# Martinsburg
## Berkeley County | West Virginia

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 | 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 |
| UCMR 3 | Third Unregulated Contaminant Monitoring Rule |
| WVDEP | West Virginia Department of Environmental Protection |

# 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 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. 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 blood for long periods. 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) have conducted 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 in and around the City of Martinsburg in Berkeley County, West Virginia, near Shepherd Field Air National Guard Base (the Base). When all EAs are complete, ATSDR will prepare a report describing the results across all sites.

The Base previously used aqueous film forming foam (AFFF) containing PFAS for its firefighter training. It is not known when the Base first used the foam, but it is believed to have started in the 1970s [WV ANGB 2015]. Over time, the PFAS from the AFFF entered the ground, moved into the groundwater to offsite locations, and affected the City of Martinsburg's Big Springs well located downgradient of the Base. This well supplies water to customers from both the City of Martinsburg and the Berkeley County Public Service Water District (PSWD). In May 2016, the City of Martinsburg removed its Big Springs well from service. A treatment system was installed in December 2017, and the City of Martinsburg now conducts routine monitoring to ensure treatment is effectively removing PFAS. Based on the information ATSDR has reviewed, the City of Martinsburg and the Berkeley County PSWD public drinking water supply currently meets the U.S. Environmental Protection Agency's (EPA) 2016 health advisory (HA) for PFAS in drinking water. At this time, ATSDR does not recommend community members who get their water from the City of Martinsburg or Berkeley County PSWD use alternative sources of water.

This EA assessed PFAS levels in the blood and urine of Berkeley County residents living near Shepherd Field Air National Guard Base. Test results were compared to PFAS levels in a nationally representative sample of people. Tap water and indoor dust samples from a subset or households were also analyzed for PFAS. These EA results will help participants and their communities better understand their PFAS exposure, explain what they can do to protect themselves from exposures, 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 Berkeley County residents who met eligibility criteria to participate in the EA. To be eligible to participate, household residents must have (1) lived within the sampling frame and received their drinking water from the City of Martinsburg or the Berkeley County PSWD for at least 1 year before May 19, 2016 (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 September and October 2019, 275 people from 165 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 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 Berkeley County residents who participated in the EA. 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 Berkeley County blood and urine data are compared to a nationally representative sample of the US population. Specifically, ATSDR compared Berkeley County 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 and tests them for chemicals, including PFAS, from a representative sample of the civilian non-institutionalized U.S. population. 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 (areas served by the City of Martinsburg and Berkeley County PSWD water supplies that receive water from the Big Springs well) population with a precision 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 5% to 21%. 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

[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.

frame community. To assess possible relationships between blood levels and various demographic and exposure variables, ATSDR used statistical models. Univariate statistics were used to evaluate one variable at a time, mostly as a tool to examine the data broadly and find patterns that existed within the data. Multivariate statistics and regression modeling were used to account for multiple variables simultaneously to control for potential confounding factors.

## Berkeley County Community-Wide Findings

### Finding 1. Average blood levels of PFHxS in the Berkeley County EA site participants are higher than national levels. Averages of other PFAS were not higher than the national average or were detected too infrequently to compare to national averages.

Geometric means (i.e., "averages") for PFHxS blood levels were statistically higher ($p<0.05$) in Berkeley County EA participants when compared to CDC's NHANES (2015–2016) data, 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 applied in NHANES 2015–2016.

Of the PFAS analyzed in blood, only PFHxS was elevated when compared to national levels. The age-adjusted geometric mean blood PFHxS level among all Berkeley County EA participants was 2.5 times higher than the national average. Blood PFHxS levels were above the national geometric mean for 83% of the Berkeley County EA participants and above the NHANES 95$^{th}$ percentile for 31%.

Other PFAS measured in this EA (PFOS, PFOA, PFNA and PFDA) were not higher than the national average. PFUnA and MeFOSAA were detected in fewer than 60% of the EA participant samples; due to the large percent of samples below the limit of detection, geometric means were not calculated.

### Finding 2. Elevated blood levels of PFHxS may be associated with past drinking water contamination.

PFHxS, the one PFAS with statistically elevated blood levels compared to the national geometric mean, was first detected in City of Martinsburg's Big Springs well in 2014. It is likely that contamination began earlier, but no data are available before 2014. This contaminated well also supplied water to the Berkeley County PSWD. The maximum concentration observed for PFHxS in active drinking water wells in these systems was 105 parts per trillion (ppt). PFOS and PFOA were also detected; the maximum concentrations observed in active drinking water wells were 114 ppt for PFOS and 46 ppt for PFOA. In 2016, City of Martinsburg reduced concentrations of PFAS in their contaminated well below U.S. 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 into other PFAS, such as PFHxS, which could explain the elevated blood PFHxS levels. PFHxS, PFOS, and PFOA have very long biological half-lives (2.1 to 35 years). There were 3 years and 5 months between the reduction of exposure via contaminated drinking water and collection of the biological samples during the EA. PFHxS has the longest estimated half-life (up to 35 years) of the three compounds. Because of its long half-life past drinking water exposures may have contributed to the EA participants' blood levels.

PFHxS, PFOS, and PFOA were positively correlated in Berkeley County residents' blood (Pearson correlation coefficient, *r* between 0.66 and 0.74). This means that typically, residents who had greater blood PFHxS levels also had greater blood PFOS and blood PFOA levels. This correlation suggests a common exposure source, such as the City of Martinsburg or Berkeley County PSWD public water supply, though other sources of exposure may also have contributed to the observed blood levels.

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

- First, in univariate models, a consistent and statistically significant predictor of participant blood levels for PFHxS was how long the resident had lived in Berkeley County during the past 20 years. Those who lived in the area longest likely drank, in total, more contaminated water. This relationship remained significant in the multivariate models.
- Second, in multivariate analyses, participants who lived in the City of Martinsburg service area had 60% higher PFHxS blood levels than those who lived in the Berkeley County PSWD service area. In both water systems, contaminated water from the Big Springs well mixed with uncontaminated water from other parts of the system. The area included within the sampling frame for each water system was determined in consultation with staff from the water systems using their knowledge of the structure and flow of water in each system. Because the shape of the sampling frame was estimated, and not based on measured PFAS concentrations, it is possible that more mixing occurred in the Berkeley County PSWD.

Multivariate models conducted separately for males and females suggest that the relationship between blood levels and public water supply was primarily observed in male participants.

### Finding 3. Age, sex, blood donation, kidney disease, and length of residency were associated with some PFAS blood levels.

PFAS blood levels varied with different demographic and exposure characteristics of the participant population. The following statistically significant relationships in the Berkeley County EA data set were observed in adult participants (and are consistent with those reported in other non-ATSDR PFAS studies):

- Blood levels of PFHxS, PFOS, and PFOA varied by age in EA participants, but the size and direction of the effect varied by sex. In females, blood levels for these compounds increased by 1.5% to 2.4% for every year of participant age. In males, blood levels for PFHxS decreased by 0.46% for every year of participant age and increased for PFOS and PFOA by 0.23% per year.
- Males had higher blood levels of PFHxS, PFOS, and PFOA than females. The difference between males and females was larger in younger people. For example, 30-year-old males had higher blood PFHxS, PFOS, and PFOA levels than 30-year-old females by 175%, 136%, and 48%, respectively. For 50-year-old males, this difference was reduced to 58% for PFHxS, 71% for PFOS, and 12% for PFOA compared to 50-year-old females.
- Only 24 participants reported donating blood at least once or more a year. Participants who reported donating blood at least once or more a year had 31% lower blood levels of PFOS than adult participants who did not do so. Because of the small sample size for people who reported donating blood at least once or more a year, these results should be interpreted with caution.
- Eight percent (n=19) of adult participants reported a diagnosis of kidney disease. Participants who reported a history of kidney disease had PFOS blood levels that were 27% lower than those who did not. Because of the small sample size for people who reported a diagnosis of kidney disease, these results should be interpreted with caution.
- Blood levels of PFHxS increased with the number of years participants lived in the sampling area. For every additional year that an adult participant lived in the Berkeley County EA site, blood PFHxS increased by 5.3%. Length of residency can be considered a proxy for potential exposure to PFAS contaminated drinking water.

Because of the small number of child participants (n=28), associations between blood PFAS levels and many variables could not be examined. Any observations in children are noted in the text, but in most cases significant associations were not observed in the small sample size. The final report on all EA sites will include an analysis of children.

### Finding 4. Only one PFAS was detected in urine and at low concentrations.

ATSDR analyzed 27 (10%) of the urine samples collected. Only perfluorobutanoic acid (PFBA) was detected; it was detected in 67% of the 27 samples analyzed. Per the study protocol, ATSDR did not analyze all participants' urine samples because the initial analysis did not show that geometric mean urine concentrations of any PFAS were higher than the NHANES 95$^{th}$ percentile values.

### Finding 5. All Berkeley County tap water samples collected during the EA in 2019 met the EPA's HA for PFAS in drinking water.

This is based on 17 unfiltered and 10 filtered tap water samples collected in 19 households during the EA.

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

Among the PFAS detected most frequently in household dust samples, PFOA and PFOS 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 looking at other U.S. communities (with or without 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 5.6% of the households participated in the EA. Participant characteristics were different that those of the area's overall population; specifically, participants were older. ATSDR addressed 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 in EA participants may improve the understanding of exposure in this community but will not provide information about all sources of exposure. Additionally, identifying every source of exposure is not possible.
- 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 0.10 and 0.20). 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 tap water consumption prior to the reduction of PFAS from the two public water supplies.
- 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, nor 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 amount.

## Recommendations

This PFAS EA has demonstrated that past exposures to PFAS in drinking water have impacted the levels of PFAS in people's bodies. 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 drinking water in the City of Martinsburg and Berkeley County PSWD service areas has been mitigated, there are actions community members and city and county 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 Martinsburg and Berkeley County PSWD, ATSDR does not recommend an alternate source of drinking water at this time.

1. What the City of Martinsburg and Berkeley County can/should do:
    a. Operators of the two public water systems should continue to monitor concentrations of PFAS in drinking water delivered to the service areas 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 for City of Martinsburg: https://www.cityofmartinsburg.org/residents/city-services/utilities; Consumer Confidence Reports for the Berkeley County PSWD, https://www.berkeleywater.org/consumer-confidence-reports)
    b. All treatment systems to remove PFAS from the public drinking water in the City of Martinsburg and Berkeley County PSWD 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 (City of Martinsburg: https://www.cityofmartinsburg.org/residents/city-services/utilities; Berkeley County PSWD: https://www.berkeleywater.org/consumer-confidence-reports) for information on the quality of the water provided by the City of Martinsburg and Berkeley County PSWD.
    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. 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: http://info.nsf.org/Certified/DWTU/ Click on "reduction devices." To learn more about testing wells for PFAS visit: https://www.wvdhhr.org/phs/water/Fact%20Sheets/PrivateWellOwners-FourStepstoWaterWellSafety.pdf.

c. Nursing mothers should continue breastfeeding. Based on current science, the known benefits of breastfeeding appear to 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.

g. Blood tests for PFAS are most useful when they are part of a scientific investigation like the EA. If you are concerned and choose to have your blood tested, test results will 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 would like to have your or your children's blood tested, 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 Berkeley County (Martinsburg) 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 in and around the City of Martinsburg in Berkeley County, West Virginia. This report summarizes the findings of the Berkeley County EA. When all EAs are complete, ATSDR will prepare a report describing the results across all sites.

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 Holiday Inn Martinsburg, between September 24 and October 7, 2019. During the same time frame, ATSDR also took water and dust samples in a subset of randomly chosen participant homes.

The PFAS exposure assessment in Berkeley County focused on a specific area near Shepherd Field Air National Guard Base. Participants were recruited from certain areas serviced by the City of Martinsburg and Berkeley County water supply systems where the highest levels of PFAS in drinking water likely occurred. Households located in parts of the City of Martinsburg located west of Interstate 81 (I-81) and Amber Woods housing complex (east of I-81), as well as in an area of Berkeley County PSWD south of the Big Springs treatment plant were invited to participate. For purposes of this report, we use Berkeley County EA to designate the exposure assessment conducted in these areas. For more information and a map of the area see the "Methods" section of the report.

The results of the EA

- tell us the amount of PFAS in the blood and urine of individual participants and the Berkeley County 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 impact 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. Nor does the EA 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 long biological half-lives. Other countries may still manufacture and use them, but U.S. manufacturers have replaced these compounds with shorter chained PFAS 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; Gluge et al. 2020; 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 Berkeley 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 from 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 some 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 who have current or past exposures 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 has been 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 Berkeley County?

Berkeley 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.[2]

PFAS and precursors that degrade to other PFAS 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 Shepherd Field Air National Guard Base used AFFF containing PFAS for its firefighter training [WV ANGB 2015]. Over time, the PFAS from the AFFF moved off site in groundwater and contaminated the City of Martinsburg's Big Springs well located downgradient of the Base.

The Big Springs well water enters the City of Martinsburg's municipal water supply and eventually mixes with other water sources. City customers who live in an area west of Interstate 81 (I-81) or in the Amber Woods housing complex (east of I-81) were more likely to receive drinking water from this well (see Figure 1). In addition, Berkeley County PSWD purchased water from the City of Martinsburg, and some of that water entered the Berkeley County system near the location of the Big Springs well. As a result, Berkeley County customers who live south of the Big Springs treatment plant (Figure 1) were also more likely to receive the contaminated drinking water.

When PFAS first entered City of Martinsburg's and Berkeley County PSWD's public water systems is not known. These substances were first detected in the City of Martinsburg's water in February 2014, through testing conducted for the U.S. Environmental Protection Agency's (EPA's) Third Unregulated Contaminant Monitoring Rule (UCMR 3) [EPA 2017]. The rule required testing for six PFAS. In 2013, prior

[2] 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.

to detection of PFAS, 20% of the City's drinking water came from the Big Springs well, with the remaining water coming from an uncontaminated source.

The levels measured during UCMR 3 were not above EPA's provisional health advisory at the time, which was 400 parts per trillion (ppt) for PFOA and 200 ppt for PFOS. However, when EPA issued a lifetime health advisory for the sum of PFOA and PFOS levels in drinking water (70 ppt) in 2016, the 2014 contamination levels were above this health advisory. On May 19, 2016, the City of Martinsburg removed its Big Springs well from service until a treatment system was installed to remove PFAS from the well water. The highest sampling result measured in the Big Springs treatment plant prior to mitigation was 105 ppt for PFHxS, 114 ppt for PFOS, and 46 ppt for PFOA [WVDEP 2016].

The West Virginia Department of Environmental Protection (WVDEP) investigated the source of PFAS contamination at the Big Springs well. WVDEP's environmental sampling study linked the Base's releases to PFAS contamination in the City of Martinsburg drinking water system [WVDEP 2016]. This conclusion was based on least two lines of evidence: the spatial pattern in contamination levels and knowledge of local subsurface features, such as underground conduits left by historic mining activity that connect regions near the Base to the City of Martinsburg's well source.

In December 2017 the Big Spring well was operational again with a granular activated carbon (GAC) system installed to remove PFAS from the water. Since 2016, routine monitoring conducted by the City of Martinsburg has consistently shown all PFAS compounds in the finished drinking water to be well below EPA's HA. This ongoing monitoring has demonstrated the effectiveness of the GAC system.

The information available to ATSDR indicates that in 2019, the drinking water serving the City of Martinsburg and the Berkeley County PSWD met the EPA's HA for PFAS in drinking water.

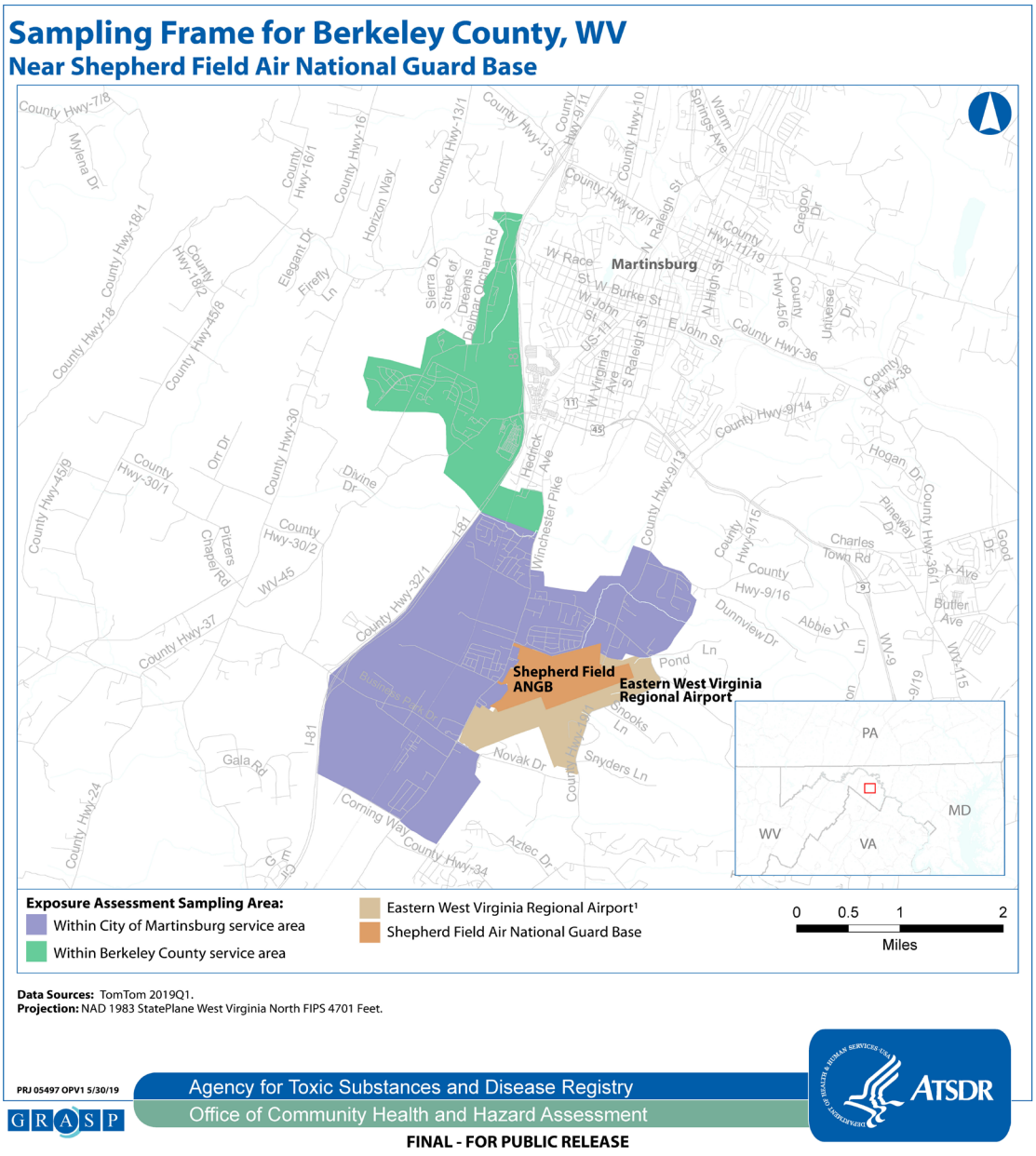
# Methods

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 Berkeley County EA.

## Sampling Frame

This EA targeted a specific geographic area, called the sampling frame or sampling area. The sampling frame for this EA included two areas (see Figure 1). One was a portion of the Berkeley County PSWD service area south of the Big Springs treatment plant. The other was certain areas in the City of Martinsburg located west of Interstate 81 (I-81) and in the Amber Woods housing complex (east of I-81). Based on a review of Berkeley County land parcel data, ATSDR determined that 2,922 households were located in the sampling frame. 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://www.wvdhhr.org/phs/water/Fact%20Sheets/PrivateWellOwners-FourStepstoWaterWellSafety.pdf.

**Figure 1. Sampling frame for Berkeley County Exposure Assessment**




## Participant Eligibility

Berkeley County residents within the sampling frame who met the following criteria were eligible to participate in the EA:

- Lived within the sampling frame (served by the City of Martinsburg and Berkeley County PSWD water supplies that receive water from the Big Springs well) for at least one year before May 19, 2016, which is when the City of Martinsburg Water Department reduced PFAS drinking water concentrations in the Big Springs 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 reimbursements or incentives and paid no costs to participate.

## Participant Recruitment

ATSDR invited all 2,922 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 could not be reached by phone. Each household for which ATSDR had a phone number received a minimum of three recruitment call attempts. 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. In-person visits occurred after each household had received an initial outreach letter and at least one recruitment call attempt.

After two waves of recruitment (initially reaching out to 448 households and later reaching out to an additional 2,474 households), 334 residents from 186 households scheduled appointments for biological sampling and questionnaire completion.

ATSDR attempted to recruit approximately 10% of participating households for environmental sampling (i.e., 15 households from which at least one person had scheduled an appointment at the time environmental recruitment calls were made). ATSDR invited 33 households to participate and 19 households scheduled environmental sampling appointments.

## Data Collection and Analysis

The Berkeley 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 Holiday Inn Martinsburg between September 24 and October 7, 2019. During the same time frame, ATSDR also collected environmental samples in a subset of randomly chosen participant homes. All data met the stringent quality control requirements for sample collection and analysis and are therefore of high quality.

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 blank consent forms are included in the PFAS EA Protocol.

ATSDR project staff handled all data collected in strict 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 West Virginia 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 334 residents who scheduled data collection appointments, 285 (85%) participated in the EA. ATSDR administered exposure history questionnaires to these 285 individuals: 254 adults and 31 children between the ages of 3 and 17. ATSDR used one questionnaire for adults and another for children. Both addressed various 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 281 participants. The phlebotomists were not able to collect samples from 4 participants because they lacked viable veins or refused to provide a blood sample. 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 six participants had not lived in the sampling frame for at least one full year before May 19, 2016, 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 275 blood samples (247 adults and 28 children) were considered in the community exposure summary. These samples were collected from participants residing in 165 unique households. This represents a household participation rate of 5.6% (i.e., 5.6% of the 2,922 recruited households had at least one person participate in the EA).

Urine samples were collected from 283 participants (254 adults and 29 children; two children could not provide a urine sample). Per the EA protocol, 10% of the urine samples were randomly selected for initial analysis. Of these 28 samples, one of these was from an individual who was among the six who were later found to not be eligible for the study. The 27 analyzed urine samples were collected from participants (24 adults and 3 children) who resided in 23 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). As part of NHANES, CDC takes blood and urine samples and tests the samples 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 the 19 households that had scheduled appointments. 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 filtration 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 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 | 2,922 |
| *Wave 1 of recruitment* | *448* |
| *Wave 2 of recruitment* | *2,474* |
| Households reached by mail | 2,612 |
| Households reached by phone | 1,113 |
| Household in-person visits | 2,509 |
| Biological sampling: | |
| Individuals enrolled | 334 |
| Households enrolled | 186 |
| Environmental sampling: | |
| Households invited | 33 |
| Households enrolled | 19 |
| **Data Collection** | |
| Completed questionnaires | 285 |
| *Adults* | *254* |
| *Children* | *31* |
| Blood samples | |
| Included in community statistics (165 households) | 275 |
| *Adults* | *247* |
| *Children* | *28* |
| Urine samples | |
| Collected | 283 |
| *Adults* | *254* |
| *Children* | *29* |
| Included in community statistics (23 households) | 27 |
| *Adults* | *24* |
| *Children* | *3* |
| Dust samples collected and analyzed (one composite sample per household) | 19 |
| Tap water samples collected and analyzed (19 households) | 27 |
| Filtered | *10* |
| Unfiltered | *17* |

## 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 of at least 15% and a 5% level of significance for PFOS), (2) compare community level data to national averages, and (3) explore relationships between reported 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 in NHANES.

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 25$^{th}$, 50$^{th}$ [median], 75$^{th}$, 90$^{th}$, and 95$^{th}$ 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, 95 times out of 100 the mean of the sampling frame population would fall within this range.

**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 Berkeley 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 including female-specific variables (e.g., women having biological children [yes/no], having breastfed children [yes/no], duration of breastfeeding across all children), 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 and low detected PFAS concentrations. ATSDR analyzed a subset of the samples and found that, for all PFAS except PFBA, 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 95$^{th}$ 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 95$^{th}$ percentile. Since only PFBA was detected in >60% of the analyzed samples, the geometric mean was calculated for only this PFAS in urine. Because the geometric mean for PFBA in urine did not exceed the 95$^{th}$ percentile from NHANES, ATSDR did not analyze the remainder of the urine samples. ATSDR did calculate the 95$^{th}$ percentile concentration for 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 the 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 0.31 to 0.52, suggesting weak to moderate 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 Berkeley County EA participants and compares their demographics to those of people in the sampling frame population, 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 Berkeley 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 Berkeley 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 Berkeley County EA participants

| Characteristics | Count of EA Participants (n)* | Percent of EA Participants (%)‡ |
|---|---|---|
| **Adults and children combined** | | |
| Age (years) | (mean =52.7) | |
| <18 | 28 | 10 |
| 18 to <50 | 78 | 28 |
| 50+ | 169 | 61 |
| Sex | | |
| Male | 128 | 47 |
| Female | 147 | 53 |
| Race and ethnicity† | | |
| White, non-Hispanic | 222 | 82 |
| non-White or Hispanic | 49 | 18 |
| **Adults only** | | |
| Years lived at current address | (mean =17.3) | |
| <10 | 70 | 28 |
| 10 to <20 | 97 | 39 |
| 20 to <30 | 38 | 15 |
| 30+ | 42 | 17 |
| Current primary drinking water source | | |
| Public water system | 169 | 68 |
| Bottled water | 78 | 32 |
| Average tap water consumption while living at current home (8-ounce cups per day) | (mean = 6.8) | |
| 0 | 23 | 9 |
| >0 to <2 | 15 | 6 |
| 2 to <4 | 43 | 17 |
| 4 to <6 | 40 | 16 |
| 6 to <8 | 40 | 16 |
| 8+ | 85 | 35 |
| Current use of treatment or filtration device | | |
| One or more filter/treatment device(s) | 185 | 75 |
| None | 61 | 25 |
| Occupational exposures to PFAS in the past 20 Years | | |
| One or more occupational exposure(s) | 28 | 11 |
| None | 216 | 89 |

* 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 sums of percentages for different fields in this table do not always add up to 100%, because not every participant answered corresponding questions during the questionnaire and because of rounding.

The average age of EA participants was 52.7 years, and 82% of the participants identified themselves as White non-Hispanic. Of EA participants, 53% identified as female and 47% identified as male, and 90% were adults, aged 18 years or older. This age cutoff is important because adults were administered a different exposure history questionnaire with more detailed questions. Among the adult participants, 72% reported living in their current homes for more than 10 years.

Adults were also asked about their current primary sources of drinking water: 68% said their current primary source of drinking water is a public water system (City of Martinsburg or Berkeley County PSWD), and 32% said bottled water is their current primary drinking water source. Adults reported drinking an average of 6.8 8-ounce cups of water a day at home, and 75% 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: 11% reported holding one or more jobs with potential PFAS exposures (e.g., firefighting, military, aviation).

## Comparison of Berkeley 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., the area shown in Figure 1). 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 one significant difference — the EA participants included a higher proportion of older adults (age 50+ years) and a lower proportion of younger adults (18–50 years) and children (<18 years) than the sampling frame population (Table 4). Specifically, 61% of the EA participants reported being 50 or older, but 30% 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, 10% of the EA participants reported being under 18, but 25% of the sampling frame population falls in that age range.

Among the race/ethnicity characteristics, none showed a significant difference between the EA participants and the sampling frame population (Table 4).

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 | 28 | 10 | 25 | <0.001 |
| 18 to 50 | 78 | 28 | 45 | <0.001 |
| 50+ | 169 | 61 | 30 | <0.001 |
| Race | | | | |
| White | 234 | 85 | 83 | 0.387 |
| Black or African American | 19 | 7 | 11 | 0.071 |
| Am. Indian and AK Native | <10 | — | 0.3 | — |
| Asian | <10 | — | 2 | — |
| Nat. Hawaiian/Pacific Islander | <10 | — | 0.04 | — |
| Ethnicity | | | | |
| Hispanic or Latino (of any race) | 17 | 6 | 4.3 | 0.198 |

* 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

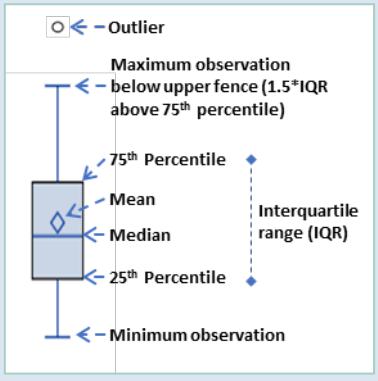
This section summarizes PFAS levels that ATSDR measured from the 275 blood samples provided by eligible participants. Results are summarized in tables and 'box and whisker' plots (see text box).

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 Berkeley County EA participants' blood for all ages. Five of the seven PFAS—PFHxS, PFOS, PFOA, PFNA, and PFDA—were detected in more than 74% 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 PFOS (geometric mean = 5.08 micrograms per liter [µg/L]), PFHxS (2.94 µg/L), and PFOA (1.46 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 5% to 21% (Appendix B, Table B2). Except for PFOA, 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 | 100.0 | 71.3 | 2.94 | 2.53–3.41 | 1.45 | 2.81 | 5.86 | 10.2 | 15.2 |
| PFOS | NA* | 66.7 | 5.08 | 4.52–5.71 | 3.10 | 5.15 | 8.57 | 12.7 | 16.6 |
| PFOA | NA* | 16.9 | 1.46 | 1.35–1.57 | 0.976 | 1.41 | 2.08 | 2.78 | 3.22 |
| PFNA | 94.5 | 7.9 | 0.377 | 0.336–0.424 | 0.191 | 0.348 | 0.569 | 0.861 | 1.14 |
| PFDA | 74.2 | 2.9 | 0.149 | 0.135–0.165 | NA† | 0.0989 | 0.181 | 0.313 | 0.481 |
| PFUnA | 59.6 | 1.1 | NA‡ | NA‡ | NA† | NA† | 0.141 | 0.233 | 0.304 |
| MeFOSAA | 50.2 | 1.5 | NA‡ | NA‡ | NA† | NA† | 0.118 | 0.223 | 0.456 |

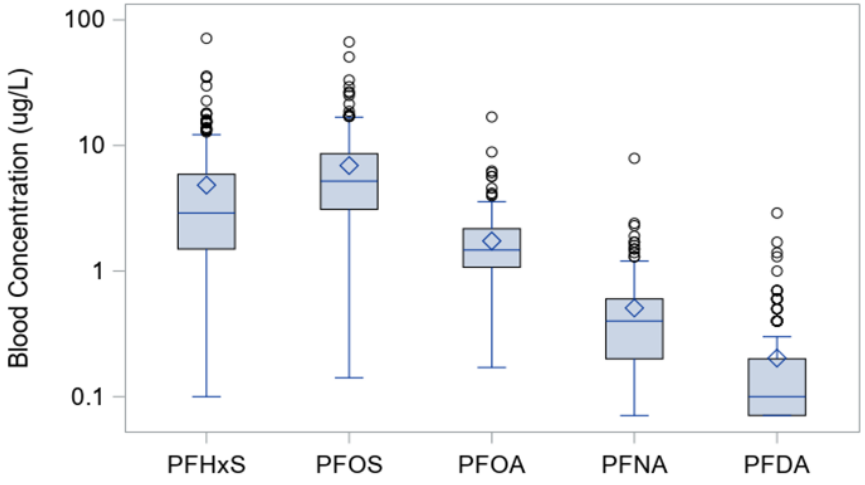
FOD = frequency of detection, CI = confidence interval, NA = not applicable

* PFOA and PFOS are calculated sums of branched and linear subsets and are not measured directly. Linear PFOA was detected in 100.0% of samples with a geometric mean of 1.37 micrograms per liter (µg/L); branched PFOA was detected in 1.1% of samples. Linear PFOS was detected in 99.6% of samples with a geometric mean of 3.52 µg/L; branched PFOS was also detected in 99.6% of samples, but with a geometric mean of 1.46 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 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 4% and 11% 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 | 2.94 | 2.53–3.41 | 2.83 | 2.29–3.51 |
| PFOS | 5.08 | 4.52–5.71 | 4.65 | 3.95–5.47 |
| PFOA | 1.46 | 1.35–1.57 | 1.30 | 1.18–1.42 |
| PFNA | 0.377 | 0.336–0.424 | 0.319 | 0.281–0.363 |
| PFDA | 0.149 | 0.135–0.165 | 0.133 | 0.118–0.149 |
| 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 Berkeley 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 compares 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, unadjusted geometric mean blood levels among Berkeley County EA participants were statistically ($p<0.05$) higher than the national geometric mean. For PFNA, the unadjusted blood levels among Berkeley County EA participants were statistically lower than the national geometric mean; for PFOS, PFOA, and PFDA, no significant difference was observed between Berkeley County EA participants and the general U.S. population.

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 Berkeley County EA participants was 2.5 times higher than the national level. Blood PFHxS levels were above the national geometric mean for 83% of the Berkeley County EA participants and above the NHANES 95$^{th}$ percentile for 31% (Table 7). The unadjusted geometric mean blood PFOS level among Berkeley County EA participants was 1.1 times higher than the national level. Blood PFOS levels were above the national geometric mean for 56% of

the EA participants and above the NHANES 95th percentile for 3%. Blood PFOA levels were above the national geometric mean for 46% of Berkeley County EA participants and above the NHANES 95th percentile for 3%.

On average, total PFOS measurements were composed of 69% 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 94% of linear PFOA (n-PFOA) and 6% 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 262 EA participants. Table 7 and Figure 3 show that blood PFAS geometric means adjusted to the NHANES population profile are minimally changed from unadjusted values. The adjusted geometric mean blood PFHxS level among Berkeley County EA participants was 2.5 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 Berkeley County, West Virginia, with the U.S. Population (NHANES 2015-2016) in micrograms per liter**

| PFAS | NHANES GM (CI)* | Berkeley County GM (CI)†: Unadjusted | Berkeley County GM (CI)†: Age-Adjusted to NHANES 2015-2016 | Percent of Berkeley County Results over NHANES Geometric Mean (%) | NHANES 95th Percentile* | Berkeley County 95th Percentile | Percent of Berkeley County Results over NHANES 95th Percentile (%) |
|---|---|---|---|---|---|---|---|
| PFHxS | 1.18 (1.08–1.30) | 2.94 (2.53-3.41) p<0.001 | 2.96 (2.45-3.57) p<0.001 | 83.3 | 4.90 | 15.2 | 31.3 |
| PFOS | 4.72 (4.40–5.07) | 5.08 (4.52-5.71) p=0.283 | 5.06 (4.37-5.86) p=0.394 | 56.4 | 18.3 | 16.6 | 3.27 |
| PFOA | 1.56 (1.47–1.66) | 1.46 (1.35-1.57) p=0.152 | 1.33 (1.23-1.44) p=0.001 | 45.5 | 4.17 | 3.22 | 2.91 |
| PFNA | 0.577 (0.535–0.623) | 0.377 (0.336-0.424) p<0.001 | 0.347 (0.308-0.391) p<0.001 | 32.7 | 1.90 | 1.14 | 1.09 |
| PFDA | 0.154 (0.140–0.169) | 0.149 (0.135-0.165) p=0.643 | 0.134 (0.123-0.147) p=0.031 | 49.1 | 0.700 | 0.481 | 1.82 |
| PFUnA | NA‡ | NA† | NA† | NA | 0.400 | 0.304 | 2.55 |
| MeFOSAA | NA‡ | NA† | NA† | NA | 0.600 | 0.456 | 2.55 |

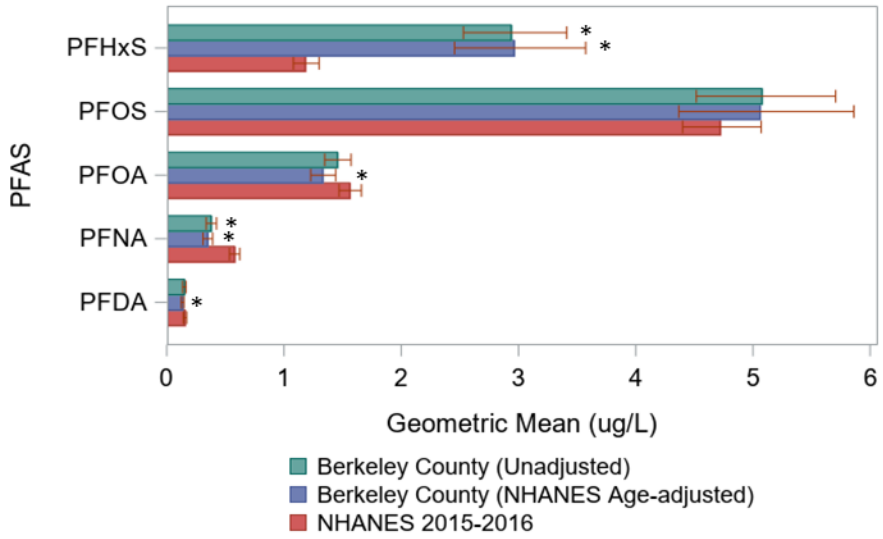
CI = 95% confidence interval, NA = not applicable

* Source: CDC 2019

† P-values represent a t-test comparison between Berkeley 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 Berkeley 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 correlated (i.e., they rise and fall in proportional amounts). Table 8 shows the Pearson correlation coefficients for the five frequently detected PFAS.

PFHxS and PFOS (*r* =0.74) and PFNA and PFDA (*r* = 0.74) showed the strongest correlations (Table 8). PFOA was moderately correlated with all compounds (*r* = 0.51–0.72). On the other hand, PFHxS and PFDA and PFHxS and PFNA had weaker correlations (*r* = 0.24, 0.43, respectively).

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

| | PFHxS | PFOS | PFOA | PFNA | PFDA |
|---|---|---|---|---|---|
| **PFHxS** | 1.00 | 0.74 | 0.66 | 0.43 | 0.24 |
| **PFOS** | 0.74 | 1.00 | 0.66 | 0.68 | 0.42 |
| **PFOA** | 0.66 | 0.66 | 1.00 | 0.72 | 0.51 |
| **PFNA** | 0.43 | 0.68 | 0.72 | 1.00 | 0.74 |
| **PFDA** | 0.24 | 0.42 | 0.51 | 0.74 | 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, their 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 data relationships that were found to be statistically significant. For this EA, the following demographic and exposure characteristics were found to be independently associated with at least one PFAS:

- age,
- sex,
- drinking water source,
- public water supply,
- length of residence in the sampling frame,
- blood donation,
- kidney disease, and
- breastfeeding (adult females only).

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 multivariate model.

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

| Parameter | PFHxS | | | PFOS | | | PFOA | | |
|---|---|---|---|---|---|---|---|---|---|
| | All Adult | Adult Female | Adult Male | All Adult | Adult Female | Adult Male | All Adult | Adult Female | Adult Male |
| Age (continuous) | ✓ | ✓ | — | ✓ | NA | NA | ✓ | NA | NA |
| Sex (categorical) | ✓ | NA | NA | ✓ | NA | NA | ✓ | NA | NA |
| Age × sex (continuous)* | ✓ | NA | NA | ✓ | NA | NA | ✓ | NA | NA |
| Years in sampling frame in the past 20 years [Residency duration] (continuous) | ✓ | ✓ | ✓ | ✓ | NA | NA | — | NA | NA |
| Public water supply [Berkeley County or City of Martinsburg] (categorical) | ✓ | — | ✓ | — | NA | NA | — | NA | NA |
| Blood donation frequency (categorical) | — | — | — | ✓ | NA | NA | — | NA | NA |
| Kidney disease history (categorical) | — | — | — | ✓ | NA | NA | — | NA | NA |
| Water source [public water system or bottled water] (categorical) | — | — | — | — | 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. While blood levels of PFNA and PFDA were not found to be statistically higher than the national geometric means, both PFAS were detected at a high enough frequency to present meaningful results. Summary statistics are provided in Appendix C for completeness, but not discussed below.
- 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.
- Table C5–C9 present multivariate modeling results for PFHxS, PFOS, and PFOA. 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 0.091 to 0.216. 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. Final multivariate male-only models and female-only models were only significant for PFHxS; the best models for PFOS and PFOA were univariate models consisting of only a single significant variable. ATSDR did not develop multivariate models for children because of the small sample size for this population (n=28).
- Figures C1–C41 present boxplots for unadjusted blood levels by each demographic and exposure characteristic included in the statistical analyses.

**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.

**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.

***Blood PFAS Levels and Age***

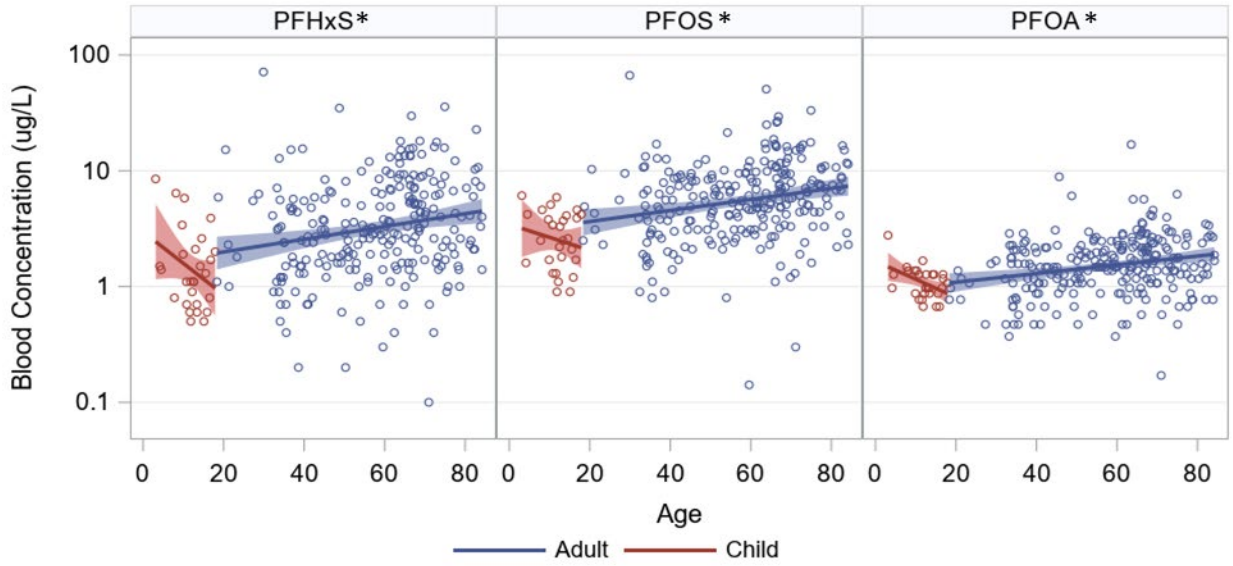
Because many studies have found that older people have higher blood PFAS levels, ATSDR investigated how Berkeley County EA participants' ages related to their blood levels. As Figure 4 illustrates, the blood levels for PFHxS, PFOS, and PFOA increased with participant age for adults, but trends were inconsistent for children.

For adults, ATSDR's univariate analysis showed that blood PFHxS, PFOS, and PFOA were higher in older individuals than in younger individuals, and this finding was statistically significant. As Figure 4 shows, PFHxS had the strongest age dependence. The univariate analysis indicates that on average, blood PFHxS levels in Berkeley County EA participants increased 1.3% for every year of participant age in adults. This suggests a 14% increase in blood PFHxS levels for every 10 years of participant age in adults. The calculated increases for PFOS (1.1% per year of participant age) and PFOA (0.87% per year of participant age) were lower.

ATSDR's multivariate analysis provided further perspective on this trend, showing that the age dependence was stronger for women than men among adults. For example, the all-adult model (Appendix C, Table C5) suggests a 2.4% annual increase in blood PFHxS levels in adult females for every year of participant age and a 0.46% decrease in blood PFHxS levels in males for every year of participant age when controlling for other characteristics; this finding was statistically significant. In the stratified male-only and female-only models, age was only significant in the female model. Age remained a significant predictor of blood levels for all three PFAS in the all-adult multivariate models.

As the trendlines in Figure 4 indicate blood PFHxS, PFOS, and PFOA levels were generally higher in younger children for participants under 18. However, in univariate analyses, this trend was not statistically significant. Note that 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*

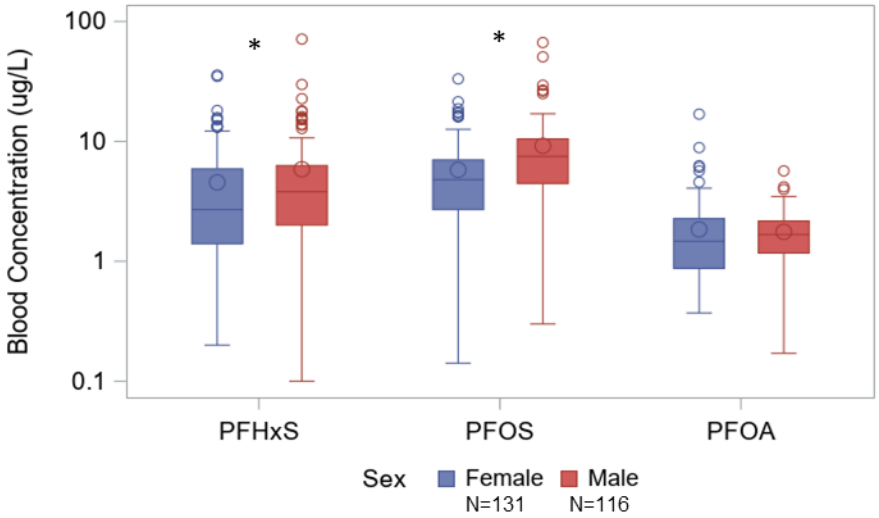
***Blood PFAS Levels by Sex***

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. ATSDR's univariate and multivariate analyses both showed that PFAS levels were higher in adult males than in adult females for PFHxS and PFOS. Modeled blood levels in adult males were 36% higher for PFHxS and 62% higher for PFOS in univariate models (Figure 5).

The all-adult multivariate models showed that the difference between males and females was larger in younger people. For example, 30-year-old males had higher blood PFHxS, PFOS, and PFOA levels than 30-year-old females by 175%, 136%, and 48%, respectively. For 50-year-old males, this difference was reduced to 58% for PFHxS, 71% for PFOS, and 12% for PFOA compared to 50-year-old females.

Blood levels of these three PFAS were not statistically associated with sex in children.

**Figure 5. PFAS blood level in adults by sex (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.

**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.

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 response were tap water (68%) or bottled water (32%). In univariate analyses, adults who primarily drank bottled water had significantly lower PFHxS (24%) and PFOA (17%) blood levels when compared to adults who primarily drank from a public water system. However, in multivariate analyses, which controlled for other potential confounders, drinking water source at home was only statistically significant in the all-adult model for PFOA (14% lower for bottled water drinkers).

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 in the previous paragraph], on average how many 8-oz 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.

ATSDR also considered participants' public water systems. In the sampling frame, adult participants either lived in homes that received drinking water from the City of Martinsburg (n=47) or from Berkeley County PSWD (n=200). In univariate analyses, blood PFAS concentrations in participants who lived in the City of Martinsburg service area did not have significantly different levels from participants who lived in the Berkeley County PSWD service area. However, in multivariate analyses, after controlling for other variables, participants who lived in the City of Martinsburg service area had 60% higher PFHxS blood levels than those who lived in the Berkeley County PSWD service area. This association remained statistically significant in male-only models, but in female-only models it was not statistically significant, suggesting that the relationship was primarily observed in male participants.

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 Berkeley County (including City of Martinsburg or Inwood) 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 the City of Martinsburg drinking water or Berkeley County PSWD.

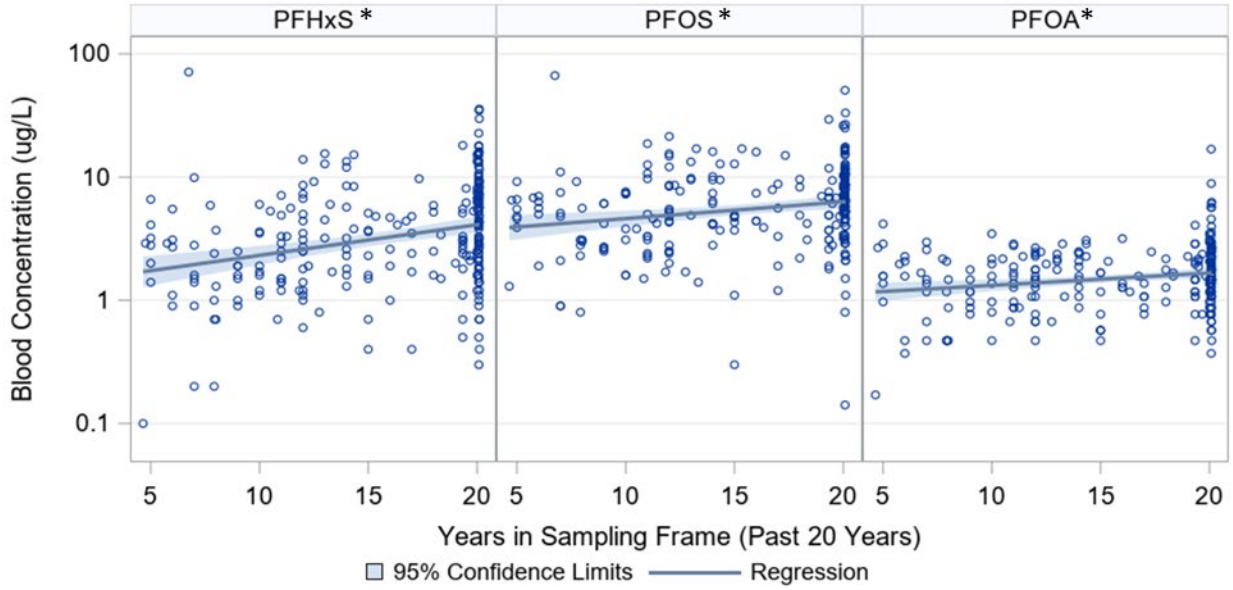
Any resident reporting prior residences in Berkeley County was assumed to fall within the sampling frame.

Figure 6 shows the relationship between reported residence duration in Berkeley County for the past 20 years and blood PFAS levels. A consistent relationship was observed for PFHxS, PFOS, and PFOA: 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 showed PFHxS and PFOS had significant relationships with residency duration: for every additional year that an adult participant lived in Berkeley County, blood PFHxS increased by 5.3%, and blood PFOS increased by 2.3%. This association was significant in both male-only and female-only models for PFHxS. For PFOA, the multivariate analysis did not show statistically significant relationships with residency duration.

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 the City of Martinsburg's and Berkeley County PSWD drinking water source (PFHxS at 105 ppt, PFOS at 114, and PFOA at 46 ppt). Therefore, one explanation for the correlation among these compounds is that the Berkeley 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 6. 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)*

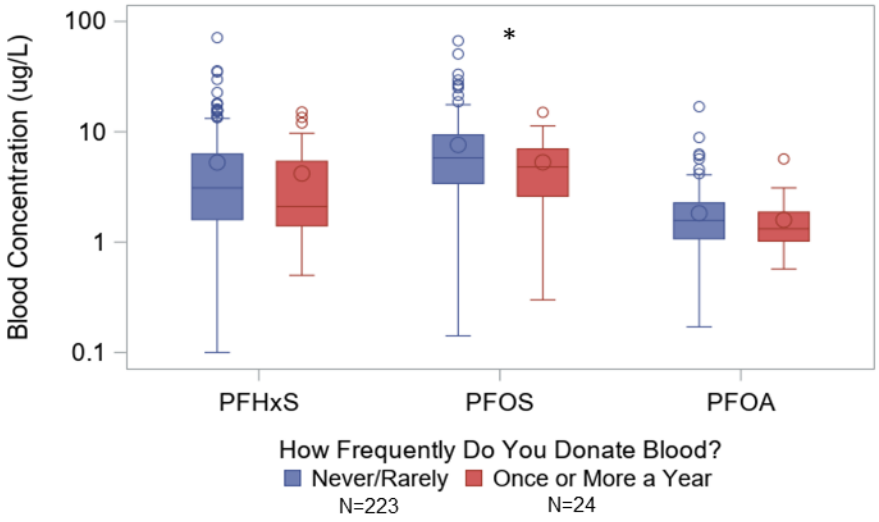
***Blood PFAS Levels and Frequency of Blood Donation***

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, and PFOA 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 7). This difference was statistically significant for PFOS only.

ATSDR's multivariate analysis, which accounted for various confounding factors, found blood PFOS concentrations among adults who donated blood once or more per year to be 31% lower than for EA participants who donated blood never or rarely. The relationship for PFHxS and PFOA was not statistically significant in multivariate models. These results are based on a small number of participants (10%, n=24) 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.

**Figure 7. 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)*

***Blood PFAS Levels and Kidney Disease***

Adult participants were asked about whether they had a history of kidney disease, because it can affect blood PFAS levels [Vaughn 2013; Watkins 2013]. The questionnaire results indicated that only 8% of adults (n=19) reported a diagnosis of kidney disease, but these adults did not have statistically different blood PFAS levels than those without a diagnosis of kidney disease in univariate analyses. However, in multivariate analyses, after controlling for other variables, participants who reported a history of kidney disease had PFOS blood levels that were 27% lower than those who did not. The results for kidney disease for this EA are based on limited data and should be interpreted with caution.

***Blood PFAS Levels and Breastfeeding***

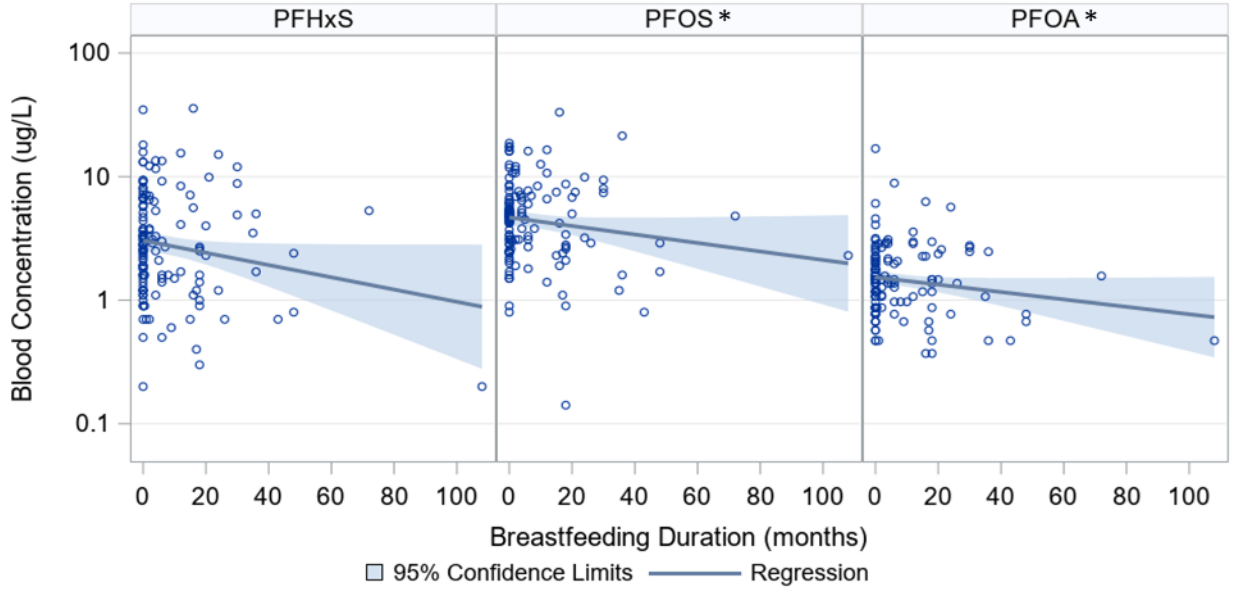
During breastfeeding, some PFAS in the breast milk might be transferred from mother to child. Therefore, breastfeeding can reduce PFAS levels in mothers and increase PFAS levels in their breastfed children [Kim 2020; Kingsley 2018]. Accordingly, the adult and child exposure history questionnaires included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

Among adult female EA participants, 52% reported that they had breastfed a child, with an average breastfeeding duration across all pregnancies of 16 months. Among adult females, univariate models showed that blood PFAS levels were not associated with whether the participant had ever breastfed. Figure 8 summarizes blood levels for females by the duration of reported breastfeeding. In general, there was a negative association between breastfeeding duration and blood PFAS levels, and this relationship was statistically significant for PFOS and PFOA in univariate models. In univariate models, for every additional month of reported breastfeeding there was a 0.8% decrease in blood PFOS levels and a 0.7% decrease in blood PFOA levels. However, these relationships were driven by a few outlier values and should be interpreted with caution (Figure 8). Note that these relationships did not remain significant in multivariate models.

The questionnaire results demonstrate that, overall, 81% of children in the Berkeley County EA were breastfed. However, no significant associations were identified between blood levels of PFHxS, PFOS, or PFOA and having been breastfed.

Approximately half of the children in the Berkeley County EA (46%) consumed infant formula reconstituted with tap water (some of these children also breastfed), but no significant associations were identified between infant formula consumption and any PFAS in blood.

**Figure 8. Blood PFAS levels in females by breastfeeding duration (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 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, or PFOS among EA study participants in univariate or multivariate analyses.

- **Race and Ethnicity.** Adult and child participants were asked to provide information about their race and ethnicity. However, because there were not enough participants in different race and ethnicity categories to support robust statistical analyses, ATSDR focused on differences between Berkeley County EA participants who self-identified as White, non-Hispanic and those who identified as non-White or Hispanic. No statistical relationship was observed for self-reported race/ethnicity and blood PFAS level 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 or children.
- **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.
- **Consumption of Selected Local Food Items.** Some PFAS accumulate in plants, fish, and animals. The questionnaire asked adult and child 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 caught fish (n=7) or locally produced milk (n=7) 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.
- **Stain-resistant product use.** Many stain-resistant products used to treat fabrics and carpet have been formulated with PFAS. The exposure history questionnaire asked adult participants how frequently they used these products, such uses may be associated with PFAS exposures. Berkeley County EA adult participants with any self-reported stain-resistant product use did not have statistically elevated blood levels of any PFAS when compared to participants who reported never using these products.
- **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, among Berkeley County EA adult participants, reported frequency of fast food consumption was not statistically associated with blood PFAS levels. In recent years, fast food packaging has likely been reformulated to contain shorter chain PFAS compounds. This shift may make it more challenging to link PFAS exposure to fast food consumption.
- **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 11% of adults (n=28) 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.
- **Childbirth (adult females) and birth order (children only).** Adult female participants were asked whether they had any biological children, and if so, how many. Children were asked their birth order. Pregnancy may lead to lower blood PFAS levels for mothers, and birth order may be related to PFAS levels in children (with first-born children having higher PFAS levels than last-born children). Approximately half of adult female EA participants (58%) reported having one or two biological children. Neither having children nor the number of children was statistically associated with blood PFAS levels. Half of all children reported being the first born; birth order was not statistically associated with blood PFAS levels.

## 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 higher than the NHANES 95$^{th}$ percentile values; however, this threshold was not met. Note that only PFBA and PFHxA were detected in more than 5% of the NHANES samples.

For the Berkeley County EA, ATSDR randomly selected 28 participants' urine samples for analysis, and 27 were ultimately analyzed. These samples were provided by 24 adults and 3 children, and these individuals lived in 23 different households. PFBA was the only PFAS detected in any of the 27 urine samples. Of note, unambiguous quantification of trace levels of PFBA faces known challenges, 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 summary statistics for the randomly selected urine samples and national statistics for comparison. 7 of the 27 samples had PFBA urine concentrations greater than the NHANES 95$^{th}$ percentile. The protocol specified that all urine samples would be analyzed if the geometric mean exceeded the 95$^{th}$ percentile from NHANES. The geometric mean for PFBA across the 27 participants' samples (0.193 µg/L) was lower than the NHANES 95$^{th}$ percentile (0.300 µg/L). Therefore, as per the study protocol, 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) | Berkeley County Geometric Mean (µg/L) | Berkeley County 95$^{th}$ Percentile (µg/L) | NHANES Geometric Mean (µg/L) | NHANES 95$^{th}$ Percentile (µg/L) |
|---|---|---|---|---|---|---|
| PFBA | 66.7 | ND–2.0 | 0.193 | 1.48 | 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 (detected in 13.3% of samples in Calafat et al. [2019]).

## PFAS in Tap Water

As noted previously, ATSDR collected tap water samples from 19 randomly selected participant households and analyzed these samples for PFAS. Two households only provided a filtered water sample, nine only provided an unfiltered water sample, and eight provided both filtered and unfiltered samples. Detection limits were 2 ppt for all PFAS, except for HFPO-DA (5 ppt). PFBS was detected in 11 of the 17 unfiltered tap water samples. No other PFAS were detected in unfiltered tap water. In three of the ten samples collected from a filter, PFBS was detected at concentrations that ranged from 2.0 ppt to 3.1 ppt. In one of these samples, PFHxS (63 ppt), PFOS (33 ppt), PFHpA (5.5 ppt), PFHxA (8.8 ppt), and PFOA (13 ppt) were also detected but at concentrations below EPA's health advisory of 70 ppt for PFOA and PFOS combined. There is no EPA HA for PFHxS, PFHpA, or PFHxA. This house had a whole house water softener and filtration system. ATSDR does not know the frequency of filter replacement or maintenance at that location. Since PFAS were detected in few samples, no statistics or range of detections is provided to protect the privacy of participants.

Why more PFAS were detected in a filtered sample is unclear, as one might assume that filtered water would be less contaminated than unfiltered water. A possible explanation is related to filter

maintenance, though this issue could not be fully explored as part of this assessment. ATSDR has discussed the sampling results and proper filter maintenance protocols with this resident.

Because of the limited PFAS detections in the tap water samples, ATSDR did not investigate correlations between these sampling results and the blood data.

## 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 compounds 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., FtS 4:2, N-EtFOSA, HFPO-DA, DONA, 9CL-PF3ONS, and 11CL-PF3OUdS).

**Table 11. Summary statistics for dust samples collected in Berkeley County**

| 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 | 42 | 683 | NA* | NA* | 2.78 | 43.6 | 123 |
| PFPeS | 11 | 140 | NA* | NA* | 0.99 | 14.4 | 46.2 |
| PFHxS | 47 | 16,400 | NA* | NA* | 1.91 | 40.3 | 1,000 |
| PFHpS | 11 | 77.4 | NA* | NA* | 0.986 | 15.9 | 56.9 |
| PFOS | 89 | 13,900 | 15.9 | 4.33–58.6 | 7.90 | 684 | 4,990 |
| PFNS | 5 | 14.2 | NA* | NA* | 0.986 | 11.4 | 11.6 |
| PFDS | 53 | 27.8 | NA* | NA* | 1.78 | 11.9 | 16.2 |
| PFDoS | 5 | 14.4 | NA* | NA* | 0.827 | 11.4 | 11.6 |
| PFBA | 37 | 736 | NA* | NA* | 6.46 | 72.8 | 134 |
| PFPeA | 37 | 72.4 | NA* | NA* | 3.01 | 27.4 | 67.8 |
| PFHxA | 89 | 460 | 8.51 | 3.99–18.2 | 6.65 | 65.1 | 242 |
| PFHpA | 63 | 456 | 5.50 | 2.34–13.0 | 3.24 | 70.8 | 95.8 |
| PFOA | 95 | 3,430 | 15.1 | 5.14–44.3 | 8.65 | 418 | 794 |
| PFNA | 68 | 74.5 | 3.85 | 2.31–6.41 | 2.68 | 11.4 | 14.6 |
| PFDA | 37 | 27.0 | NA* | NA* | 1.60 | 11.4 | 12.2 |
| PFUnA | 37 | 11.5 | NA* | NA* | 1.36 | 6.84 | 11.4 |
| PFDoA | 26 | 13.9 | NA* | NA* | 1.27 | 11.4 | 11.6 |
| PFTrA | 21 | 11.5 | NA* | NA* | 0.986 | 5.07 | 11.4 |
| PFTA | 26 | 11.5 | NA* | NA* | 1.34 | 5.07 | 11.4 |
| PFOSA | 11 | 472 | NA* | NA* | 0.986 | 11.4 | 34.5 |
| N-MeFOSA | 5 | 289 | NA* | NA* | 0.984 | 13.1 | 26.9 |
| MeFOSAA | 42 | 3,810 | NA* | NA* | 2.04 | 30.9 | 386 |

| 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 |
| N-MeFOSE | 37 | 6,940 | NA* | NA* | 16.4 | 338 | 2,580 |
| EtFOSAA | 63 | 300 | 8.64 | 3.76–19.8 | 9.35 | 43.7 | 60.6 |
| N-EtFOSE | 21 | 2,280 | NA* | NA* | 8.14 | 42.5 | 196 |
| FtS 6:2 | 5 | 82.7 | NA* | NA* | 5.62 | 36.5 | 82.1 |
| FtS 8:2 | 21 | 45.8 | NA* | NA* | 4.84 | 20.3 | 45.5 |

FOD = frequency of detection, ng/g = nanograms per gram, NA = not applicable

A total of 19 dust samples are summarized in this table. FtS 4:2, HFPO-DA, ADONA, 9Cl-PF3ONS, and 11Cl-PF3OUdS were not detected in any dust samples and therefore not included 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 75% of the households evaluated. Of these, PFOA and PFOS were measured at the highest levels on average, with geometric mean values of 15.1 nanograms/gram (ng/g)[3] (95% confidence interval = 5.1–44.3 ng/g) and 15.9 ng/g (95% confidence interval = 4.3–58.6 ng/g), respectively. Every other PFAS chemical had geometric mean concentrations less than 8.6 ng/g.

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 (in areas with or without known PFAS contamination). 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 as 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 may suggest that PFAS measured in the dust samples in Berkeley County are at lower levels than elsewhere in the United States, note that the studies referenced here do not necessarily provide representative comparisons and are only provided 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 29 blood samples collected from participants residing in the same homes. Using log-transformed data, ATSDR calculated Pearson correlation coefficients for all of the PFAS measured in at least 60% of the dust and the same PFAS

[3] 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.

measured blood samples for this assessment. Data were log-transformed because dust and blood concentrations were log-normally distributed.

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 0.1 to 0.23, indicating weak correlation between concentrations measured in dust and blood. Note that the sample size for dust measurements in Berkeley 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 Berkeley 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 for Berkeley County (detection frequencies above 74%).

Results from this EA were compared to NHANES data from 2015–2016.[4] Age-adjusted geometric mean blood levels of PFHxS were statistically higher than the national geometric mean (2.5 times higher), and age-adjusted blood concentrations of PFOS, PFOA, PFNA, and PFDA were similar to or lower than the national geometric means. EA participants had statistically higher blood PFHxS levels than national levels.

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 Berkeley 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 Berkeley County EA blood levels and the NHANES 2015-2016 geometric mean presented here.

ATSDR compiled blood PFAS levels from other studies to provide further context on the current (2019) Berkeley County EA blood levels (Appendix A, Table A2):

- For PFHxS, PFOS, and PFOA, blood levels among Berkeley County EA participants are lower than those recently observed in other communities with contaminated drinking water: Westhampton Beach/Quogue Area, New York; Portsmouth, New Hampshire; Little Hocking, Ohio; Decatur Alabama; and Montgomery and Bucks Counties, PA [NYDOH 2019; NH DPHS 2016; Frisbee et al. 2009; Olsen et al. 2003; PA DOH 2019]

[4] 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.

- Berkeley County EA participants' blood PFHxS levels are higher than the national geometric means from 1999–2000, the time NHANES first measured PFAS and the time the highest PFAS levels were observed [CDC 2019]. PFHxS has been detected in legacy AFFF formulations and may be present in groundwater because of degradation of other PFAS. The half-life of PFHxS is between 4.7 and 35 years and is longer than the half-lives for PFOS and PFOA, which may explain why blood PFHxS levels were more elevated than levels of other PFAS. [ATSDR 2021]
- PFOA and PFOS, on the other hand, did not exhibit these trends. These substances' blood levels in Berkeley County EA participants were considerably lower than blood levels observed in Little Hocking and Portsmouth and the NHANES 1999–2000 blood levels [Frisbee et al. 2009; NH DPHS 2016; CDC 2019].

## Generalizability of Berkeley 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., Berkeley County PSWD customers who live in areas south of the Big Springs treatment plant and City of Martinsburg customers who live west of I-81 or in the Amber Woods housing complex [east of I-81]). Although all households in the sampling frame were invited to participate in this EA, the population that ultimately enrolled was older. Specifically, adults aged 50 or older represented 61% of the EA population compared with 30% of the sampling frame. Given the 18% response rate, it is also possible that other factors were present at different rates than the community as a whole.

Since age was 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 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 this bias 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 moderately high by 9% to 18%. Therefore, the sampling frame age-adjusted geometric means may be 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 PFHxS and PFOS. This trend has been observed 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, breast feeding, pregnancy, and possible in renal clearance rates differences [ATSDR 2018]. 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. In this EA, gestation (as measured by the number of children a female reported having), was not a significant predictor of PFAS blood levels, but increasing breastfeeding duration was found to be statistically associated with decreasing blood levels of PFOS and PFOA among adult women.

In univariate models, blood PFAS levels were statistically higher in older adults than younger adults, and the effect of age was stronger in female participants than males. In contrast, blood PFAS levels were found to be higher in younger children or remain unchanged 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 [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, and PFOA 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 are found in breastmilk [ATSDR 2021]. In addition, hand-to-mouth touching and spending more time closer to the floor with settled dust in toddlers is much greater 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].

## 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 blood levels in EA participants were statistically higher than the 2015-2016 NHANES national geometric means. This chemical was first detected in the City of Martinsburg's water supply in 2014. It is likely that contamination began earlier, but no data are available before 2013. Among the site documents ATSDR reviewed, the highest PFHxS concentration in finished drinking water from the City of Martinsburg's Big Springs treatment plant was 105 ppt. In 2016, City of Martinsburg mitigated the contamination; however, estimates of the half-life of PFHxS are between 4.6 and 35 years. Therefore, even though drinking water PFAS exposures were significantly reduced in May 2016, past drinking water exposures were likely a contributing factor to the EA participants' elevated blood PFAS levels, observed 3 years and 5 months later. Furthermore, in this EA, adults who currently primarily drank bottled water had significantly lower PFHxS (24%) blood levels when compared to adults who primarily drank from a public water system in the univariate analysis. However, this relationship was not statistically significant in multivariate regressions.
- PFHxS blood levels were correlated with blood PFOS ($r$ = 0.74) and PFOA ($r$ = 0.66), 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. While correlations between PFAS have been observed in other studies [NH DPHS 2016; ATSDR 2013; CDC 2019], the correlation observed between PFHxS and PFOS in the blood results for this EA is higher than those observed in the general U.S. population ($r$ = 0.56) [Calafat et al. 2007]. In contrast, the correlation between PFOS and PFOA here is

identical to that observed in the U.S. population. The higher correlations between PFHxS and PFOS are consistent with those found in the blood of people living in communities with contaminated drinking water [ATSDR 2013], providing further evidence that drinking water was a possible contributing source of exposure among Berkeley County EA participants.

- Univariate statistical analyses of the EA data found that one of the most consistent predictors of adult blood PFAS levels was length of residency in Berkeley County. ATSDR considered residency duration to be a suitable surrogate for drinking water exposures because only residents who lived in the sampling frame before May 2016 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 and PFOS levels. In multivariate models conducted separately for males and females, the association for residency duration with PFHxS 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 0.10 and 0.20), indicating that there may be many factors not accounted for.
- One line of evidence that ATSDR considered was EA participants' self-reported drinking water source (i.e., which public water system residents get water from) and blood PFAS levels. No statistical association was seen in univariate analyses. However, in multivariate analyses, participants who lived in the City of Martinsburg service area had 60% higher PFHxS blood levels than those who lived in the Berkeley County PSWD service area. In both water systems, contaminated water from the Big Springs well mixed with uncontaminated water from other parts of the system. The area included within the sampling frame for each water system was determined in consultation with staff from the water systems using their knowledge of the structure and flow of water in each system. Because the shape of the sampling frame was estimated, and not based on measured PFAS concentrations, it is possible that more mixing occurred in the Berkeley County PSWD.

Taken together, the data suggest that past drinking water exposure contributed to the elevated blood levels of PFHxS observed in the Berkeley 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:

- **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 a multivariate model, lower PFOS blood levels were observed in the few (10%, n=24) Berkeley 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.
- **Kidney disease.** Previous research shows that kidney disease can affect blood PFAS levels [Vaughn 2013; Watkins 2013]. Eight percent of adult participants (n=19) reported a diagnosis of

kidney disease, but these adults did not have statistically different blood PFAS levels than those without a diagnosis of kidney disease in univariate analyses. However, in multivariate analyses participants who reported a history of kidney disease had PFOS blood levels that were 27% lower than those who did not. These results are based on limited data and should be interpreted with caution.

# Berkeley County Community-Wide Findings

**Finding 1. Average blood levels of PFHxS in the Berkeley County EA site participants are higher than national levels. Averages of other PFAS were not higher than the national average or were detected too infrequently to compare to national averages.**

Geometric means (i.e., "averages") for PFHxS blood levels were statistically higher ($p<0.05$) in Berkeley County EA participants when compared to CDC's NHANES (2015–2016) data, 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 applied in NHANES 2015–2016.

Of the PFAS analyzed in blood, only PFHxS was elevated when compared to national levels. The age-adjusted geometric mean blood PFHxS level among all Berkeley County EA participants was 2.5 times higher than the national average. Blood PFHxS levels were above the national geometric mean for 83% of the Berkeley County EA participants and above the NHANES 95$^{th}$ percentile for 31%.

Other PFAS measured in this EA (PFOS, PFOA, PFNA and PFDA) were not higher than the national average. PFUnA and MeFOSAA were detected in fewer than 60% of the EA participant samples; due to the large percent of samples below the limit of detection, geometric means were not calculated.

**Finding 2. Elevated blood levels of PFHxS may be associated with past drinking water contamination.**

PFHxS, the one PFAS with statistically elevated blood levels compared to the national geometric mean, was first detected in City of Martinsburg's Big Springs well in 2014. It is likely that contamination began earlier, but no data are available before 2014. This contaminated well also supplied water to the Berkeley County PSWD. The maximum concentration observed for PFHxS in active drinking water wells in these systems was 105 parts per trillion (ppt). PFOS and PFOA were also detected; the maximum concentrations observed in active drinking water wells were 114 ppt for PFOS and 46 ppt for PFOA. In 2016, City of Martinsburg reduced concentrations of PFAS in their contaminated well below U.S. 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 into other PFAS, such as PFHxS, which could explain the elevated blood PFHxS levels. PFHxS, PFOS, and PFOA have very long biological half-lives (2.1 to 35 years). There were 3 years and 5 months between the reduction of exposure via contaminated drinking water and collection of the biological samples during the EA. PFHxS has the longest estimated half-life (up to 35 years) of the three compounds. Because of its long half-life past drinking water exposures may have contributed to the EA participants' blood levels.

PFHxS, PFOS, and PFOA were positively correlated in Berkeley County residents' blood (Pearson correlation coefficient, *r* between 0.66 and 0.74). This means that typically, residents who had greater blood PFHxS levels also had greater blood PFOS and blood PFOA levels. This correlation suggests a common exposure source, such as the City of Martinsburg or Berkeley County PSWD public water supply, though other sources of exposure may also have contributed to the observed blood levels.

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

- First, in univariate models, a consistent and statistically significant predictor of participant blood levels for PFHxS was how long the resident had lived in Berkeley County during the past 20 years. Those who lived in the area longest likely drank, in total, more contaminated water. This relationship remained significant in the multivariate models.
- Second, in multivariate analyses, participants who lived in the City of Martinsburg service area had 60% higher PFHxS blood levels than those who lived in the Berkeley County PSWD service area. In both water systems, contaminated water from the Big Springs well mixed with uncontaminated water from other parts of the system. The area included within the sampling frame for each water system was determined in consultation with staff from the water systems using their knowledge of the structure and flow of water in each system. Because the shape of the sampling frame was estimated, and not based on measured PFAS concentrations, it is possible that more mixing occurred in the Berkeley County PSWD.

Multivariate models conducted separately for males and females suggest that the relationship between blood levels and public water supply was primarily observed in male participants.

### Finding 3. Age, sex, blood donation, kidney disease, and length of residency were associated with some PFAS blood levels.

PFAS blood levels varied with different demographic and exposure characteristics of the participant population. The following statistically significant relationships in the Berkeley County EA data set were observed in adult participants (and are consistent with those reported in other non-ATSDR PFAS studies):

- Blood levels of PFHxS, PFOS, and PFOA varied by age in EA participants, but the size and direction of the effect varied by sex. In females, blood levels for these compounds increased by 1.5% to 2.4% for every year of participant age. In males, blood levels for PFHxS decreased by 0.46% for every year of participant age and increased for PFOS and PFOA by 0.23% per year.
- Males had higher blood levels of PFHxS, PFOS, and PFOA than females. The difference between males and females was larger in younger people. For example, 30-year-old males had higher blood PFHxS, PFOS, and PFOA levels than 30-year-old females by 175%, 136%, and 48%, respectively. For 50-year-old males, this difference was reduced to 58% for PFHxS, 71% for PFOS, and 12% for PFOA compared to 50-year-old females.
- Only 24 participants reported donating blood at least once or more a year. Participants who reported donating blood at least once or more a year had 31% lower blood levels of PFOS than adult participants who did not do so. Because of the small sample size for people who reported donating blood at least once or more a year, these results should be interpreted with caution.
- Eight percent (n=19) of adult participants reported a diagnosis of kidney disease. Participants who reported a history of kidney disease had PFOS blood levels that were 27% lower than those who did not. Because of the small sample size for people who reported a diagnosis of kidney disease, these results should be interpreted with caution.
- Blood levels of PFHxS increased with the number of years participants lived in the sampling area. For every additional year that an adult participant lived in the Berkeley County EA site, blood PFHxS increased by 5.3%. Length of residency can be considered a proxy for potential exposure to PFAS contaminated drinking water.

Because of the small number of child participants (n=28), associations between blood PFAS levels and many variables could not be examined. Any observations in children are noted in the text, but in most cases significant associations were not observed in the small sample size. The final report on all EA sites will include an analysis of children.

### Finding 4. Only one PFAS was detected in urine and at low concentrations.

ATSDR analyzed 27 (10%) of the urine samples collected. Only perfluorobutanoic acid (PFBA) was detected; it was detected in 67% of the 27 samples analyzed. Per the study protocol, ATSDR did not analyze all participants' urine samples because the initial analysis did not show that geometric mean urine concentrations of any PFAS were higher than the NHANES 95$^{th}$ percentile values.

### Finding 5. All Berkeley County tap water samples collected during the EA in 2019 met the EPA's HA for PFAS in drinking water.

This is based on 17 unfiltered and 10 filtered tap water samples collected in 19 households during the EA.

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

Among the PFAS detected most frequently in household dust samples, PFOA and PFOS 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 looking at other U.S. communities (with or without 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 5.6% of the households participated in the EA. Participant characteristics were different that those of the area's overall population; specifically, participants were older. ATSDR addressed 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 in EA participants may improve the understanding of exposure in this community but will not provide information about all sources of exposure. Additionally, identifying every source of exposure is not possible.
- 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 0.10 and 0.20). 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 tap water consumption prior to the reduction of PFAS from the two public water supplies.
- 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, nor 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 amount.

## Recommendations

This PFAS EA has demonstrated that past exposures to PFAS in drinking water have impacted the levels of PFAS in people's bodies. 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 drinking water in the City of Martinsburg and Berkeley County PSWD service areas has been mitigated, there are actions community members and city and county 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 Martinsburg and Berkeley County PSWD, ATSDR does not recommend an alternate source of drinking water at this time.

1. What the City of Martinsburg and Berkeley County can/should do:
    a. Operators of the two public water systems should continue to monitor concentrations of PFAS in drinking water delivered to the service areas 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 for City of Martinsburg: https://www.cityofmartinsburg.org/residents/city-services/utilities; Consumer Confidence Reports for the Berkeley County PSWD, https://www.berkeleywater.org/consumer-confidence-reports)
    b. All treatment systems to remove PFAS from the public drinking water in the City of Martinsburg and Berkeley County PSWD 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 (City of Martinsburg: https://www.cityofmartinsburg.org/residents/city-services/utilities; Berkeley County PSWD: https://www.berkeleywater.org/consumer-confidence-reports) for information on the quality of the water provided by the City of Martinsburg and Berkeley County PSWD.
    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. 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: http://info.nsf.org/Certified/DWTU/ Click on "reduction devices." To learn more about testing wells for PFAS visit: https://www.wvdhhr.org/phs/water/Fact%20Sheets/PrivateWellOwners-FourStepstoWaterWellSafety.pdf.

c. Nursing mothers should continue breastfeeding. Based on current science, the known benefits of breastfeeding appear to 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.
g. Blood tests for PFAS are most useful when they are part of a scientific investigation like the EA. If you are concerned and choose to have your blood tested, test results will 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 would like to have your or your children's blood tested, 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 Berkeley County (Martinsburg) 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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