7% (i.e., 6.7% of the 2,516 recruited households had at least one person participate in the EA).

Urine samples were collected from 346 participants (301 adults and 45 children). Per the EA protocol, 10% of the urine samples were randomly selected for initial analysis. ATSDR randomly selected 35 samples for analysis, but one participant was later deemed ineligible. These 34 samples were collected from participants (32 adults and 2 children) who resided in 33 unique households.

CDC's National Center for Environmental Health laboratory analyzed the serum portion of blood and urine samples for the suite of PFAS measured in the 2015–2016 National Health and Nutrition Examination Survey (NHANES) [CDC 2019]. As part of NHANES, CDC takes biological samples and tests them for chemicals, including PFAS, from a representative sample of 5,000 people across the country during each two-year cycle. All laboratory analyses followed established procedures for quality assurance and control according to the Center's methodology.

During the consent process, participants were given the option to allow ATSDR to store biological samples for potential future PFAS analysis. Blood and urine samples from participants who provided this consent are being stored frozen at CDC for potential future analysis.

Environmental Sampling

ATSDR collected tap water and dust samples from 19 of the 20 households that had scheduled appointments. One household was unavailable to complete their scheduled environmental sampling appointment. At each participating household, ATSDR collected a drinking water sample from the kitchen tap. If point-of-use filtration was in place, ATSDR project staff attempted to collect a sample before and after filtration. Tap water samples were collected and analyzed in accordance with EPA's *Method 537.1: Determination of Selected Per- and Polyfluorinated Alkyl Substances in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry* [Shoemaker and Tettenhorst 2018].

Project staff also collected a composite dust sample from the floor at a minimum of three locations inside each selected home: the primary living space as identified by the homeowner (e.g., living room, family room, television room), the kitchen, and the bedroom in which participants reported spending the most time. Dust collection was intended to generate more information about the contribution of

non-drinking-water exposures to overall PFAS exposure. Participants were instructed not to vacuum carpeting or sweep floors for five days prior to the scheduled visit. Adapting methods described in Scher et al. [2018], ATSDR collected dust samples using a high-volume air sampler connected to an open-faced 37 millimeter filter cassette with an 0.8 micron filter. A wooden 2 square foot (ft^2) sampling template was used to mark off each sampling area. ATSDR project staff attempted to collect at least 1 gram of dust in the open-faced cassettes from each home by vacuuming the same 2 ft^2 surface at least four times with the cassette (vertically, horizontally, and in circles). Samples were taken preferentially from mats, carpets, and area rugs. Household dust samples were analyzed in accordance with SGS AXYS Method MLA-110 (revision 01, version 06), *Analytical Procedure for the Analysis of Per- and Polyfluoroalkyl Substances (PFAS) in Aqueous Samples, Solids and Solvent Extracts by LC-MS/MS* [SGS AXYS 2019].

The environmental samples collected during the EA were consumed in the analytical process and are not available for potential future analysis.

Table 1. Summary of recruitment and data collection efforts

Recruitment	
Households invited to participate by mail	2,516
Households reached by mail	1,805
Households reached by phone	626
Household door-to-door visits	2,166
Biological sampling:	
Individuals enrolled	391
Households enrolled	194
Environmental sampling:	
Wave 1 households invited	*32*
Wave 2 households invited	*7*
Households enrolled	20
Data Collection	
Completed questionnaires	349
Adults	*302*
Children	*47*
Blood samples	
Included in community statistics (168 households)	333
Adults	*286*
Children	*47*
Urine samples	
Collected	346
Adults	*301*
Children	*45*
Included in community statistics (33 households)	34
Adults	*32*
Children	*2*
Dust samples collected and analyzed (one composite sample per household)	19
Tap water samples collected and analyzed (19 households)	26
Filtered	7
Unfiltered	19

Table 2. List of PFAS measured for in blood, urine, tap water, and dust

PFAS Abbreviation	PFAS Chemical Name	Measured in Blood?	Measured in Urine?	Measured in Water?	Measured in Dust?
PFBS	perfluorobutane sulfonic acid		✓	✓	✓
PFPeS	perfluoropentane sulfonic acid				✓
PFHxS	perfluorohexane sulfonic acid	✓	✓	✓	✓
PFHpS	perfluoroheptane sulfonic acid				✓
PFOS	perfluorooctane sulfonic acid	✓	✓	✓	✓
n-PFOS	sodium perfluoro-1-octanesulfonate	✓	✓		
Sm-PFOS	mixture of sodium perfluoro-5-methylheptane sulfonate isomers	✓	✓		
PFNS	perfluorononane sulfonic acid				✓
PFDS	perfluorodecane sulfonic acid				✓
PFDoS	perfluorododecanesulfonate				✓
PFBA	perfluorobutanoic acid		✓		✓
PFPeA	perfluoropentanoic acid		✓		✓
PFHxA	perfluorohexanoic acid		✓	✓	✓
PFHpA	perfluoroheptanoic acid		✓	✓	✓
PFOA	perfluorooctanoic acid	✓	✓	✓	✓
n-PFOA	ammonium perfluorooctanoate	✓	✓		
Sb-PFOA	mixture of perfluoro-5-methylheptanoic acid isomers	✓	✓		
PFNA	perfluorononanoic acid	✓	✓	✓	✓
PFDA	perfluorodecanoic acid	✓	✓	✓	✓
PFUnA	perfluoroundecanoic acid	✓	✓	✓	✓
PFDoA	perfluorododecanoic acid			✓	✓
PFTrA	perfluorotridecanoic acid			✓	✓
PFTA	perfluorotetradecanoic acid			✓	✓
PFOSA	perfluorooctanesulfonamide				✓
N-MeFOSA	N-methylperfluorooctanesulfonamide				✓
MeFOSAA	N-methyl perfluorooctanesulfonamidoacetic acid	✓		✓	✓
N-MeFOSE	N-methylperfluorooctanesulfonamidoethanol				✓
N-EtFOSA	N-ethylperfluorooctanesulfonamide				✓
N-EtFOSAA	N-ethyl perfluorooctanesulfonamidoacetic acid			✓	✓
N-EtFOSE	N-ethylperfluorooctanesulfonamidoethanol				✓
FtS 4:2	fluorotelomer sulfonic acid 4:2				✓
FtS 6:2	fluorotelomer sulfonic acid 6:2				✓
FtS 8:2	fluorotelomer sulfonic acid 8:2				✓
HFPO-DA (GenX)	hexafluoropropylene oxide dimer acid		✓	✓	✓
DONA	4,8-dioxa-3H-perfluorononanoic acid		✓	✓	✓
9Cl-PF3ONS	9-chlorohexadecafluoro-3-oxanone-1-sulfonic acid		✓	✓	✓
11Cl-PF3OUdS	11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid			✓	✓

Statistical Analysis

The EA Protocol describes the statistical methods used. Briefly, the data objectives of this EA were to (1) estimate geometric mean concentrations of PFAS in the sampling frame population (with a precision target of at least 15% and a 5% level of significance for PFOS), (2) compare community level data to national levels, and (3) explore relationships between questionnaire data and measured biological and environmental data.

ATSDR processed the PFAS sampling results in two ways before performing statistical analyses:

- First, ATSDR substituted all non-detect observations with a value equal to the limit of detection (LOD) divided by the square root of 2. (A non-detect result means the sample did not contain enough PFAS to be reliably measured by this project's highly sensitive laboratory methods.) This substitution method is consistent with that applied in CDC's NHANES. Note that Appendix B provides the results of a sensitivity analysis exploring alternate substitution approaches.
- Second, ATSDR calculated the total PFOA and total PFOS concentrations measured in each blood and urine sample. The laboratory reports two different measurements for PFOA and PFOS. For PFOA, the laboratory reports the amount of branched PFOA (Sb-PFOA) measured in the sample separate from the amount of linear PFOA (n-PFOA) in the same sample. ATSDR summed these values and performed statistical analyses using total PFOA results. Similarly, ATSDR calculated total PFOS by summing the linear PFOS (n-PFOS) and branched PFOS (Sm-PFOS) concentrations. These same summation methods are applied to NHANES data.

For blood and urine, ATSDR first calculated summary statistics for each PFAS (i.e., frequency of detection, maximum detected concentration, geometric mean, 95% confidence intervals around the geometric mean, and 25th, 50th [median], 75th, 90th, and 95th percentiles). The protocol specified that geometric means would be calculated if >=60% of samples had detections.

Statistical Terms

Geometric mean: The geometric mean is a type of average and provides an estimate of the central point of a set of numbers. It is often used for environmental data that exhibit a skewed distribution (e.g., a data set with several values that are much higher than the rest of the results). The geometric mean is less influenced by high values than an arithmetic mean.

Percentiles (25th, 50th, 75th, 90th, 95th): A percentile provides additional information about the distribution of a data set and represents the value below which a certain percentage of the data fall. For example, a 95th percentile of 25 micrograms per liter (µg/L) indicates that 95% of results fall below this concentration.

Confidence intervals: A confidence interval provides information about the reliability of a statistic. In this EA, ATSDR estimated geometric means for the PFAS blood levels measured among study participants. The 95% confidence interval around the geometric mean represents the range within which the true population mean is expected to lie. More specifically, if we hypothetically repeated the study 100 times, the true mean of the sampling frame population would fall within the confidence intervals in 95 out of 100 repetitions.

Precision: Precision provides information on the reproducibility of a study and is associated with sample size. The larger the sample size the higher the precision. In the context of this EA, precision was estimated based on the width of confidence intervals around the geometric mean. A wide confidence interval indicates low precision while a narrow confidence interval suggests high precision.

Geometric means were calculated as the measures of central tendency because of the lognormal distribution of blood and urine measurements. Note that many of the statistics could not be calculated for urine due to the low detection frequency.

One of the objectives of this EA was to estimate community-level exposures. ATSDR evaluated demographic differences between the Spokane County EA participants and all residents in the sampling frame. This was done for age, race, and ethnicity using a two-sample test for equality of proportions. To correct for participation bias, ATSDR also calculated geometric means adjusted to the age distribution of the sampling frame population using 2010 Census block data.

ATSDR compared community-level statistics for PFAS in blood to national PFAS data reported by CDC in the 2015–2016 NHANES (i.e., for the EA sample population 12 years of age and older). To control for differences in the age distribution, the EA geometric means were adjusted to the age distribution of the U.S. population during NHANES 2015–2016. Note that NHANES 2017-2018 data were not available at the time this report was originally drafted. For urine, ATSDR compared community-level data to national-level data from the 2013–2014 NHANES compiled by Calafat et al. [2019], the only nationally representative data available for PFAS in urine. ATSDR relied on two sample t-tests for these comparisons, using a p-value of less than 0.05 to identify statistically significant differences.

A **p-value** helps determine the significance of the results of a statistical test, such as the difference between two means. The lower the p-value the more likely the observed difference is not due chance alone. In this report, a p-value of less than 0.05 ($p<0.05$) is described as *statistically significant*.

ATSDR then used information gathered in the exposure questionnaire to understand and quantify how demographic data and other exposure characteristics relate to PFAS measurements in blood. For this, ATSDR relied on self-reported information, such as age, race/ethnicity, sex, length of residency in the sampling frame, tap water and food consumption patterns, and work/school history. All numerical responses were treated as continuous variables. In some cases, categorical variables were collapsed when there were too few responses (<10) in a given category. In order to explore sex-specific associations (e.g., women having biological children [yes/no], having breastfed children [yes/no], duration of breastfeeding), ATSDR also evaluated multivariate models for males and females only.

ATSDR did not conduct detailed statistical analyses for urine data because of low frequencies of detection. ATSDR analyzed a subset of urine samples and found that, for all PFAS, the frequency of detection was <60%. The protocol specified that all urine samples would be analyzed if the geometric mean calculated for any site exceeded the 95th percentile from NHANES. The protocol specified that geometric means would be calculated if >=60% of samples had detections, and the rest of the samples would be analyzed if the calculated geometric mean exceeded the NHANES 95th percentile. Since no PFAS were detected in 60% or more of the analyzed samples, no geometric means were calculated for any PFAS in urine and ATSDR did not analyze the remainder of the urine samples. ATSDR did calculate the 95th percentile concentrations for PFHxS and PFBA.

For tap water data, ATSDR compared PFAS levels measured with and without filtration to EPA's health advisory value (70 ppt for PFOA and PFOS combined) for PFAS in drinking water. For dust, ATSDR calculated summary statistics and compared results to those in selected peer-reviewed literature. ATSDR also evaluated correlations between PFAS levels measured in household dust and blood collected from participants residing in homes where dust samples were collected.

ATSDR conducted all statistical analyses in SAS (release 9.4, SAS Institute, Cary, NC) using complex survey procedures (e.g., SURVEYMEANS, SURVEYREG). To do this, ATSDR assigned household IDs to all participants and calculated summary statistics while accounting for clustering at the household level. For blood results across all EA participants, intra-cluster correlation coefficients ranged from 0.41 to 0.69, suggesting moderate to strong correlation of PFAS blood levels within a household. Appendix B provides more information on clustering, as well as further details on the statistical methods used for this EA and how results from this EA compared to the assumptions used to estimate the target sample size of 395 participants.

Results

This section summarizes EA findings. It first profiles the Spokane County EA participants and compares their demographics to those of people in the sampling frame, then reviews the blood, urine, tap water, and household dust measurements that ATSDR collected. Those reviews use exposure history questionnaire data to provide further context on the measurements. (The next section, "Discussion," further evaluates the observed trends using insights from the broader scientific literature on PFAS drinking water exposures.)

Most analyses in this section reflect the entire Spokane County EA participant population, but some pertain to subsets of that population. This is because separate exposure history questionnaires were administered to adults and children and because some questions on the adult questionnaire only applied to females.

Profile of Spokane County EA Participants

EA participants responded to exposure history questions and reported information on many characteristics, such as their age, sex, race/ethnicity, residential and occupational history, and drinking water consumption. Table 3 summarizes this information.

Table 3. Characteristics of Spokane County EA participants

Characteristics	Count of EA Participants (n)*	Percent of EA Participants (%)
Adults and children combined		
Age (years)	(mean =47.2)	
<18	47	14
18 to <50	105	32
50+	181	54
Sex		
Male	154	46
Female	179	54
Race and ethnicity†		
White, non-Hispanic	274	83
non-White or Hispanic	55	17

Characteristics	Count of EA Participants (n)*	Percent of EA Participants (%)
Adults only		
Years lived at current address	(mean =11.1)	
<10	153	53
10 to <20	91	32
20 to <30	23	8
30+	19	7
Current primary drinking water source		
Public water system	182	64
Bottled Water	102	36
Average tap water consumption while living at current home (8-ounce cups per day)	(mean = 7.8)	
0	26	9
>0 to <2	11	4
2 to <4	32	11
4 to <6	49	17
6 to <8	36	13
8+	129	46
Current use of treatment or filtration device		
One or more filter/treatment device(s)	136	48
None	149	52
Occupational exposures to PFAS in the past 20 Years		
One or more occupational exposure(s)	38	13
None	248	87

* The sums of participants for different fields in this table do not always add up to expected values, because not every participant answered corresponding questions during the questionnaire.

† ATSDR collapsed categories for race and ethnicity for all analyses because of the few responses across categories.

The average age of EA participants was 47.2 years, and 83% of the participants identified themselves as White, non-Hispanic. Of EA participants, 54% identified as female, 46% identified as male, and 86% were adults, aged 18 years or older. The age cutoff is important because adults were administered a different exposure history questionnaire with more detailed questions. Among the adult participants, 53% reported living in their current homes for less than 10 years.

Adults were also asked about their current primary source of drinking water: 64% said Airway Heights' public water system, and 36% said bottled water. Adults reported drinking an average of 7.8 8-ounce cups of water a day at home, and 48% said they currently use some type of filtering or treatment device for their drinking water. Examples include filters on refrigerators, pitchers, and faucets; whole-house carbon filtration systems; and reverse osmosis treatment systems. The questionnaire asked adults for their occupational histories over the past 20 years; 13% reported holding one or more jobs with potential PFAS exposures (e.g., firefighting, military, aviation).

Comparison of Spokane County EA Participants' Demographics to Sampling Frame Demographics

This EA was designed to estimate PFAS levels in blood that were generalizable to the sampling frame as a whole (i.e., Airway Heights households west of Hayford Road that received municipal water). The recruitment method used for this EA ensures the absence of selection bias—that is, everyone in the sampling frame was invited to participate and therefore had an equal chance of doing so. However, ATSDR also explored the potential for participation bias—that is, substantive differences between those who chose to participate and those who did not.

ATSDR used 2010 Census data (Table 4) [USCB 2010] to compare the EA participants' demographic profile with the profile of all residents in the sampling frame. ATSDR found two significant differences:

- **Age distribution.** The EA participants included a higher proportion of older adults (age 50+ years) and a lower proportion of younger adults (18–50 years) than the sampling frame population (Table 4). Specifically, 54% of the EA participants reported being 50 or older, but 22% of the sampling frame population falls in this age range. (ATSDR chose 50 years as a cutoff for older and younger adults based on the median age of menopause in the United States, which may affect exposure profiles.) Similarly, 32% of the EA participants reported being 18–50, but 61% of the sampling frame population falls in that age range.
- **Race/ethnicity.** Among the race/ethnicity characteristics, the percent of residents who identify as White and Hispanic or Latino showed a significant difference between the EA participants and the sampling frame population (Table 4). Specifically, the EA population had statistically more participants who identified as White (87%) than the sampling frame population (79%), and statistically fewer participants who identified as Hispanic or Latino (4%) than the sampling frame (8%). For this comparison, combined race and ethnicity were not available at the block level from the Census. Therefore, only ethnicity and the race categories of White and Asian were statistically compared because of the small number of respondents in other categories. The proportion of EA participants who identified as Asian alone was not statistically different from the proportion in the sampling frame. There were also fewer EA participants who identified as Black (<10) compared to the sampling frame population (7%), although there were too few EA participants to statistically compare the two proportions.

The effect of age on blood levels and its implications on community statistics is further explored throughout this report. Refer to the "Discussion" section for ATSDR's assessment of how these demographic differences influence data interpretations.

Table 4. Demographic comparison of EA participants and the sampling frame population

Demographics	Number of Participants (n)*	Percent of Participants (%)	Sampling Frame Distribution (%)†	p-Value‡
Age Group (years)				
<18	47	14.1	17.2	0.161
18–50	105	31.5	60.8	<0.001
50+	181	54.4	21.9	<0.001
Race				
White	288	86.5	78.5	<0.001
Black or African American	<10	—	7.2	—
Am. Indian & AK Native	<10	—	3.7	—
Asian	16	4.8	3.5	0.263
Nat. Hawaiian/Pacific Islander	<10	—	0.9	—
Ethnicity				
Hispanic or Latino (of any race)	14	4.2	8.3	0.0105

* Counts may not sum to total because participants may have refused to answer questions. Counts are not shown for categories with fewer than 10 participants.

† Sampling frame data are based on the 2010 U.S. Census. Demographic characteristics of the sampling frame may have changed between 2010 and 2019, the time of this EA.

‡ Two-sample test for equality of proportions with continuity correction comparing EA and 2010 Census data. A p-value of less than 0.05 indicates a statistically significant difference between EA participants and all residents in the sampling frame.

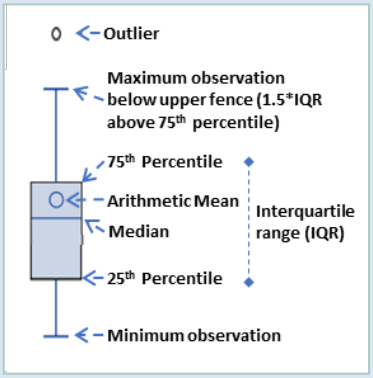
PFAS in Blood

This section summarizes PFAS levels that ATSDR measured from the 333 blood samples provided by eligible participants. Results are summarized in tables and 'box and whisker' plots (see text box).

Unadjusted Community Statistics for PFAS in Blood

ATSDR first calculated the mean levels of PFAS without accounting for the possible effect of age. Table 5 summarizes results for the seven PFAS measured in Airway Heights EA participants' blood for all ages. Five of the seven PFAS—PFHxS, PFOS, PFOA, PFNA, and PFDA—were detected in more than 89% of the blood samples. ATSDR's statistical analyses throughout this section focus on these five chemicals, and Figure 2 shows the distributions of the individual measurements on a $\log_{10}$ scale. The $\log_{10}$ scale allows for more easily visualizing the wide range of serum concentrations as it uses equal spacing for each factor of 10 increase. The PFAS found at highest levels were PFHxS (geometric mean = 72.9 micrograms per liter (µg/L)), PFOS (42.4 µg/L), and PFOA (9.72 µg/L).

How to read a box and whisker plot:
A box and whisker plot illustrates a summary of the data using different statistical measures. See the image below for how to interpret the figures throughout this report.



Two PFAS—PFUnA and MeFOSAA—were detected in fewer than 60% of the samples. These low frequencies of detection are consistent with NHANES data. Detailed statistics are not included for these chemicals, and concentration percentiles (25^{th}, 50^{th}, 75^{th}, 90^{th}, 95^{th}) are shown only for measurements above the LOD.

The precision of geometric mean estimates for this EA for all PFAS ranged from approximately 3% to 38% (Appendix B, Table B2). Except for PFNA, these values are all below the desired precision of 15% used to determine the target sample size for this EA. The collected data met the precision target specified in the EA protocol.

Table 5. Community statistics for PFAS in blood in micrograms per liter

PFAS	FOD (%)	Max	Geometric Mean	95% CI for Geometric Mean	Percentiles				
					25th	50th (Median)	75th	90th	95th
PFHxS	100	1,210.0	72.9	61.8–85.9	41.2	81.6	160	318	415
PFOS	NA*	963.7	42.4	36.6–49.1	23.6	42.9	84.6	142	192
PFOA	NA*	172.6	9.72	8.57–11.0	6.01	10.0	18.7	28.7	40.4
PFNA	98.5	3.9	0.742	0.662–0.832	0.401	0.738	1.32	2.01	2.35
PFDA	89.8	2.3	0.204	0.185–0.224	0.094	0.158	0.257	0.451	0.578
PFUnA	39.0	1.0	NA‡	NA‡	NA†	NA†	NA†	0.153	0.206
MeFOSAA	39.6	2.9	NA‡	NA‡	NA†	NA†	NA†	0.271	0.417

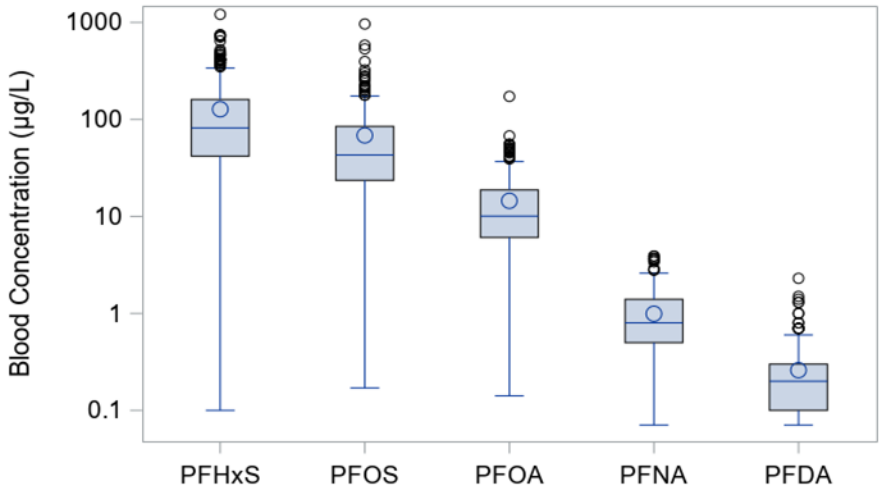
FOD = frequency of detection, CI = confidence interval, NA = not applicable

* PFOA and PFOS are calculated sums of branched and linear subsets and are not measured directly. Linear PFOA was detected in 99.7% of samples with a geometric mean of 9.54 micrograms per liter (µg/L); branched PFOA was detected in 15.3% of samples. Linear PFOS was detected in 100.0% of samples with a geometric mean of 28.9 µg/L; branched PFOS was detected in 99.7% of samples, with a geometric mean of 13.3 µg/L.

† Percentile is below the LOD.

‡ Per the EA protocol, geometric means were not calculated for PFAS detected in less than 60% of samples.

Figure 2. Distribution of PFAS blood levels (log scale)



See 'How to read a box and whisker plot' earlier in the PFAS in Blood section.
A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.

Community Statistics for PFAS in Blood Age-Adjusted to the Sampling Frame

Since the demographic profile comparison reported above showed that EA participants were significantly older than the sampling frame as a whole, ATSDR also calculated geometric means that were age-adjusted to the sampling frame population based on 2010 Census data for comparison. Age-adjusted geometric means correct for the participation bias discussed earlier and are more generalizable to the sampling frame community. Table 6 shows that in general, age-adjusted blood PFAS geometric means are lower than unadjusted values. Of the three PFAS with the highest concentration (PFHxS, PFOS, and PFOA), age-adjusted geometric means are between 18% and 25% lower than unadjusted values. The lower values for age-adjusted geometric means reported here are consistent with older adults having higher blood PFAS levels than younger adults. The effect of age and the implications of these age-adjusted statistics are further discussed throughout this report.

Table 6. Geometric means for PFAS in blood in micrograms per liter, unadjusted and age-adjusted to the sampling frame

	Unadjusted		Age-Adjusted to Sampling Frame	
PFAS	Geometric Mean	95% CI for Geometric Mean	Geometric Mean	95% CI for Geometric Mean
PFHxS	72.9	61.8–85.9	55.0	46.0–65.8
PFOS	42.4	36.6–49.1	32.7	28.1–38.2
PFOA	9.72	8.57–11.0	7.97	6.92–9.18
PFNA	0.742	0.662–0.832	0.610	0.535–0.695
PFDA	0.204	0.185–0.224	0.180	0.161–0.201
PFUnA	NA*	NA*	NA*	NA*
MeFOSAA	NA*	NA*	NA*	NA*

CI = confidence interval

* Per the EA protocol, ATSDR did not calculate geometric means for PFAS detected in less than 60% of samples.

Comparison of EA Participants' PFAS Blood Levels to the National Population

This section compares PFAS levels among Spokane County EA participants to levels found in the U.S. general population. To explore effects related to differences in the age distribution of EA participants vs. the NHANES populations, ATSDR calculated both unadjusted geometric means of all EA participants and geometric means adjusted to the age distribution of the U.S. population in NHANES 2015–2016.

Table 7 shows the unadjusted comparison for the entire pool of EA participants to the geometric means for the 2015–2016 NHANES survey [CDC 2019]. For PFHxS, PFOS, PFOA, PFNA, and PFDA, unadjusted geometric mean blood levels among Spokane County EA participants were statistically ($p<0.05$) higher than the national geometric mean.

Of the PFAS analyzed in blood, PFHxS levels had the largest elevations when compared to national levels. The unadjusted geometric mean blood PFHxS level among Spokane County EA participants was 62 times higher than the national level. Blood PFHxS levels were above the national geometric mean and above the NHANES 95th percentile for 99% of EA participants (Table 7). The unadjusted geometric mean blood PFOS and PFOA levels among Spokane County EA participants were 9.0 and 6.2 times higher, respectively, than the national level. Blood PFOS levels were above the national geometric mean for 98% of the EA participants and above the NHANES 95th percentile for 82%. Blood PFOA levels were above the national geometric mean for 95% of EA participants and above the NHANES 95th percentile for 83%. Unadjusted geometric means for blood PFNA and PFDA among EA participants were 1.3 times higher than the national average.

On average, total PFOS measurements were composed of 68% linear PFOS (n-PFOS) and 31% branched PFOS (Sm-PFOS). The proportion of n-PFOS found in EA participants' blood is lower than that found in standard PFOS products (76%–79%) [Kärrman et al. 2007] but comparable to levels found in the blood of the general U.S. population [CDC 2019]. Measurements of total PFOA were composed of 98% linear PFOA (n-PFOA) and 2% branched PFOA (Sb-PFOA), which is also comparable to the proportions found in the U.S. population [CDC 2019]. All remaining statistical analyses in this report focus on total PFOA and PFOS rather than treating linear and branched isomers separately.

For this EA, ATSDR also calculated geometric means age-adjusted to the NHANES population. Because the 2015–2016 NHANES survey does not report data for individuals under 12 years of age, these geometric mean calculations are based on 305 EA participants. Table 7 and Figure 3 show that blood PFAS geometric means adjusted to the NHANES population profile are reduced from unadjusted values. Of the three PFAS with the highest concentration (PFHxS, PFOS, and PFOA), NHANES age-adjusted geometric means are between 8% and 10% lower than unadjusted values. The adjusted geometric mean blood PFHxS level among Spokane County EA participants was 56 times the national level. Even when controlling for the age-distribution in the population, EA participants still had statistically higher blood levels of PFHxS than the U.S. population.

Table 7. Comparison of PFAS blood geometric means (GMs) and 95th percentiles in Spokane County, Washington, with the U.S. population (NHANES 2015–2016) in micrograms per liter

PFAS	NHANES GM (CI)*	Spokane County GM (CI)†: Unadjusted	Spokane County GM (CI)†: Age-Adjusted to NHANES 2015-2016	Percent of Spokane County Results over NHANES Geometric Mean (%)	NHANES 95th Percentile*	Spokane County 95th Percentile	Percent of Spokane County Results over NHANES 95th Percentile (%)
PFHxS	1.18 (1.08–1.30)	72.9 (61.8–85.9) *p<0.001*	65.6 (55.8–77.1) *p<0.001*	99.1	4.90	415	98.5
PFOS	4.72 (4.40–5.07)	42.4 (36.6–49.1) *p<0.001*	39.1 (33.9–45.0) *p<0.001*	97.6	18.3	192	82.3
PFOA	1.56 (1.47–1.66)	9.72 (8.57–11.0) *p<0.001*	8.91 (7.84–10.1) *p<0.001*	95.5	4.17	40.4	82.6
PFNA	0.577 (0.535–0.623)	0.742 (0.662–0.832) *p<0.001*	0.694 (0.615–0.783) *p=0.009*	65.5	1.90	2.35	10.8
PFDA	0.154 (0.140–0.169)	0.204 (0.185–0.224) *p<0.001*	0.200 (0.179–0.214) *p<0.001*	70.9	0.700	0.578	2.70
PFUnA	NA‡	NA†	NA†	NA	0.400	0.206	2.70
MeFOSAA	NA‡	NA†	NA†	NA	0.600	0.417	2.40

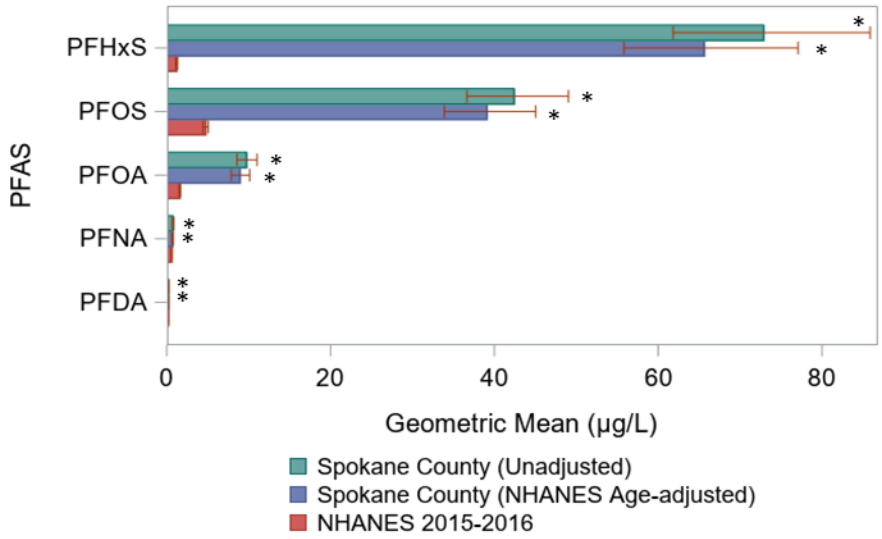
CI = 95% confidence interval, NA = not applicable

* Source: CDC 2019

† P-values represent a t-test comparison between Spokane County GM and NHANES GM.

‡ Per the protocol, geometric means were not calculated for PFAS detected in less than 60% of samples.

Figure 3. EA average PFAS blood levels compared to national averages



Error bars represent 95% confidence intervals. Note that overlapping confidence intervals do not mean that differences are not statistically significant.
**Statistically significant difference from NHANES (p<0.05)*

Correlations Among PFAS in Blood

ATSDR also evaluated correlations between PFAS in blood (log_{10}). This analysis determined whether any PFAS tended to have similar patterns in the blood of Spokane County EA participants. ATSDR used Pearson correlation coefficients (*r*) for this analysis. An *r* of 0 means two data sets are uncorrelated, and an *r* of 1 means two data sets are exactly correlated (i.e., they rise and fall in proportional amounts). Table 8 shows the Pearson correlation coefficients for the five frequently detected PFAS.

PFHxS, PFOS, and PFOA blood levels showed the strongest correlations (Table 8). All pairings among these chemicals had Pearson correlation coefficients close to 1 (r = 0.91–0.96). PFNA was strongly correlated with all PFAS though to a lesser degree (r = 0.75–0.85). PFDA was moderately correlated with PFNA (r = 0.75) and more weakly correlated with the other PFAS (r = 0.52–0.61).

Table 8. Pearson correlation coefficients between PFAS in blood (log_{10})*

	PFHxS	PFOS	PFOA	PFNA	PFDA
PFHxS	1.00	0.96	0.92	0.79	0.52
PFOS	0.96	1.00	0.91	0.85	0.61
PFOA	0.92	0.91	1.00	0.84	0.55
PFNA	0.79	0.85	0.84	1.00	0.75
PFDA	0.52	0.61	0.55	0.75	1.00

* p<0.001 for all correlations.

PFAS Blood Levels by Demographics and Other Exposure Characteristics

This section examines how the demographic and exposure history information collected during the questionnaire relates to blood PFAS levels. Since different questionnaires were administered to adult and child participants, responses were analyzed separately. Additionally, some questions were applicable only to female adult participants and are therefore also presented separately. Appendix C (Tables C1 and C2) presents a complete summary of all adult and child questionnaire responses.

ATSDR used univariate and multivariate models to evaluate the relationships between questionnaire data and blood PFAS levels. This section summarizes relationships that were found to be statistically significant. For this EA, the following demographic and exposure characteristics were found to be associated with at least one PFAS in either univariate or multivariate models:

- age,
- sex,
- race/ethnicity,
- tap water consumption,
- drinking water source,
- use of a water filtration or treatment device,
- length of residence in the sampling frame,
- use of stain-resistant products,
- blood donation frequency,
- fast food consumption,
- consumption of selected local food items,
- breastfeeding (children only), and
- child count (adult females).

ATSDR created mathematical models to identify demographic and lifestyle characteristics associated with PFAS blood levels.

Univariate models evaluated the effects of one variable, or exposure characteristic, at a time while multivariable models evaluated the joint effect of multiple characteristics on blood PFAS levels at the same time. **Multivariable regression models** describe the average increases in PFAS blood levels for each unit increase in the exposure characteristics.

Table 9 summarizes the demographic and exposure characteristics that were statistically significant in each adult multivariate model.

Table 9. Summary of statistically significant variables (p<0.05) in multivariate regression models

Parameter	PFHxS			PFOS			PFOA			PFNA			PFDA		
	All Adult	Adult Female	Adult Male	All Adult	Adult Female	Adult Male	All Adult	Adult Female	Adult Male	All Adult	Adult Female	Adult Male	All Adult	Adult Female	Adult Male
Age (continuous)	✓	✓	—	✓	✓	✓	✓	✓	—	✓	✓	✓	✓	—	—
Sex (categorical)	—	NA	NA	—	NA	NA	—	NA	NA	✓	NA	NA	—	NA	NA
Age × sex (continuous)*	—	NA	NA	—	NA	NA	—	NA	NA	✓	NA	NA	—	NA	NA
Race/ethnicity (categorical)	—	—	—	—	—	—	—	—	—	✓	—	—	✓	—	—
Drinking water consumption (continuous)	—	—	—	—	—	—	—	—	—	—	—	—	✓	—	—
Drinking water source [bottled, tap] (categorical)	✓	—	—	✓	—	—	—	—	—	—	—	—	—	—	—
Drinking water filter use (categorical)	✓	—	✓	✓	✓	✓	✓	—	✓	✓	✓	✓	—	—	—
Years in sampling frame in the past 20 years [Residency duration] (continuous)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	—	—	—	—	—
Stain-resistant product use (categorical)	—	—	—	—	—	—	—	—	—	—	—	—	✓	—	—
Blood donation frequency (categorical)	✓	✓	—	—	—	—	✓	✓	—	✓	✓	—	—	—	—
Fast-food consumption (categorical)	✓	—	✓	✓	—	✓	✓	—	✓	✓	—	✓	✓	—	—
Child count (continuous)	NA	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA	NA	—	NA

✓ = statistically significant, '—' = not statistically significant, NA = not applicable

*This variable is an interaction term, which means the effect of one variable on serum PFAS levels depends on the value of another.

The following subsections briefly summarize results for these topics. All other results are presented in Appendix C, as described below.

- Tables C1 and C2 present response frequencies for all questions included in the adult and child questionnaire, respectively. These tables also present geometric means and 95% confidence intervals around geometric means stratified by the response options (e.g., statistics are presented separately for males and females) for PFHxS, PFOS, PFOA, PFNA, and PFDA.
- Tables C3 and C4 present univariate modeling results for all questions in the adult and child questionnaire for the same five PFAS, as data allow. Data are presented only when a category had at least 10 responses. Some categories were collapsed to meet this threshold.
- Tables C5–C17 present multivariate modeling results for PFHxS, PFOS, PFOA, PFNA, and PFDA. Multivariate models, including the goodness-of-fit measure, R-squared or R^2, are presented separately for all adults, male adults only, and female adults only. The closer the R^2 value is to 1, the more the variables in the model explain the variability in blood PFAS levels. Across all models, R^2 values ranged from 0.14 to 0.40. ATSDR modeled males and female adults separately to explore sex-specific differences including the potential effect of childbirth and breastfeeding on female blood PFAS levels. The variables considered in male-only and female-only models were limited to those that were significant in final all-adult models. ATSDR did not develop multivariate models for children because of the small sample size for this population (n=47).
- Figures C1–C38 present box and whisker plots for unadjusted blood levels by each demographic and exposure characteristic included in the statistical analyses.

Goodness of Fit Measure

R-squared or R^2 is a statistical measure used to evaluate how well a mathematical model explains the measured data by looking at the differences between the observed PFAS concentrations and values predicted by the model.

- An R^2 of 1 means the model completely predicts the observed PFAS concentrations, so that there are no differences between the model and the PFAS concentrations and 100% of the PFAS concentrations are explained by the model.
- An R^2 of less than 1 means that there are measurements scattered higher and/or lower than the model predictions and there are differences between the two.

Variability describes the spread or dispersion of data values. If the values are similar to each other there is little variability, if the values are spread out there is more variability.

Multivariable regression can help us understand how much of the variability in PFAS blood levels can be explained by the combination of factors in the model such as age, sex, and length of residency among others. If the model does not explain a large portion of the variability, that means there are other unknown factors influencing PFAS levels in blood.

Blood PFAS Levels and Age

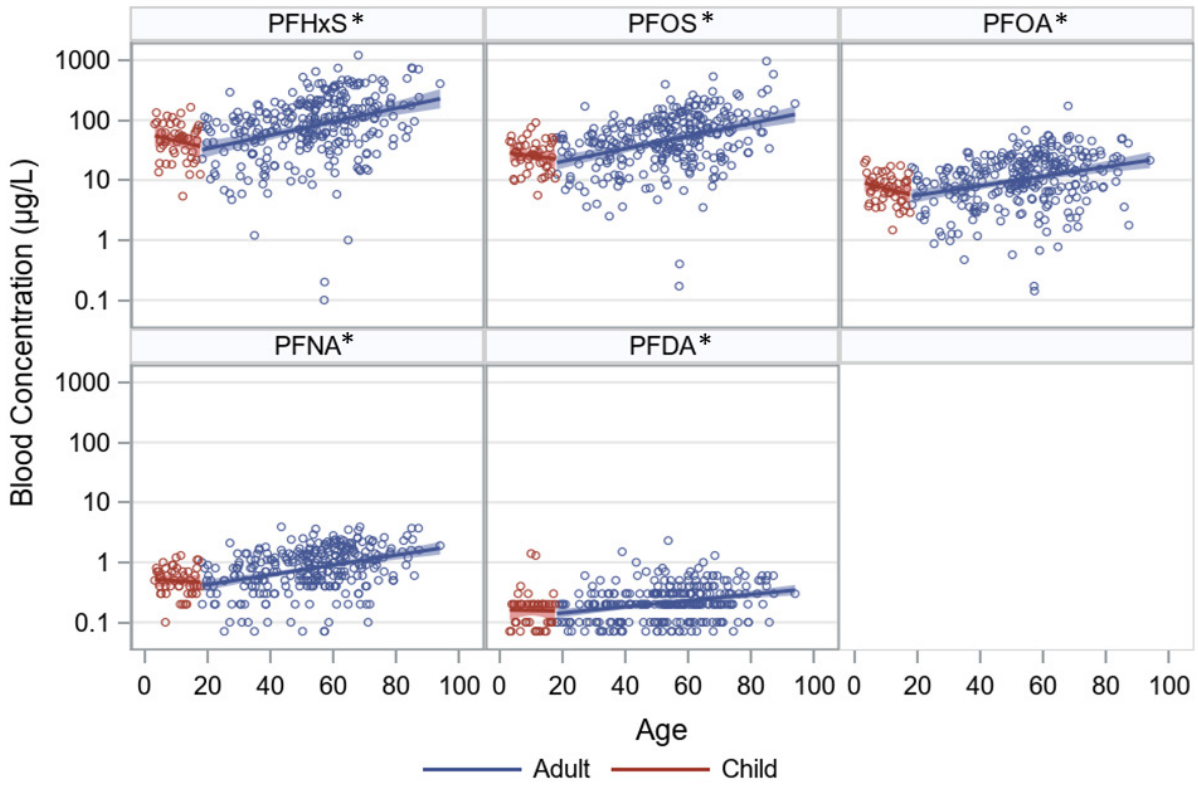
Because many studies have found that older people have higher blood PFAS levels, ATSDR investigated how Spokane County EA participants' ages related to their blood levels. As Figure 4 illustrates, the blood levels for PFHxS, PFOS, PFOA, PFNA, and PFDA statistically increased with participant age for adults, but trends for children were not statistically significant.

For adults, ATSDR's univariate analysis showed that blood PFHxS, PFOS, PFOA, PFNA, and PFDA levels were higher in older individuals than in younger individuals, and this finding was statistically significant. As Figure 4 shows, PFHxS and PFOS had the strongest age dependence. The univariate analysis indicates that, on average, blood PFHxS levels in Spokane County EA participants increased 2.6% for every year of participant age in adults, and blood PFOS levels increased by 2.5% for every year of participant age in adults. This suggests a 29% and 28% increase in blood PFHxS and PFOS levels for every 10 years of participant age in adults, respectively. The calculated increases for PFOA (1.8% per year of participant age), PFNA (1.9% per year of participant age), and PFDA (1.2% per year of participant age) were lower.

ATSDR's multivariate analysis provided further perspective on this trend, showing that age remained a significant predictor of blood levels in all-adult multivariate models when controlling for other variables. For each year of participant age, the calculated increases were as follows: 1.6% for PFHxS, 1.8% for PFOS, and 1.1% for PFOA. Multivariate models also showed that age dependence was generally stronger for females than males. For example, the adult female-only model (Appendix C, Table C6) suggests a 2.8% increase in blood PFHxS levels in adult females for every year of participant age, and age was not statistically significant in the male-only model (Appendix C, Table C7).

The model results depicted in Figure 4 showed that blood PFHxS, PFOS, PFOA, PFNA, and PFDA levels were not statistically associated with age for participants under 18. Multivariate models were not explored for children because of the relatively small sample size.

Figure 4. PFAS blood levels in adults and children (log scale)



A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically significant trend (p<0.05) in adults*
†Statistically significant trend (p<0.05) in children

Blood PFAS Levels by Sex

ATSDR investigated how blood PFAS levels vary between males and females because previous research has shown that, all other factors considered equal, adult males tend to have higher blood PFAS levels than adult females. However, ATSDR's univariate analyses did not show significant differences in PFAS levels by sex.

ATSDR's all-adult multivariate model, which controlled for potential confounders, showed that PFNA levels were higher in adult males than in adult females. Modeled blood levels in adult males were 77% higher than in adult females.

In children, blood levels of PFHxS, PFOS, PFOA, and PFNA were not statistically associated with their sex. For PFDA, child males on average had serum levels 58% greater than child females.

What are confounders?

Confounding is a distortion in the estimated relationship between a potential predictor and measure of exposure due to the presence of a third variable—called a confounder. In order for confounding to occur, that third variable must be associated with both the predictor (or independent variable) and the measure of exposure (or dependent variable). For example, age can act as a confounder on the estimated strength of association between length of residence in the sampling frame and blood PFAS levels.

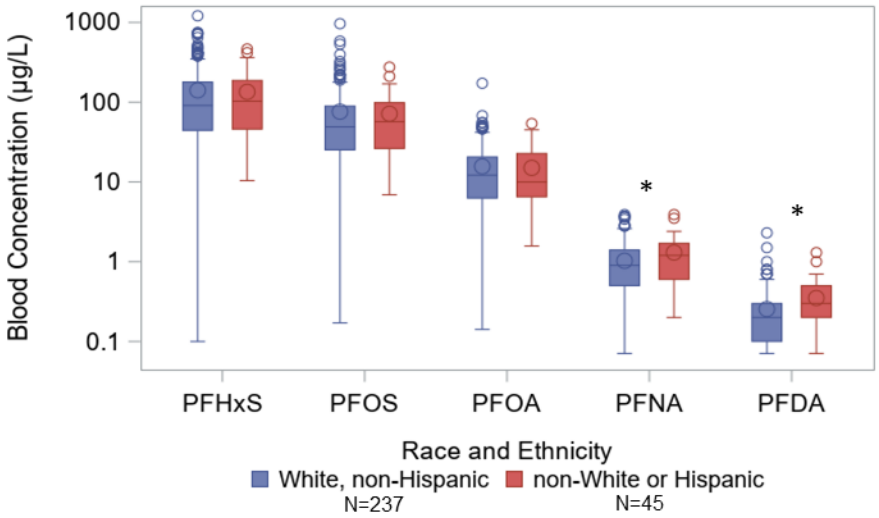
By adjusting for these types of confounding variables in multivariate statistical models, ATSDR can calculate less biased estimates of the relationships between dependent and independent variables of interest.

Blood PFAS Levels by Race/Ethnicity

The exposure history questionnaire asked participants to provide information about their race and ethnicity. Because there were not enough participants in different race and ethnicity categories to support robust statistical analyses, ATSDR focused on differences between Spokane County EA participants who self-identified as White, non-Hispanic and those who identified as non-White, or Hispanic.

Figure 5 shows that on average, when compared to those who identified as White, non-Hispanic, blood levels in non-White or Hispanic participants were 36% greater for PFNA and 37% greater for PFDA. These relationships remained significant in multivariate analyses (37% for PFNA and 33% for PFDA).

Figure 5. PFAS blood level in adults by race and ethnicity (log scale)



See 'How to read a box and whisker plot' earlier in the PFAS in Blood section.
A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically significant difference (p<0.05)*

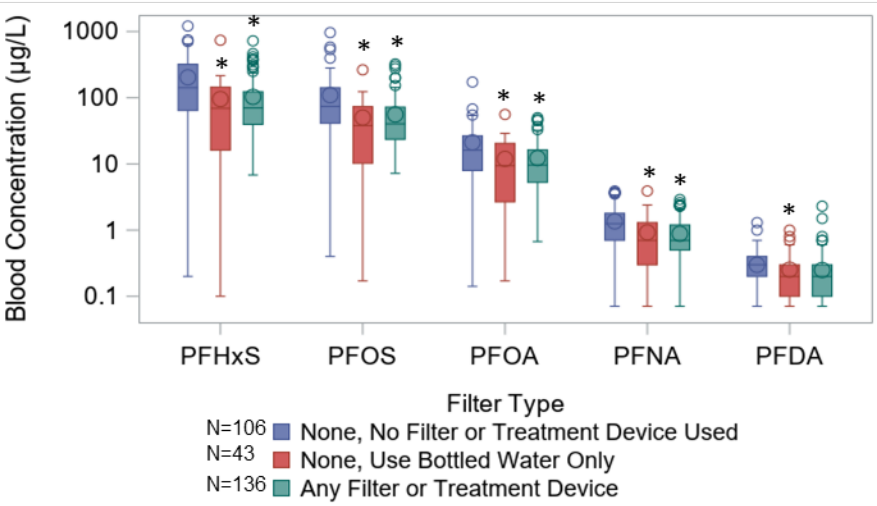
Blood PFAS Levels and Tap Water Consumption

ATSDR investigated several questions from the adult and child questionnaires to characterize relationships between blood PFAS levels and consumption of PFAS-contaminated drinking water. These questions are about the drinking water source, amount of tap water consumed at home or school, and residential history. In some cases, data trends may have been affected by subtleties in the wording of exposure history questions, as described below.

For adults, ATSDR first considered participants' primary drinking water source. Adult participants were asked, "What is your current main source of drinking water in your home?" Nearly all of the responses were tap water (64%) or bottled water (36%). In univariate models, participants who reported drinking tap water on average had blood PFHxS levels 36% greater and PFOS serum levels 34% greater than those who reported not drinking tap water. These associations remained statistically significant in multivariate models, when controlling for other variables (29% for PFHxS and 25% for PFOS). PFOA, PFNA, and PFDA were not statistically associated with drinking water source. Note that the exposure history question asked about current drinking water sources. It is possible that some participants who reported currently drinking bottled water previously drank tap water when the water supply was contaminated.

ATSDR also considered relationships between blood PFAS levels and current use of drinking water filtering and water treatment devices. 48% of participants reported using a filter or treatment device on the tap water that they drink at home, 37% of participants reported no filter or treatment device on the tap water that they drink at home, and 15% reported not drinking tap water at all. In ATSDR's univariate analyses (Figure 6), participants who reported using a filter or treatment device on the tap water that they drink at home on average had statistically lower blood levels of PFHxS (44%), PFOS (41%), PFOA (36%), PFNA (34%), and PFDA (21%) when compared to participants who drank tap water but did not use a filter. Similarly, participants who reported drinking bottled water only had statistically lower levels of blood PFHxS (65%), PFOS (60%), PFOA (52%), and PFNA (44%) in univariate models.

Figure 6. PFAS blood level in adults by filter type (log scale)



See 'How to read a box and whisker plot' earlier in the PFAS in Blood section.
A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically significant difference (p<0.05)*

The associations between blood PFAS levels and filter use remained statistically significant in multivariate models but controlling for other variables weakened the effect of the relationship. In multivariate models, participants who reported using a filter or treatment device on the tap water that they drink had lower blood levels for PFHxS (28%), PFOS (29%), PFOA (27%), and PFNA (26%) when compared to participants who drank tap water but did not use a filter. Similarly, when controlling for other variables, participants who reported drinking bottled water only had statistically lower levels of blood PFHxS (40%), PFOS (39%), PFOA (44%), and PFNA (43%).

ATSDR also considered participants' self-reported tap water consumption rates. Adult participants were asked, "During the time you lived in a home served by the water source identified above [i.e., for the question quoted three paragraphs ago], on average how many 8-ounce cups of water or beverages prepared with tap water did you drink while at home per day?" ATSDR's univariate and multivariate analyses did not reveal a significant linear relationship between blood PFAS levels and the amount of tap water consumed.

For adults, ATSDR also considered the length of residency. The exposure history questionnaire asked adults where they had lived for the past 20 years. ATSDR calculated the total amount of time participants reported living in the sampling frame over this period. These responses can serve as a proxy for potential exposure to PFAS-contaminated drinking water in the community. That is, the longer the residency within the sampling frame, the greater the likelihood of past PFAS exposure from contaminated drinking water. Any resident reporting prior residences with addresses in Airway Heights were assumed to fall within the sampling frame.

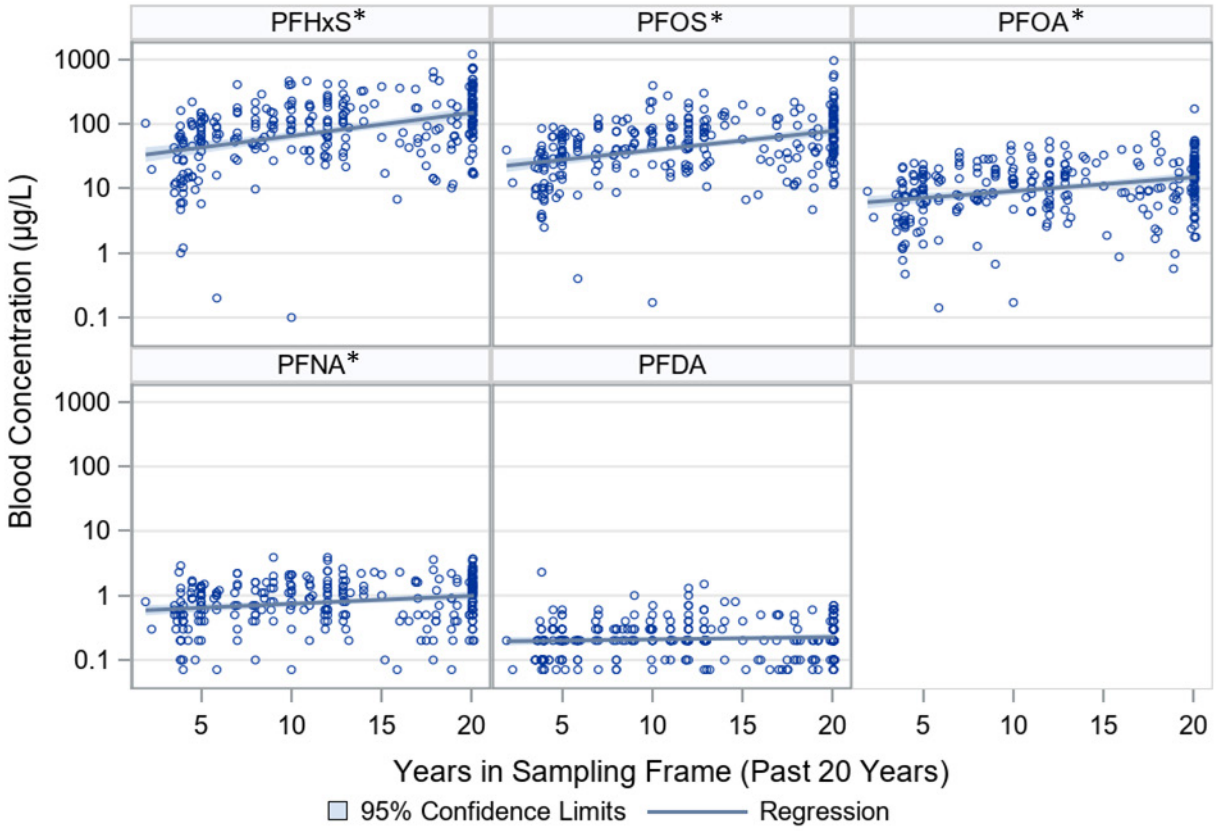
Figure 7 shows the relationship between reported residence duration in Airway Heights for the past 20 years and blood PFAS levels. A consistent relationship was observed for PFHxS, PFOS, PFOA, and PFNA: blood levels increased with the number of years participants lived in the sampling frame, and this effect was most pronounced for PFHxS. The multivariate analysis confirmed this relationship for PFHxS, PFOS, PFOA, and PFNA: for every additional year that an adult participant lived in Airway Heights, blood PFHxS

increased by 7.2%, blood PFOS increased by 5.6%, blood PFOA increased by 3.9%, and blood PFNA increased by 1.8%. In both male-only and female-only models, the association remained statistically significant and was generally stronger in males than females.

Finally, an exposure history question pertained to whether adult participants drank tap water while at work. However, because identifying whether a participant's place of employment was in the sampling frame was difficult, ATSDR did not evaluate the data for drinking water consumption patterns at work.

PFHxS, PFOS, and PFOA were detected in Airway Heights' drinking water sources (PFHxS at 1,500 ppt, PFOS at 1,200 ppt, and PFOA at 320 ppt). Therefore, one explanation for the correlation among these compounds in the blood is that the Spokane County EA participants had a common exposure profile for PFHxS, PFOS, and PFOA, such as drinking water. However, the correlations alone cannot be used to identify the underlying source or combination of sources that contributed most to exposure.

Figure 7. PFAS blood levels in adults by length of residence in sampling frame (log scale)



A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically significant trend (p<0.05)*

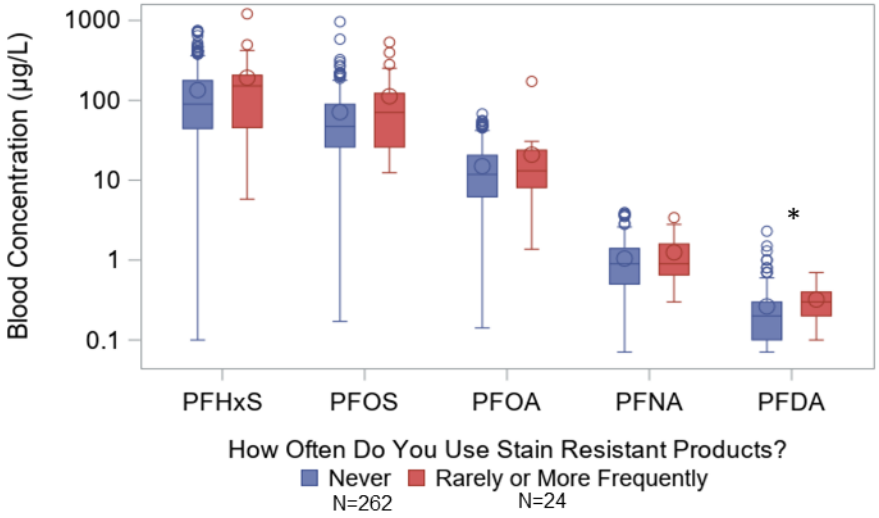
Blood PFAS Levels and Use of Stain-Resistant Products

Many stain-resistant products used to treat fabrics and carpet have been formulated with PFAS. The exposure history questionnaire asked adult EA participants how frequently they used these products, because such uses may be associated with PFAS exposures. The questionnaire had several response options, including "never," "rarely," "a few times per year," "a few times per month," and "3 times per

week or more." Because of the small sample size for some response options, ATSDR collapsed responses into just two categories: never used stain-resistant products (262 adult EA participants) and any reported use (24 adult EA participants). Figure 8 shows how blood PFAS levels varied between these two categories of EA participants.

As Figure 8 shows, Spokane County EA adult participants with any self-reported stain-resistant product use had statistically elevated blood levels of PFDA when compared to participants who reported never using these products. In the multivariate statistical analysis, this trend remained statistically significant. In the all-adult model, with other variables controlled for, blood levels of PFDA were 26% higher in participants who reported using these products than in participants who never used them. These results are based on a small number of participants (8%, n=24) who reported ever using stain-resistant products and will be explored further in the final report for all EA sites. The results for stain-resistant product use for this EA are based on limited data and should be interpreted with caution.

Figure 8. PFAS blood level in adults by stain-resistant product use (log scale)

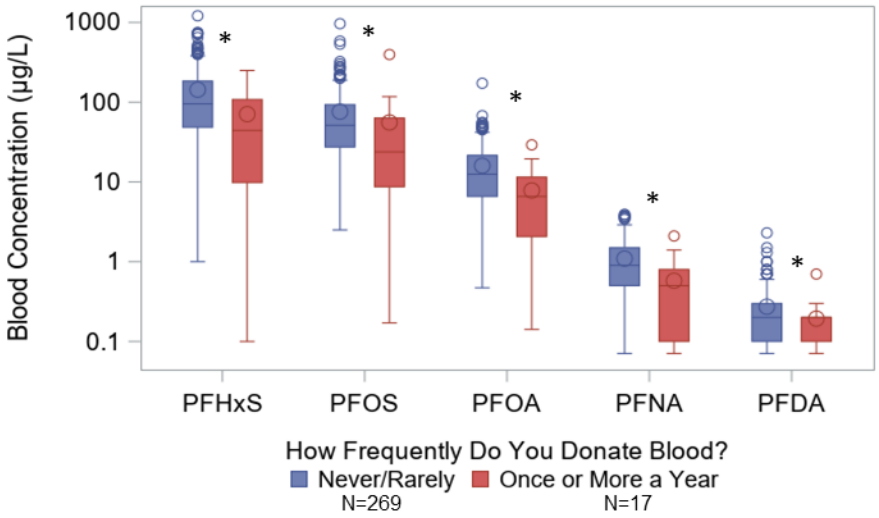


See 'How to read a box and whisker plot' earlier in the PFAS in Blood section.
A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically significant difference (p<0.05)*

Blood PFAS Levels and Frequency of Blood Donation

Adult participants were asked how often they donate blood or plasma, because frequent blood and plasma donations are expected to result in decreasing blood PFAS levels. Consistent with expectations, blood levels of PFHxS, PFOS, PFOA, PFNA, and PFDA were higher among EA participants who reported never or rarely donating blood when compared to blood levels for EA participants who donated blood at least once per year (Figure 9).

Figure 9. PFAS blood level in adults by blood-donation frequency (log scale)



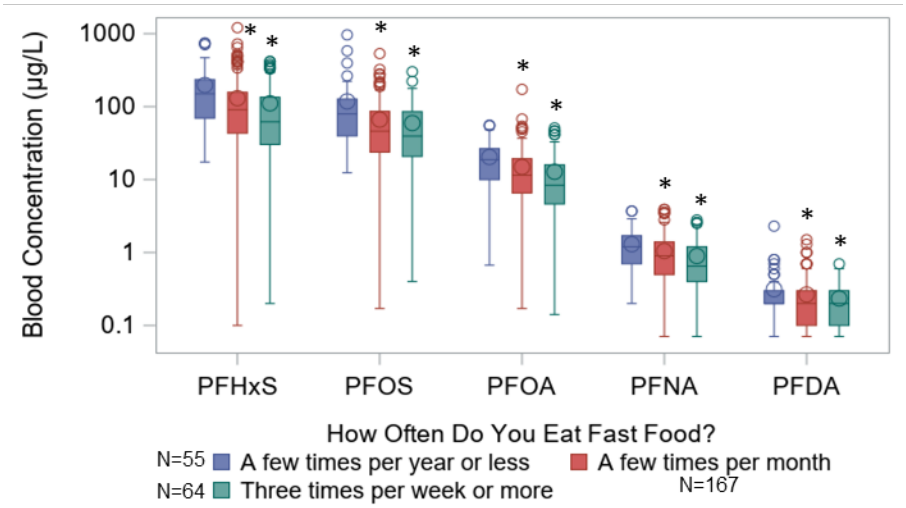
See 'How to read a box and whisker plot' earlier in the PFAS in Blood section.
A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically significant difference (p<0.05)*

ATSDR's multivariate analysis found blood PFHxS concentrations among adults who donated blood once or more per year to be 67% lower than for EA participants who donated blood never or rarely. The same EA participants had 58% lower PFOA blood levels, and 48% lower PFNA blood levels. The relationships for PFOS and PFDA were not statistically significant in multivariate models. These results are based on a small number of participants (9%, n=17) who donated blood and will be explored further in the final report for all EA sites. The results for blood donation for this EA are based on limited data and should be interpreted with caution.

Blood PFAS Levels and Fast Food Consumption

PFAS may be present in fast food take-away containers and food packaging. Consumption of fast food may serve as an additional source of PFAS exposure; however, the Spokane County EA found lower levels of PFAS in people reporting higher levels of fast food consumption. Figure 10 shows that the 19% (n=55) of study participants reported eating fast food a few times per year or less had significantly higher blood PFAS levels than the 58% (n=167) who reported eating fast food a few times per month, and the 22% (n=64) who reported eating fast food three times per week or more. In multivariate models these differences remained statistically significant. Participants who reported eating fast food a few times per month on average had lower blood PFHxS (43%), PFOS (41%), PFOA (36%), and PFNA (24%) levels compared to participants who reported eating fast food a few times per year or less. Similarly, participants who reported eating fast food three times per week or more on average had lower blood PFHxS (48%), PFOS (44%), PFOA (41%), and PFNA (27%) levels.

Figure 10. PFAS blood level in adults by frequency of fast food consumption (log scale)



See 'How to read a box and whisker plot' earlier in the PFAS in Blood section.
A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically significant difference (p<0.05)*

Blood PFAS Levels and Consumption of Selected Local Food Items

Some PFAS accumulate in plants, fish, and animals. The questionnaire asked adult and child EA participants how often they consume locally grown fruits and vegetables, locally caught fish, and milk from animals in the sampling frame. Too few adult EA participants reported consuming locally produced milk (n=1) to allow for meaningful statistical analyses, and a statistically significant relationship was not observed between consumption of locally grown fruits and vegetables and blood PFAS levels.

Blood PFDA levels were higher by 52% among adult EA participants who reported any local fish consumption (n=10) than among participants who reported no such consumption. Note that this relationship did not remain significant in multivariate models for all adults.

Blood PFAS Levels and Breastfeeding

During breastfeeding, some PFAS in the breast milk might be transferred from mother to child. Therefore, breastfeeding might reduce PFAS levels in mothers and increase PFAS levels in their breastfed children [Kim 2020; Kingsley 2018]. Accordingly, the adult and child exposure history questionnaires included questions about breastfeeding. A question was also included for children about their consumption of formula (as opposed to breast milk), and if the formula was made using tap water.

Among adult female participants, breastfeeding (yes/no) and breastfeeding duration were not associated with PFAS serum levels in either univariate models or female-only multivariate models.

The questionnaire results demonstrate that, overall, 74% of children in the Spokane County EA were breastfed. In univariate models, children who had breastfed had significantly higher serum levels of PFNA (59%) than children who had never breastfed; no other relationships were identified between breastfeeding and other PFAS serum levels. Children's breastfeeding duration was also not correlated with PFAS levels.

Most children in the Spokane County EA (72%) consumed infant formula reconstituted with tap water (some of these children also breastfed). Children who drank formula prepared with tap water had significantly higher serum levels of PFHxS (2.2% per month on formula) and PFOS (1.5% per month on formula) than children who never drank formula prepared with tap water.

Blood PFAS Levels and Childbirth (adult females and children only). The adult questionnaire asked female participants whether they had any biological children, and if so, how many. The child questionnaire asked participants their birth order. Most adult female EA participants (81%) reported having biological children. Neither having children nor the number of children was statistically associated with blood PFAS levels in univariate models. However, in multivariate models, the more children a female participant had the lower their blood PFHxS (11.7% per child), PFOS (9.3% per child), PFOA (13.7% per child), and PFNA (8.1% per child) levels.

Birth order was not statistically associated with blood PFAS levels among the child participants.

Blood PFAS Levels and Other Variables

Through the exposure history questionnaires, ATSDR gathered information on several other behaviors and possible contributing factors to PFAS exposures. The variables listed below were not statistically associated with blood levels of PFHxS, PFOA, PFOS, PFNA, or PFDA among EA study participants in univariate or multivariate analyses.

- **Kidney disease.** The exposure history questionnaire asked about kidney disease because it can affect blood PFAS levels [Barry 2013; Watkins 2013]. The questionnaire results indicated that only 6% of adults (n=16) reported a diagnosis of kidney disease, and these adults did not have statistically different blood PFAS levels than those without such a diagnosis. Note that kidney disease was self-reported and there may be misclassification with this variable.
- **Cleaning frequency.** Adult participants were asked how often their homes are cleaned. No statistically significant relationship was observed for self-reported cleaning frequency and blood PFAS levels in adults.
- **Soil exposure.** Adult and child participants were asked how often they play in or touch soil or dirt in the sampling frame. No statistically significant relationship was observed for self-reported soil contact frequency and blood PFAS levels in adults.
- **Flooring.** Adult participants were asked about the type of flooring in their living rooms, kitchens, and bedrooms. While carpet has been linked to increased PFAS exposure because PFAS containing stain- and grease-repelling coatings are often applied to carpet [Beesoon et al. 2012], the presence of carpet in EA participants' rooms was not statistically associated with blood PFAS levels among adults.
- **Occupation.** Adult participants were asked about their occupational history over the past 20 years. Participants were specifically asked about experience working at manufacturers of PFAS or PFAS-containing products (e.g., nonstick cookware, water-resistant clothing) and past work in firefighting, the military, or aviation. The 13% of adults (n=38) who identified working in at least one job with potential exposures to PFAS in the past 20 years did not have statistically different PFAS levels than those without occupational exposures.

PFAS in Urine

The study protocol calls for ATSDR to initially analyze 10% of urine samples collected. The protocol indicates that ATSDR will analyze all participants' urine samples if the initial analysis shows geometric mean urine concentrations of any PFAS greater than the NHANES 95th percentile values; however, this threshold was not met. Note that only PFBA and PFHxA were detected in more than 5% of the NHANES samples.

Information on urinary concentrations of PFAS in humans is limited, yet it may be important to understand exposure to short-chain and alternative PFAS. Because urine is the primary route of excretion for many PFAS, urinary concentrations may reflect more recent exposures than do serum concentrations. Some PFAS were detected in serum but not in urine. These seemingly contradictory results highlight the importance of using the appropriate biomonitoring matrix for exposure assessment. Concentrations of biologically persistent compounds (like some PFAS) are expected to be higher in serum than in urine, as was observed in this assessment. This trend is also evident in other biomonitoring studies in the general population and in communities with known PFAS exposures [Calafat et al. 2019].

For the Spokane County EA, ATSDR randomly selected 35 participants' urine samples for analysis. One person was later determined to have not met the EA's eligibility criteria, and results from this sample were not included in the following analysis. The samples used for summary statistics were provided by 32 adults and 2 children, and these individuals lived in 33 different households. PFBA and PFHxS were the only PFAS detected in any of the 34 urine samples. Of note, there are challenges in measurement of trace levels of PFBA, including selectivity of the analytical instrumentation and potential for external contamination [Abraham et al. 2021]. Therefore, we advise caution when interpreting the PFBA results. Table 10 presents PFBA and PFHxS summary statistics for the randomly selected urine samples and national statistics for comparison. Geometric mean concentrations were not calculated for either substance, because the frequency of detection did not exceed 60%. 5 of the 34 urine samples had PFBA concentrations greater than the NHANES 95th percentile. PFHxS is not generally found in urine [Calafat 2019]; detection of PFHxS suggests recent exposure or elevated PFHxS levels in blood. Since no PFAS were detected in more than 60% of the analyzed samples, no geometric means were calculated for any PFAS in urine and ATSDR did not analyze the remainder of the urine samples.

Table 10. Community statistics for PFAS in urine reported in micrograms per liter

PFAS	Frequency of Detection (%)	Range of Concentrations (µg/L)	Spokane County Geometric Mean (µg/L)	Spokane County 95th Percentile (µg/L)	NHANES Geometric Mean (µg/L)	NHANES 95th Percentile (µg/L)
PFHxS	26.5	ND–0.4	NA*	0.315	NA*	NA†
PFBA	52.9	ND–2.2	NA*	0.660	NA*	0.300

µg/L = micrograms per liter, ND = not detected, NA = not applicable

* Geometric mean was not calculated because chemical was not detected in at least 60% of the samples (PFBA and PFHxS were detected in 13.3% and <0.1% of samples, respectively, in Calafat et al. [2019]).

† 95th percentile is below the limit of detection.

PFAS in Tap Water

As noted previously, ATSDR collected 26 tap water samples from 19 randomly selected participant households and analyzed these samples for PFAS. PFAS were not detected in any of the 19 unfiltered and 7 filtered water samples. Therefore, summary statistics were not calculated for any PFAS. The detection limit, and measured concentrations were far below EPA's health advisory of 70 ppt for PFOA and PFOS combined, and the Washington state action levels adopted in January 2022. Detection limits were 2 ppt for all PFAS, except for HFPO-DA (5 ppt).

PFAS in Household Dust

ATSDR collected dust samples from the same 19 randomly selected participant households where tap water samples were collected and analyzed these samples for PFAS. These samples were taken from multiple locations in each household, including the primary living space as identified by the homeowner (e.g., living room, family room, television room), the kitchen, and the bedroom in which participants reported spending the most time. When necessary, additional sampling was performed in other rooms to allow ATSDR to collect the proper amount of dust for testing. Table 11 lists the specific PFAS that were measured in dust along with detailed summary statistics (i.e., frequency of detection, geometric means, 95% confidence intervals around the geometric means, and percentiles). Note that several PFAS were not detected in any sample and are therefore not included in Table 11 (i.e., PFNS, PFDS, PFDoS, N-EtFOSA, FtS 4:2, HFPO-DA, ADONA, 9CL-PF3ONS, and 11CL-PF3OUdS).

Table 11. Summary statistics for dust samples (n=19) collected in Airway Heights

PFAS	FOD (%)	Maximum Detected Result (ng/g)	Geometric Mean (ng/g)	95% Confidence Interval for Geometric Mean (ng/g)	Percentiles (ng/g)		
					50th (Median)	90th	95th
PFBS	32	126	NA*	NA*	3.85	15.9	33.1
PFPeS	5	14.6	NA*	NA*	3.11	6.41	7.51
PFHxS	53	526	NA*	NA*	4.60	12.8	40.1
PFHpS	16	14.6	NA*	NA*	3.11	6.05	7.51
PFOS	74	544	14.4	7.59–27.2	11.8	48.1	169
PFBA	37	191	NA*	NA*	13.5	61.1	91.9
PFPeA	26	29.1	NA*	NA*	6.23	10.6	15.0
PFHxA	79	79.5	8.00	4.62–13.8	5.30	39.5	50.9
PFHpA	47	50.9	NA*	NA*	3.85	16.2	32.1
PFOA	74	258	8.88	4.72–16.7	6.23	44.9	131
PFNA	58	14.6	NA*	NA*	4.45	8.08	8.77
PFDA	26	197	NA*	NA*	3.38	9.12	21.0
PFUnA	16	14.6	NA*	NA*	2.95	5.72	7.51
PFDoA	21	118	NA*	NA*	3.26	5.05	12.7
PFTrA	5	14.6	NA*	NA*	2.95	5.05	7.51
PFTA	21	67.6	NA*	NA*	2.95	5.05	10.2
PFOSA	11	14.6	NA*	NA*	2.95	5.05	7.51
N-MeFOSA	16	16.8	NA*	NA*	3.88	5.81	8.63
MeFOSAA	21	87.2	NA*	NA*	3.71	21.4	83.0
N-MeFOSE	32	585	NA*	NA*	39.7	170	396

PFAS	FOD (%)	Maximum Detected Result (ng/g)	Geometric Mean (ng/g)	95% Confidence Interval for Geometric Mean (ng/g)	Percentiles (ng/g)		
					50th (Median)	90th	95th
EtFOSAA	26	53.6	NA*	NA*	7.39	26.7	30.4
N-EtFOSE	16	109	NA*	NA*	22.1	37.9	56.4
FtS 6:2	16	156	NA*	NA*	22.4	58.0	118
FtS 8:2	11	69.8	NA*	NA*	12.4	31.6	58.8

FOD = frequency of detection, ng/g = nanograms per gram, NA = not applicable
A total of 19 dust samples are summarized in this table.
* Per the EA protocol, geometric means were not calculated for PFAS detected in less than 60% of samples.

PFOS, PFHxA, and PFOA were detected in more than 74% of the households evaluated. PFOS, PFHxA, and PFOA had geometric mean values of 14.4 nanograms/gram (ng/g)[5] (95% confidence interval = 7.59–27.2 ng/g), 8.00 ng/g (95% confidence interval = 4.62–13.8 ng/g), and 8.88 ng/g (95% confidence interval = 4.72–16.7 ng/g), respectively. Geometric means were not calculated for any other PFAS because these PFAS were detected in less than 60% of samples.

To provide some context to the results summarized above, average levels of PFAS measured in the 19 samples collected as part of this EA were compared to average dust levels reported in other U.S.-based studies. This includes evaluations of indoor dust collected at 30 homes in the greater Boston area [Fraser et al. 2013], 124 homes in California [Wu 2015], 15 U.S. homes [Karásková et al. 2016], and 19 homes in Minnesota cities with PFAS-contaminated soil and drinking water [Scher et al. 2018]. Across these studies and in this EA, PFOA and PFOS were consistently reported at the highest concentrations. Geometric mean concentrations ranged from 24 to 45 ng/g for PFOA and 27 to 35 ng/g for PFOS [Fraser et al. 2013; Wu et al. 2015]. Two of the studies did not report geometric means; for these studies, median concentrations were reported at 9 ng/g and 51 ng/g for PFOA and 14 ng/g and 67 ng/g for PFOS [Karásková et al. 2016 and Scher et al. 2018, respectively]. Geometric mean and median concentrations for PFOA and PFOS measured in the 19 samples collected as part of this EA were lower than what was reported from these four studies. Details on these studies and comparisons with all other measured PFAS can be found in Appendix A, Table A1.

While these results suggest that PFOS and PFOA measured in the dust samples collected in Airway Heights were found at lower levels than reported elsewhere in the United States, note that the studies referenced here do not necessarily provide representative comparisons and are provided only for additional context. The sample collection methods and analytical methods were also not consistent among these studies.

ATSDR also evaluated the correlation between PFAS measured in dust and blood. This analysis included analytical data from 19 dust samples summarized above and from the 30 blood samples collected from participants residing in the same homes. Using log-transformed data, ATSDR calculated Pearson correlation coefficients for the PFAS measured in at least 60% of the dust and the same PFAS measured blood samples for this assessment. Data were log-transformed because dust and blood concentrations were log-normally distributed.

[5] This unit (in this case, representing nanograms of PFAS measured per gram of dust collected) is equivalent to parts per billion and micrograms per kilogram.

None of the PFAS measured in dust were statistically correlated ($p<0.05$) with the same PFAS measured in blood. Pearson correlation coefficients for these comparisons ranged from -0.25 to 0.21 indicating weak correlation between concentrations measured in dust and blood. Note that the sample size for dust measurements in Spokane County is relatively small. ATSDR will further explore these findings, as well as correlations between different PFAS measured in dust and blood (e.g., the correlation between PFOA in dust and PFOS in blood) in the PFAS EA report for all EA sites.

The dust results presented here are exploratory and should be interpreted with caution. They are based on a limited set of samples, and in some cases those samples are based on a small sample mass. The target sample mass for this study was 1 gram, but this target was not always met. Results based on less than 1 gram of dust have higher detection limits, a possible source of bias.

Discussion

At least one PFAS was detected in the blood of all Spokane County EA participants (100%). Because of the widespread use of PFAS, such high detection frequencies are common in the general U.S. population [CDC 2019]. PFHxS, PFOS, PFOA, PFNA, and PFDA were the most frequently detected compounds in Spokane County EA participants (detection frequencies above 90%).

Results from this EA were compared to the NHANES data from 2015–2016.[6] Age-adjusted geometric mean blood levels of PFHxS, PFOS, PFOA, PFNA, and PFDA were statistically higher than these national geometric means (1.2 to 56 times higher).

All PFAS measured in blood for this EA have been phased out of production in the United States. Following this phase-out, national blood PFAS levels have been steadily declining since 2000 [CDC 2019]. Differences between geometric mean Spokane County EA blood levels, collected in 2019, and the NHANES 2019-2020 geometric mean (not yet available) could be greater than the differences between geometric mean Spokane County EA blood levels and the NHANES 2015-2016 geometric mean presented here.

ATSDR compiled blood PFAS levels for the three most prevalent PFAS (PFHxS, PFOS, and PFOA) to provide further context on the current (2019) Spokane County EA blood levels (Appendix A, Table A2):

- For PFHxS and PFOS, blood levels among Spokane County EA participants are higher than the range of those observed in other communities with contaminated drinking water (Appendix A, Table A2). The levels reported here are also higher than the national geometric mean PFHxS and PFOS levels for 1999–2000 (2.1 ppt and 30.4, respectively), the time NHANES first measured PFAS and the time the highest PFAS levels were observed [CDC 2019].
- For PFOA, blood levels among Spokane County EA participants are lower than those observed in two other communities with contaminated drinking water: Little Hocking, Ohio; and Decatur Alabama [Frisbee et al. 2009; ATSDR 2013]. However, PFOA blood levels in Spokane County EA participants are higher than more recent studies in Westhampton Beach/Quogue Area, New

[6] Newer NHANES data are now available, but this report (and all individual EA reports) compares EA results to 2015-2016 NHANES data to be consistent with individual results letters provided to participants. ATSDR will consider including the newer data in the report analyzing data across all EA sites.

York; Portsmouth, New Hampshire; and Montgomery and Bucks Counties, Pennsylvania [NYDOH 2019; NH DHHS 2016; PA DOH 2019].

Generalizability of Spokane County EA Community Statistics

The recruitment method used for this EA was designed to produce summary statistics of blood PFAS levels that were generalizable to the sampling frame as a whole (i.e., Airway Heights households west of Hayford Road). Although all households in the sampling frame were invited to participate in this EA, the population that ultimately enrolled was older, identified more as White, and identified less as Hispanic or Latino, and Black. Specifically, adults aged 50 or older represented 54% of the EA population compared with 22% of the sampling frame, participants who identified as White represented 86% of the EA population compared to 78% of the sampling frame population, and participants who identified as Hispanic or Latino represented 4% of the EA population compared to 8% of the sampling frame. There were also fewer EA participants who identified as Black (<10) compared to the sampling frame population (7%), although there were too few EA participants to statistically compare the two proportions. Given the 7% response rate, it is also possible that other factors were present at different rates than the community as a whole.

Since both age and ethnicity were associated with blood PFAS levels in univariate analyses, the summary statistics for blood PFAS (Table 5) may be biased, or deviate from the true value, when generalizing to the entire sampling frame. ATSDR believes that any bias caused by differences in ethnicity would be minimal because of the overall small proportion of Hispanic or Latino participants in the sampling frame (8%), and because race and ethnicity were not statistically significant in multivariate analyses for PFHxS, PFOS, and PFOA. However, ATSDR was concerned about the potential bias caused by the older age of EA participants since levels of PFAS are known to vary depending on people's age. Therefore, ATSDR quantified the magnitude of the bias introduced by age by calculating geometric means that were adjusted to the age distribution of sampling frame (Table 6). This analysis showed that differences in age distribution between the sampling frame and the EA participants resulted in unadjusted geometric means for blood PFHxS, PFOS, PFOA, PFNA, and PFDA that were biased high by 11% to 25%. Therefore, the sampling frame age-adjusted geometric means for PFAS are more representative of the average levels in the community.

Relationships Between Demographics and PFAS Blood Levels

When evaluating differences in demographic factors by PFAS levels, adult males had statistically higher geometric mean blood levels for PFNA, based on results from the all-adult multivariate models, but did not have statistically elevated differences for other PFAS. In other studies in communities with contaminated drinking water and for the general U.S. population [e.g., ATSDR 2013; NH DPHS 2016; CDC 2019], sex-based differences are likely due to additional excretion routes in females including through menstrual fluid, breastfeeding, pregnancy, and renal clearance rate differences [ATSDR 2021]. PFAS have been demonstrated to pass through the placental barrier and into the developing fetus during gestation and have been measured in maternal serum, cord blood, breast milk [Cariou et al. 2015], placenta [Chen et al. 2017], fetal tissue [Mamsen et al. 2019], and neonates [Wang et al. 2014]. These studies suggest gestation, birth, and breastfeeding as excretion pathways for mothers and gestation and breastfeeding as potential exposure pathways for infants. However, in this EA, sex was not associated with most PFAS in blood, and breastfeeding was not associated with levels in adult women. Having children was found to be associated with lower blood levels of multiple PFAS among adult women. Children who were breastfed had higher PFNA levels than those who did not, but other PFAS concentrations were not related to breastfeeding.

Blood PFAS levels were statistically higher in older adults than younger adults, and the effect of age was stronger in female participants than males. Blood PFAS levels were not statistically associated with age among children (3–18 years). Differences in the associations between blood PFAS levels and age in adults and children have been observed in other studies, and the results of this EA are consistent with the findings for adults [ATSDR 2013; NH DPHS 2016; CDC 2019]. Generally, increasing blood levels in adults are due to the long biological half-lives of PFAS and diminishing excretion rates with increasing age. The half-life of a chemical is the amount of time it takes for 50% of the substance to be eliminated from the body. Some studies estimate that the half-life of PFHxS is between 4.7 and 35 years [ATSDR 2021]. Half-life estimates range from 3.3 to 27 years for PFOS and from 2.1 to 10.1 years for PFOA [ATSDR 2021]. In the presence of continued exposures that exceed clearance rates, PFAS will accumulate in the human body over time. In this EA, blood PFHxS, PFOS, PFOA, PFNA, and PFDA levels were higher in younger children for participants under 18. Although this trend was not statistically significant, this association is likely due to multiple factors including early life exposures and growth dilution. Early-life exposures may have occurred during gestation, since PFAS can cross the placenta and is found in breast milk [ATSDR 2021]. In addition, hand-to-mouth touching and spending more time closer to the floor with settled dust is much greater in toddlers than in older children. As a child grows, these early-life exposure factors diminish. Additionally, large increases in body size lower blood levels despite increasing or constant PFAS body burdens. This process is known as growth dilution [Koponen et al. 2018].

Participants who identified as non-White, or Hispanic had greater blood PFNA and PFDA levels than those who identified as White, non-Hispanic in both univariate and multivariate models. These results are based on limited data and should be interpreted with caution.

Significance of Drinking Water Exposures

ATSDR conducted EAs to learn more about how exposure to PFAS-contaminated drinking water affects blood PFAS levels. This relationship is complicated because EA participants were likely exposed to PFAS not only in contaminated drinking water but also in various consumer products and food items unrelated to the water. ATSDR considered the following lines of evidence to understand the potential significance of the drinking water exposure pathway:

- PFHxS, PFOS, PFOA, PFNA, and PFDA blood levels in EA participants were statistically higher than 2015-2016 NHANES national geometric means. PFAS were first detected in the City of Airway Heights' water supply in 2017. We do not know if contamination began earlier, because no data are available before 2017. Among the site documents ATSDR reviewed, the highest sampling results from an active well in the Airway Heights system were 1,500 ppt for PFHxS, 1,200 ppt for PFOS, and 320 ppt for PFOA. In 2017, City of Airway Heights reduced PFAS levels below the EPA health advisory for PFOS and PFOA. However, these PFAS have very long biological half-lives (2.1 to 35 years). Therefore, even though drinking water PFAS concentrations in the City of Airway Heights were significantly reduced by June 2017, past drinking water exposures would contribute to the EA participants' elevated blood PFAS levels, observed 2 years and 5 months later. Furthermore, in this EA, PFHxS exceeded the national average by the greatest margin (56 times higher when adjusted for age) and showed the greatest association with reported drinking water consumption, which is what would be expected given that PFHxS has the longest half-life of the three PFAS (up to 35 years) and was found at the highest concentration in the drinking water. PFOS exceeded by the next greatest margin (8.3 times higher), followed by PFOA (5.7 times higher).

- Univariate statistical analyses of the EA data found that one of the most consistent predictors of adult blood PFAS levels was longer length of residency in Airway Heights. ATSDR considered residency duration to be a suitable surrogate for drinking water exposures because only residents who lived in the sampling frame before June 2017 would have had any exposure to the PFAS-contaminated drinking water and because of the likelihood that exposure would increase with the number of years that EA participants lived in the area. However, since older adults tended to live in the sampling frame longer, this variable was highly correlated with age in adults. Because of this, it was unclear from univariate models alone whether the association between the time someone lived in the sampling frame and PFAS blood levels was primarily due to age. After controlling for age, sex, and other data characteristics, the multivariate statistical analysis found that residency duration remained statistically associated with blood PFHxS, PFOS, PFOA, and PFNA blood levels, and age remained statistically associated with blood PFHxS, PFOS, PFOA, PFNA, and PFDA levels. In multivariate models conducted separately for males and females the association with PFHxS, PFOS, and PFOA levels remained significant suggesting that this relationship was robust and applied to both males and females. However, multivariate regression models did not explain a large portion of the variability in participants' blood PFAS levels (R^2 ranged between 0.26 and 0.37 for PFHxS, PFOS, and PFOA), indicating that there may be many factors not accounted for.
- ATSDR also considered associations with blood PFAS levels and multiple exposure history questions pertaining to drinking water. Notably, these questions pertained to current drinking water practices. It is uncertain whether these responses would have applied to past drinking water practices. Drinking water consumption rates were not associated with blood PFAS levels with the exception of PFDA. In ATSDR's univariate and multivariate analyses, participants who reported using a filter or treatment device on tap water at home had lower PFHxS, PFOS, PFOA, and PFNA blood levels. Similarly, participants who reported drinking primarily tap water had higher blood PFHxS and PFOS levels than those who reported primarily drinking bottled water. These results provide uncertain and mixed evidence for a drinking water exposure route.
- PFHxS, PFOS, and PFOA were very highly correlated in blood (r = 0.91–0.96) suggesting similar or common background sources or exposure pathways. PFHxS and PFOS, and to a lesser extent PFOA, have many common exposure sources, as these compounds are often found together in consumer products. In addition, a common historical formulation of AFFF contained PFOS and precursors that can break down to PFHxS and PFOA. While correlations between PFAS have been observed in other studies [NH DPHS 2016; ATSDR 2013; CDC 2019], the correlations observed between these three PFAS in the blood results for this EA are much higher than those observed in the general U.S. population (r between 0.46 and 0.66) [Calafat et al. 2007]. The high correlation between PFHxS, PFOS, and PFOA observed in Spokane County is consistent with those found in the blood of people living in a community with contaminated drinking water [ATSDR 2013], providing further evidence that drinking water was likely a contributing source of exposure among Spokane County EA participants. In addition, the correlations between PFHxS, PFOS, and PFOA in this study are much higher than the correlations observed for PFNA and PFDA, providing further evidence of a distinct exposure pathway for PFHxS, PFOS, and PFOA.

Taken together, the data suggest that past drinking water exposure contributed to the elevated blood levels of PFHxS, PFOS, and PFOA observed in the Spokane County EA participants.

Other Exposure Characteristics

Other exposure characteristics that showed statistically significant associations with blood levels of one or more PFAS in either univariate or multivariate analyses included the following:

- **Stain-resistant product use.** Stain-resistant products are sometimes applied to carpeting or upholstered furniture and have been linked to PFAS exposures [Beesoon et al. 2012]. Few participants reported frequent use of stain-resistant products at home; however, the 8% (n=24) of participants who reported "ever" these products had elevated PFDA levels in both univariate and multivariate models compared to those did not. Both PFOS and PFHxS are primary ingredients in historical formulations of stain-resistant consumer products used to treat carpet, furniture, and clothing. PFDA may be present in these products, but it is not a generally a primary ingredient. These results are based on limited data and should be interpreted with caution.
- **Blood donation frequency.** Previous research clearly demonstrates that PFAS have a strong affinity for binding to blood proteins and accumulate in human blood [Jian et al. 2018]. Blood donation therefore has the potential to remove PFAS from the body. In both univariate and multivariate models, lower PFAS blood levels were observed in the few (6%, n=17) Spokane County EA participants who reported donating blood at least once per year. These results are based on limited data and should be interpreted with caution.
- **Fast food consumption.** PFAS may be present in fast food take-away containers and food packaging. Consumption of fast food may serve as an additional source of PFAS exposure. In both univariate and multivariate analyses, participants who reported eating fast food a few times per month and participants who reported eating fast food three times per week or more had lower PFHxS, PFOS, PFOA, and PFNA serum levels than participants that reported eating fast food a few times per year or less. This result differs from other studies and may be due to differences in diet and lifestyle correlated with fast food consumption (e.g., water consumption rates may be lower for individuals who consume more fast food). The final report on all EA sites will include a more robust analysis of fast food consumption and PFAS.
- **Consumption of selected local food items.** Some PFAS accumulate in plants, fish, and animals. In univariate models, participants who reported eating locally caught fish (3%, n=10) had significantly higher blood levels of PFDA. This finding is consistent with longer-chained PFAS such as PFDA bioaccumulating more in fish than shorter-chained PFAS. These results are based on limited data and should be interpreted with caution.

Spokane County Community-Wide Findings

Finding 1. Average blood levels of PFHxS, PFOS, PFOA, PFNA, and PFDA in Airway Heights EA site participants are higher than national levels.

Geometric means (i.e., averages) for PFHxS, PFOS, PFOA, PFNA, and PFDA blood levels were statistically higher ($p<0.05$) in Spokane County EA participants when compared to CDC's NHANES (2015–2016) testing, which was limited to people over 12 years old. The statistically higher blood PFAS levels were observed for both unadjusted geometric means for all EA participants and geometric means adjusted to the age distribution of the U.S. population from NHANES 2015–2016.

Of the PFAS analyzed in blood, PFHxS had the largest elevations when compared to national levels. The age-adjusted geometric mean blood PFHxS level among all EA participants was 56 times higher than the national geometric mean. Blood PFHxS levels were above the national geometric mean and above the

NHANES 95th percentile for 99% of the Spokane County EA participants. Compared to national levels, the age-adjusted geometric mean blood levels among EA participants were 8.3 times higher for PFOS, 5.7 times higher for PFOA, 1.2 times higher for PFNA, and 1.3 times higher for PFDA.

PFUnA and MeFOSAA were detected in fewer than 60% of the EA participant samples; due to the large percentage of samples below the limit of detection, geometric means were not calculated.

Finding 2. Elevated blood levels of PFHxS, PFOS, and PFOA may be associated with past drinking water contamination.

Three PFAS (PFHxS, PFOS, and PFOA) with statistically elevated blood levels compared to national geometric means were detected in Airway Heights drinking water in 2017. We do not know if contamination began earlier because no data are available before 2017. The maximum concentrations observed in active drinking water wells in Airway Heights were 1,500 parts per trillion (ppt) for PFHxS, 1,200 ppt for PFOS, and 320 ppt for PFOA. In June 2017, Airway Heights changed water sources which reduced its PFAS levels below EPA health advisory levels (70 ppt for PFOA and PFOS combined). Before 2016, PFAS-containing AFFF were primarily formulated with PFOS, but also contained various PFAS precursors that could break down in the environment into other PFAS, such as PFHxS, which could explain the elevated blood PFHxS levels. PFHxS, PFOS, and PFOA have long biological half-lives (2.1 to 35 years). There were 2 years and 5 months between when Airway Heights changed water sources to reduce exposure to contaminated drinking water and collection of biological samples during the EA. Because of the long half-lives of PFHxS, PFOS, and PFOA, past drinking water exposures may have contributed to the EA participants' blood levels. PFHxS has the longest estimated half-life of the three compounds (up to 35 years), which may be why it exceeded the NHANES 2015-2016 geometric mean by the largest margin.

PFHxS, PFOS, and PFOA were highly correlated in Airway Heights residents' blood (Pearson correlation coefficient, *r*, between 0.91 and 0.96). This means that typically, residents who had elevated blood PFHxS levels also had elevated blood PFOS and blood PFOA levels. This correlation suggests a common exposure source, such as the Airway Heights public water supply (prior to June 8, 2017), though other sources of exposure may also have contributed to the observed blood levels.

Additional observations from the multivariate analyses support the finding that past exposure to contaminated drinking water may also have contributed to the elevated blood levels.

- First, a consistent and statistically significant predictor of participant blood levels for PFHxS, PFOS, and PFOA was how long the resident had lived in Airway Heights during the past 20 years. Those who lived in the area longest likely drank, in total, a larger volume of contaminated water. For every year a participant reported having lived in Airway Heights, there was an increase in blood levels of PFHxS by 7.2%, PFOS by 5.6%, and PFOA by 3.9%.
- Second, adults who used at least one filter or treatment device had statistically lower blood levels of PFHxS (28%), PFOS (29%) and PFOA (27%) when compared to those who did not have a filter.
- Third, adults who reported mainly drinking tap water at home on average had statistically higher blood levels of PFHxS (29%) and PFOS (25%) when compared to those who reported mainly drinking bottled water.

PFNA and PFDA blood levels in Spokane County EA participants were also statistically elevated compared to the U.S. population. Blood levels for these PFAS were not as closely correlated to those for

the other three PFAS (PFHxS, PFOS, PFOA). This suggests that drinking water contamination may not have been as strong a predictor of exposure for PFNA and PFDA .

Finding 3. Age, sex, race and ethnicity, stain-resistant product use, blood donation frequency, fast food consumption, and child births were associated with some PFAS blood levels.
PFAS blood levels varied with different demographic and exposure characteristics of the participant population. The following relationships were statistically significant in multivariate analyses in the Spokane County EA data set in adult participants (and are consistent with those reported in other non-ATSDR PFAS studies except where noted below for fast food consumption):

- Blood levels of PFHxS, PFOS, and PFOA were higher in older participants. Blood levels of these compounds increased by 1.1% to 1.8% for every year of participant age.
- Males had higher blood levels of PFNA than females. Blood levels in adult males were 77% higher for PFNA.
- On average, adult participants who identified as non-White or Hispanic on average had higher blood PFNA (37%) and PFDA (33%) levels than adult participants who identified as White and non-Hispanic.
- Only 24 participants reported ever using stain resistant products, and most of these reported their frequency of use as "rarely." Participants who reported ever using stain-resistant products had 26% higher blood levels of PFDA than those who reported never using these products. Because of the small sample size for people who ever used stain resistant products, these results should be interpreted with caution.
- Only 17 participants reported donating blood at least once or more a year. Participants who reported donating blood at least once or more a year had lower blood levels of PFHxS (67%), PFOA (60%), and PFNA (49%) than adult participants who reported never or rarely donating blood. Because of the small sample size for people who reported donating blood once or more a year, these results should be interpreted with caution.
- Participants who reported more fast food consumption had lower PFHxS, PFOS, PFOA, PFNA, and PFDA blood levels. Participants who reported eating fast food a few times per month on average had lower blood PFHxS (43%), PFOS (41%), PFOA (36%), and PFNA (24%) levels compared to participants who reported eating fast food a few times per year or less. This effect was stronger for participants who reported eating fast food three times per week or more. This finding differs from other studies and may be due to differences in diet and lifestyle correlated with fast food consumption. This finding does not mean that eating more fast food will reduce exposure to PFAS.
- Female participants' blood levels for some PFAS decreased with increasing number of children they had given birth to. This effect was observed for blood levels of PFHxS (11.7% reduction in blood levels per child), PFOS (9.3% per child), PFOA (13.7% per child), and PFNA (8.1% per child).

Two associations were observed in children (<18 years), though many variables could not be examined because of the small number of child participants (n=47). Because of the small sample size, results should be interpreted with caution. Specifically, children who were breastfed had 59% higher blood levels of PFNA than non-breastfed children. Second, children who drank formula prepared with tap water had significantly higher serum levels of PFHxS (2.2% per month on formula) and PFOS (1.5% per month on formula) than children who never drank formula prepared with tap water. Infants born to mothers exposed to PFAS can be exposed in utero and while breastfeeding. However, based on current

science, the benefits of breastfeeding outweigh the risks for infants exposed to PFAS in breast milk. The final report on all EA sites will include a more robust analysis of children.

Finding 4. Only two PFAS were detected in urine.

ATSDR analyzed 34 (10%) of the urine samples collected. Only perfluorobutanoic acid (PFBA) and PFHxS were detected; they were detected in 53% and 26%, respectively, of the 34 samples analyzed. ATSDR did not analyze all participants' urine samples because none of the species were detected in more than 60% of the samples analyzed.

Finding 5. All Airway Heights tap water samples collected during the EA in 2019 met the EPA's HA and Washington state public health guidelines for PFAS in drinking water.

This is based on 19 unfiltered and 7 filtered tap water samples collected in 19 households during the EA.

Finding 6. Patterns and levels of dust contamination measured in participating EA households are comparable to those reported in selected U.S. studies.

Among the PFAS detected most frequently in household dust samples, PFOS, PFOA, and PFHxA were measured at the highest concentrations. No nationally representative comparison values are available, but geometric mean and median concentrations for PFAS measured in dust collected in a small subset of participating households (n=19) were within the range of levels reported in a few published studies of other U.S. communities (with or without known PFAS contamination). None of the PFAS measured in this EA's household dust samples were statistically correlated with the same PFAS measured in participants' blood. The final report on all EA sites will include a more robust comparison of PFAS measured in dust and blood.

Limitations

There are several limitations associated with this assessment.

- The EA participant sample may not be representative of the community. All households in the study area were invited to participate, and 7% participated in the EA. Participant characteristics were different than those of the area's overall population. Participants were older and more likely to identify as White. ATSDR addressed some of these differences by calculating geometric mean estimates that were adjusted to the age distribution of the community.
- Measurement of blood, urine, and environmental PFAS concentrations for EA participants may improve the understanding of exposure in this community but will not provide information about all sources of exposure. Additionally, identifying every potential confounding exposure is not possible.
- There are challenges in measurement of trace levels of PFBA in urine, including selectivity of the analytical instrumentation and potential for external contamination. Therefore, we advise caution when interpreting the PFBA results in urine.
- Multivariate regression models did not explain a large portion of the variability in participants' blood PFAS levels (R-squared or R^2, a measure of model goodness-of-fit, ranged between 0.30 and 0.40). This means that other factors not identified could influence the relationships reported in this assessment (see "Statistical Analysis" section for details).
- This study did not directly assess participants' tap water consumption prior to the reduction of PFAS in the municipal water system.

- This EA was not designed to investigate health outcomes. Without additional information about exposure-response relationships, the results of this EA cannot be used to assess current or past health problems or predict the future occurrence of disease. PFAS found in a person's blood or urine means that exposure has occurred. The presence of PFAS in blood or urine does not tell us how, where, when, or for how long a person was exposed to PFAS. Exposure to PFAS does not mean adverse health effects will result, either now or in the future.
- The dust results are exploratory and should be interpreted with caution. They are based on a limited set of samples, and in some cases those samples are based on a small sample mass.

Recommendations

This PFAS EA provides evidence that past exposures to PFAS in drinking water have impacted the levels of PFAS in people's bodies. These PFAS are eliminated from the body over a long period of time. This allowed ATSDR to measure PFAS even though exposures through drinking water were mitigated, or lowered, years ago.

Although the exposure contribution from PFAS in public drinking water in Airway Heights has been mitigated, there are actions community members and city officials can take to further reduce exposures to PFAS and protect public health.

Based on the PFAS drinking water test results from the City of Airway Heights' municipal water system, ATSDR does not recommend an alternate source of drinking water at this time.

1. What the City of Airway Heights can/should do:
    a. Operators of the municipal water system should continue to monitor concentrations of PFAS in drinking water delivered to the Airway Heights community to ensure that concentrations of PFAS remain below the EPA's HA for specific PFAS in drinking water. Results of PFAS monitoring should be shared with community members through appropriate communication channels (Consumer Confidence Reports: http://www.cawh.org/departments/public-works/water-reports).
    b. All treatment systems to remove PFAS from the public drinking water in Airway Heights should be maintained appropriately to ensure that PFAS concentrations remain below the EPA's HA for specific PFAS in drinking water.
2. What community members can/should do:
    a. Become familiar with Consumer Confidence Reports (http://www.cawh.org/departments/public-works/water-reports) for information on the City of Airway Heights' water quality.
    b. Private well owners living in the area affected by PFAS should consider having their wells tested for PFAS if testing has not been conducted before. To learn more about testing wells for PFAS visit: https://ecology.wa.gov/Water-Shorelines/Water-supply/Wells/Testing-drinking-water. Global public health organization NSF International has developed a test method to verify a water filter's ability to reduce PFOA and PFOS to below the health advisory levels set by the EPA. NSF International-approved devices can be found at: https://info.nsf.org/Certified/DWTU/. Click on "reduction devices" at the bottom of the page for PFOA and PFOS.

c. Nursing mothers should continue breastfeeding. Based on current science, the known benefits of breastfeeding outweigh the risks for infants exposed to PFAS in breast milk.

d. When possible, eliminate or decrease potential exposure to PFAS in consumer products such as stain-resistant products and food packaging materials. To learn more, visit: https://www.fda.gov/food/chemical-contaminants-food/questions-and-answers-pfas-food.

e. Pay attention to advisories about food consumption, such as local fish advisories.

f. Discuss any health concerns or symptoms with your health care provider. Share results of PFAS blood testing with your health care provider and make them aware of ATSDR resources for clinicians (https://www.atsdr.cdc.gov/pfas/resources/info-for-health-professionals.html). Follow the advice of your health care provider and the recommendations for checkups, vaccinations, and health screening tests.

j. At this time, ATSDR does not have plans to conduct additional blood testing for PFAS or recommend PFAS EA participants get individually retested for PFAS in blood.

   - The biological half-lives of many of the PFAS measured in people's blood are long. PFHxS, in particular, has one of the longest half-lives–some estimates range in the decades. This means that PFAS blood levels are not expected to change significantly in the near term, even if exposure stops. Additionally, it is unclear what an individual's PFAS test results mean in terms of possible health effects.

   For the general population, blood tests for PFAS are most useful when they are part of a scientific investigation like the EA. Test results tell you how much of each PFAS is in your blood, but it is unclear what the results mean in terms of possible health effects. In addition, blood testing for PFAS is not a routine test offered by most doctors or health departments. If you are concerned about the effect of PFAS on your health, talk to your health care provider and make them aware of ATSDR resources for clinicians (https://www.atsdr.cdc.gov/pfas/resources/info-for-health-professionals.html).

g. Follow the advice of your child's health care provider and the recommendations for well child checkups, vaccinations, and recommended health screening tests. Consult https://health.gov/myhealthfinder to help identify those vaccinations and tests.

h. For additional information about environmental exposures and children's health, contact the Pediatric Environmental Health Specialty Units, a nationwide network of experts in reproductive and children's environmental health (https://www.pehsu.net/).

For More Information

If you have questions or comments or want more information on the Spokane County (Airway Heights) EA site, call 800-CDC-INFO or email pfas@cdc.gov. For more information on the work CDC/ATSDR is doing to address PFAS exposure, visit ATSDR's PFAS website: https://www.atsdr.cdc.gov/pfas/. For other EA or PFAS-related questions, email pfas@cdc.gov.

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This list includes references for Appendices A, B, and *C, as well as the sections above.*

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