Security-Widefield

El Paso County | Colorado

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

XX/XX/XXXX

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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
AFCEC	Air Force Civil Engineer Center
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
GAC	granular activated carbon
HA	health advisory
HFPO-DA (GenX)	hexafluoropropylene oxide dimer acid
LOD	limit of detection
MeFOSAA	N-methyl perfluorooctanesulfonamidoacetic acid
MHP	mobile home park
µg/L, or ug/L	micrograms per liter (same as parts per billion or 1,000 parts per trillion)
ng/g	nanograms per gram (same as parts per billion or micrograms per kilogram)
NHANES	National Health and Nutrition Examination Survey
N-EtFOSA	N-ethyl perfluorooctanesulfonamide
N-EtFOSE	N-ethyl perfluorooctanesulfonamidoethanol
N-MeFOSA	N-methyl perfluorooctanesulfonamide
N-MeFOSE	N-methyl perfluorooctanesulfonamidoethanol
n-PFOA	linear isomer of PFOA
n-PFOS	linear isomer of PFOS
PFAS	per- and polyfluoroalkyl substances
PFAS-AWARE	PFAS Assessment of Water and Resident Exposure
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
WD	water district
WSD	water and sanitation district

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. Major exposure routes for PFAS include drinking contaminated water and eating contaminated food, but exposure can also occur through other routes (i.e., ingestion of contaminated dust). Once PFAS enter people's bodies, some of them (including PFOA, PFOS, PFHxS, and PFNA) can remain in the body for long periods and can be measured in the blood years after exposure. Most people in the United States have been exposed to PFAS. At least one PFAS was detected in more than 99% of National Health and Nutrition Examination Survey (NHANES) samples collected for the 1999-2000 survey cycle.

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

Possibly as early as the 1970s, the Base used aqueous film forming foam (AFFF) containing PFAS for its firefighter training. Over time, the PFAS from the AFFF entered the ground, moved into the groundwater to offsite locations, and affected nearby municipal wells. PFAS were first detected in municipal wells downgradient of the Base in 2013. The affected wells supplied water to customers from the Security Water District (WD), the western portion of the Widefield Water and Sanitation District (WSD), and the Security Mobile Home Park (MHP). Between January and November of 2016, Security WD and Widefield WSD inactivated their contaminated groundwater wells and shifted to uncontaminated surface water sources. In 2017, Widefield WSD installed an ion exchange system to treat PFAS in water from its contaminated wells. Security WSD currently uses uncontaminated surface water sources. Residents of Security MHP were provided bottled water beginning in the summer of 2016 until a treatment system was installed in November of 2017. From 2018 to 2019, a PFAS Assessment of Water and Resident Exposure (PFAS AWARE) study was conducted by the Colorado School of Public Health and the Colorado School of Mines that evaluated exposure to PFAS in drinking water in the El Paso County community. The PFAS AWARE study evaluated 200 participants in 2018 and resampled 50 of the participants in 2019. The study evaluated serum PFAS along with markers of health related to liver function, cholesterol, and immune response. The results of the study indicated that the primary source of PFAS in people's blood was PFAS in the drinking water.

Based on the information ATSDR has reviewed, the public drinking water supplies in Security-Widefield currently meet or are below the U.S. Environmental Protection Agency's (EPA) 2016 health advisory (HA). At this time, ATSDR does not recommend community members who get drinking water from Security WD, Widefield WSD, or Security MHP use alternative sources of water.

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

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

Exposure Assessment Activities

ATSDR invited a randomly selected sample of Security-Widefield households to participate in this EA. To be eligible to participate, household residents must have (1) been served by the drinking water systems of Security Water District (WD), Security Mobile Home Park (MHP), or the western portion of the Widefield Water and Sanitation District (WSD) for at least 1 year before November 10, 2016 (these residents have the greatest likelihood of past exposures to PFAS via drinking water), (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. Results from randomly selected households allow ATSDR to estimate exposure for all community members, even those who were not tested.

In September 2020, 346 eligible people (318 adults and 28 children) from 188 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 every participant
- collected tap water and dust samples from the homes of 18 randomly selected participants
- tested for 7 PFAS in blood, 14 in urine, 18 in water, and 33 in dust[1]
- measured PFHxS, PFOS, PFOA, PFNA, PFDA, and PFUnA across all media (blood, urine, tap water, and dust)
- mailed individual biological and environmental results to participants in May 2021

This report summarizes community PFAS blood levels, measured in serum, for the group of Security-Widefield 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 Security-Widefield blood and urine results are compared to a nationally representative sample of the US population. Specifically, ATSDR compared Security-Widefield data to those collected by CDC as part of its National Health and Nutrition Examination Survey (NHANES). The NHANES survey collects blood and urine samples from a representative sample of the civilian non-institutionalized U.S. population and tests them for chemicals, including PFAS. PFAS levels are also shown by age, race/ethnicity, sex, number of years living in the community, drinking water consumption patterns, and other exposure parameters.

[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.

The samples were collected and analyzed in 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 (i.e., the Security-Widefield area served by the drinking water systems of the Security WD, Security MHP, and the western portion of the Widefield WSD) population, with a precision goal of 15% or less. 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 3.9% to 16%. ATSDR also calculated geometric means that were adjusted to the age distribution of the sampling frame population to correct for participation bias and to provide an estimate that is more generalizable to the sampling frame community. ATSDR also calculated geometric means that were adjusted to the national age distribution for comparison with the 2015–2016 NHANES survey. To assess possible relationships between blood levels and various demographic and exposure variables, ATSDR used statistical models. Univariate statistics, which evaluate one variable at a time, were used as a tool to examine the data broadly and find patterns within the data. Multivariate statistics and regression modeling were used to simultaneously account for multiple variables and to control for potential confounding factors.[2] In this report we use the term 'average' to refer to the national age-adjusted geometric mean.

Security-Widefield Community-Wide Findings

Finding 1. Average blood levels of PFHxS and PFOA in the Security-Widefield EA site participants are higher than national levels. Averages of other PFAS were not higher than the national levels or were detected too infrequently to compare to national levels.

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

Of the PFAS analyzed in blood, PFHxS had the largest elevations when compared to national levels. The age-adjusted geometric mean blood PFHxS level among EA participants was 6.8 times the national level. Blood PFHxS levels were above the national geometric mean for 96% of the Security-Widefield EA participants and above the NHANES 95th percentile for 75% of the participants. The age-adjusted geometric mean blood PFOA level was 1.2 times the national level.

Other PFAS measured in this EA (PFOS, PFNA, PFDA) were not higher than national levels. ATSDR was unable to compare the geometric mean MeFOSAA levels because MeFOSAA was detected in less than 60% of NHANES samples. PFUnA was detected in less than 60% of the EA participant samples; due to the large percentage of samples below the limit of detection, geometric means were not calculated.

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

PFHxS, PFOS, and PFOA were detected in Security-Widefield water systems as early as 2013, though contamination likely began earlier. Two of these PFAS (PFHxS and PFOA) had statistically elevated blood

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

levels compared to national geometric means. The maximum concentrations observed in drinking water in Security-Widefield water systems were 590 ppt for PFHxS, 210 ppt for PFOS, and 90 ppt for PFOA.

By November 2016, actions taken by the three affected water systems reduced PFAS levels in drinking water below EPA's HA for PFOS and PFOA. Before 2016, PFAS-containing AFFF were primarily formulated with PFOS, but also contained various PFAS precursors that could break down in the environment into other PFAS, such as PFHxS, which could explain the elevated blood PFHxS levels. PFHxS and PFOA have very long biological half-lives (on the order of years). There were 3 years and 10 months between when the water systems took action to reduce exposure to contaminated drinking water and collection of biological samples during the EA. Because of the long half-lives of PFHxS and PFOA, past drinking water exposures may have contributed to the EA participants' blood levels. PFHxS has the longest estimated half-life of the three compounds (up to 35 years), which may contribute to why it exceeded the NHANES 2015-2016 geometric mean by the largest margin.

PFHxS and PFOA were highly correlated in Security-Widefield EA participants' blood (Pearson correlation coefficient, $r = 0.73$). This means that, typically, residents who had elevated blood PFHxS levels also had elevated blood PFOA levels. This correlation suggests a common exposure source, such as the pre-2017 Security-Widefield public drinking water supplies, though other sources of exposure may also have contributed to the observed blood levels.

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

- First, a consistent and statistically significant predictor of participant blood levels for PFHxS and PFOA was how long the resident had lived in Security-Widefield during the past 20 years. Each year of residence in the sampling frame over the past 20 years was associated with a 7.1% increase in PFHxS levels and a 2.0% increase in PFOA levels.
- Second, adults who reported not drinking tap water at all at home on average had statistically lower PFHxS (36%) and PFOA (24%) blood levels when compared to those who reported drinking tap water at home with no filter or treatment device.

Multivariate models conducted separately for males and females suggest differences in the associations (between blood levels and residency duration/tap water consumption) between males and female participants.

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

Finding 3. Age, sex, occupational exposure, kidney disease history, local fruit and vegetable consumption, and home cleaning frequency were associated with some PFAS blood levels.
PFAS blood levels varied with different demographic and exposure characteristics of the participant population. The following relationships were statistically significant in multivariate analyses in the Security-Widefield EA dataset in adult participants:

- Blood levels of PFHxS, PFOS, and PFOA were higher in older participants, and the size of the effect varied by sex for PFHxS. In males, blood levels for these compounds increased by 1.0% to 1.7% for every year of participant age. In females, blood levels for these compounds increased by 1.0% to 2.5% for every year of participant age.

- Males had statistically higher blood levels of PFHxS and PFOS than females. PFOS blood levels in males were 42% higher than in females. For PFHxS, the difference between males and females was larger in younger people. For example, 30-year-old males had higher blood PFHxS levels than 30-year-old females by 70%. For 50-year-old males, this difference was reduced to 35%.
- Adult participants who reported at least one occupational exposure in the past 20 years on average had lower PFHxS (28%) than adult participants who reported no occupational exposures in the past 20 years. Although this result was the opposite of expected, it is based on a relatively small sample of participants with occupational exposure and should be interpreted with caution.
- Adult participants who reported a history of kidney disease had PFHxS blood levels that were 39% lower than those who did not. This result is based on a relatively small sample of participants self-reporting a history of kidney disease and should be interpreted with caution.
- Adult EA participants who reported any consumption of locally grown fruits or vegetables had blood PFOS levels that were 52% higher compared to participants who reported no such consumption. While PFOS levels were higher in participants who reported consuming local produce compared to those who did not, PFOS blood levels were not elevated in the community.
- Adult participants who reported cleaning their homes three times per week or more on average had 24% higher PFOS blood levels than adult participants who reported cleaning their homes a few times per month or less; however, PFOS blood levels were not elevated in the community.

A few associations were observed in children (<18 years) in univariate analyses, though many variables could not be examined because of the small number of child participants (n=28). Because of the small sample size, results should be interpreted with caution. Specifically, the longer a child was breastfed, the higher blood levels of PFOS and PFOA compared to non-breastfed children, and children that reported ever drinking formula reconstituted with tap water on average had blood PFHxS, PFOS, and PFOA levels that were lower than children that reported never drinking formula reconstituted with tap water. Infants born to mothers exposed to PFAS can be exposed in utero and while breastfeeding. However, based on current science, the benefits of breastfeeding outweigh the risks for infants exposed to PFAS in breast milk. The final report on all EA sites will include a more robust analysis of children.

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

ATSDR analyzed 36 (10%) of the urine samples collected. Only perfluorobutanoic acid (PFBA) was detected; it was detected in 2.8% of the 36 samples that were analyzed. ATSDR did not analyze all participants' urine samples because none of the species were detected in more than 60% of the samples analyzed.

Finding 5. All Security-Widefield drinking water samples collected during the EA in 2020 met the EPA's HA for specific PFAS in drinking water.

This is based on 17 filtered and 17 unfiltered water samples collected in 18 households during the EA. These results are consistent with recent data collected from the Widefield WSD, Security WD, and Security MHP water systems.

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

Among the PFAS detected most frequently in household dust samples, N-MeFOSE and PFOS were measured at the highest average concentrations. No nationally representative comparison values are available, but geometric mean and median concentrations for PFAS measured in dust collected in the

small subset of participating households (n=18) were within the range of levels reported in a few published studies of other U.S. communities (with or without known PFAS contamination). Of the PFAS measured in this EA's household dust samples, PFOA (r=0.46) and MeFOSAA (r=0.57) 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 random sampling recruitment method used for this EA was designed to measure blood PFAS concentrations that were generalizable to all Security-Widefield residents who were customers of the Security WD, Widefield WSD, or Security MHP. However, the EA participant sample may not be fully representative of the community. Only 6.3% of the households from the random sample participated in the EA. Participant characteristics were different than those of the area's overall population. Participants were older, more likely to identify as White, and less likely to identify as more than one race. ATSDR addressed some of these differences by calculating geometric mean estimates that were adjusted to the age distribution of the community.
- Measurement of blood, urine, and environmental PFAS concentrations 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 potential confounding exposure is not possible.
- There are challenges in measurement of trace levels of PFBA in urine, including selectivity of the analytical instrumentation and potential for external contamination. Therefore, we advise caution when interpreting the PFBA results in urine.
- Multivariate regression models explained a small to moderate portion of the variability in participants' blood PFAS levels (R-squared or R^2, a measure of model goodness-of-fit, ranged between 0.13 and 0.30 in all-adult models). This means that other factors not identified could influence the relationships reported in this assessment (see "Statistical Analysis" section for details).
- This EA did not directly assess participants' tap water consumption prior to the reduction of PFAS in the municipal water systems.
- This EA was not designed to investigate health problems associated with exposure to PFAS. Without additional information about exposure-response relationships, the results of this EA cannot be used to assess current or past health problems or predict the future occurrence of disease. PFAS found in a person's blood or urine means that exposure has occurred. The presence of PFAS in blood or urine does not tell us how, where, when, or for how long a person was exposed to PFAS. Exposure to PFAS does not mean adverse health effects will result, either now or in the future.
- The dust results are exploratory and should be interpreted with caution. They are based on a limited set of samples, and in some cases those samples are based on a small sample mass.

Recommendations

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

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

Based on the PFAS drinking water test results from drinking water wells in Security-Widefield, ATSDR does not recommend an alternate source of drinking water at this time.

1. What the Security WD, Widefield WSD, and Security MHP can/should do:
    a. Operators of these three public water systems should continue to monitor concentrations of PFAS in drinking water delivered to the Security-Widefield community to ensure that concentrations of PFAS remain below the EPA's HA or other applicable guidelines for specific PFAS in drinking water. Results of PFAS monitoring should be shared with community members through appropriate communication channels (Consumer Confidence Reports for Security WD: http://securitywsd.com/water-quality/; Consumer Confidence Reports for the Widefield WSD, https://www.wwsdonline.com/consumer-confidence-report).
    b. All treatment systems to remove PFAS from the municipal drinking water in Security-Widefield should be maintained appropriately to ensure that PFAS concentrations remain below the EPA's HA or other applicable guidelines for specific PFAS in drinking water.
2. What community members can/should do:
    a. Become familiar with Consumer Confidence Reports for information on water quality in Security-Widefield (Consumer Confidence Reports for Security WD: http://securitywsd.com/water-quality/; Consumer Confidence Reports for the Widefield WSD, https://www.wwsdonline.com/consumer-confidence-report).
    b. Private well owners living in the area affected by PFAS should consider having their wells tested for PFAS if testing has not been conducted before. To learn more about testing wells for PFAS visit: https://www.elpasocountyhealth.org/news/news-release/2019/resources-for-pfc-water-contamination-and-testing. Global public health organization NSF International has developed a test method to verify a water filter's ability to reduce PFOA and PFOS to below the health advisory levels set by the EPA. NSF International-approved devices can be found at: https://info.nsf.org/Certified/DWTU/ Click on "reduction devices" at the bottom of the page for PFOA and PFOS.
    c. Nursing mothers should continue breastfeeding. Based on current science, the known benefits of breastfeeding outweigh the risks for infants exposed to PFAS in breast milk.
    d. When possible, eliminate or decrease potential exposure to PFAS in consumer products, such as stain-resistant products and food packaging materials. To learn more visit: https://www.fda.gov/food/chemical-contaminants-food/questions-and-answers-pfas-food
    e. Pay attention to advisories about food consumption, such as local fish advisories.
    f. Discuss any health concerns or symptoms with your health care provider. Share results of PFAS blood testing with your health care provider and make them aware of ATSDR resources for clinicians (https://www.atsdr.cdc.gov/pfas/resources/info-for-health-professionals.html). Follow the advice of your health care provider and the recommendations for checkups, vaccinations, prenatal care, and health screening tests.
    g. At this time, ATSDR does not have plans to conduct additional blood testing for PFAS nor recommend PFAS EA participants get individually retested for PFAS in blood. The biological half-lives of many of the PFAS measured in people's blood are long. PFHxS has one of the longest half-lives. This means that PFAS blood levels are not expected to change significantly

in the near-term, even if exposure stops. Additionally, it is unclear what an individual's PFAS test results mean in terms of possible health effects.

For the general population blood tests for PFAS are most useful when they are part of a scientific investigation like this EA. 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 are concerned about the effect of PFAS on your health, talk to your health care provider and make them aware of ATSDR resources for clinicians (https://www.atsdr.cdc.gov/pfas/resources/info-for-health-professionals.html).

h. ATSDR is funding a multi-site health study, including one site in the El Paso County area called the Colorado Study on Community Outcomes from PFAS Exposure (CO-SCOPE). The CO-SCOPE is being conducted by the same investigative team that completed the PFAS AWARE study. The study will evaluate PFAS levels in serum as well as health markers and neurobehavioral outcomes in children. If you are interested in being included in the study or want further information, please contact Fountain Valley PFAS Study | PFAS Multi-Site Study Colorado: CO SCOPE (co-scope.org)

i. 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.

j. 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 Security-Widefield 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 Security-Widefield in El Paso County, Colorado. This report summarizes the findings of the Security-Widefield EA. When all EAs are complete, ATSDR will prepare a report describing the results across all sites.

Exposure assessment (EA) participants were recruited among El Paso County residents living near the Peterson Air Force Base who received drinking water from the Security Water District, western portions of the Widefield Water Sanitation District, or Security Mobile Home Park that had PFAS levels above state or federal guidelines. For purposes of this report, we refer to the "Security-Widefield EA" to describe the EA conducted in this area. For more information and a map of the area see the "Methods" section of the report.

The EA involved collecting responses to exposure history questionnaire responses, biological samples (blood and urine), and environmental samples (tap water and household dust). ATSDR collected biological samples at the Security Village Fire Station between September 15 and September 28, 2020. During this same time frame, ATSDR administered questionnaires over the phone and took water and dust samples in a subset of randomly chosen participant homes.

The results of the EA:

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

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

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

What Are PFAS?

Human exposure to PFAS is a growing environmental health concern. PFAS are synthetic chemicals used in many industries and consumer products since the 1950s. They have been used in nonstick cookware; water-repellent clothing; stain-resistant fabrics and carpets; cosmetics; firefighting foams; and products

that resist grease, water, and oil [Buck et al. 2011; Gluge et al. 2020; Wang et al. 2017]. Exposure to PFAS has been associated with increased cholesterol, decreased vaccine response in children, changes in liver enzymes, small decreases in infant birth weights, increased risk of high blood pressure or pre-eclampsia in pregnant women, and increased risk of kidney and testicular cancer [ATSDR 2021].

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

PFAS do not occur naturally but are widespread in the environment. PFAS can be released into the environment during their production, use, or disposal. PFAS have been found in soil, sediment, water, 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 Security-Widefield are not expected to be an important contributor to PFAS exposure relative to the contribution from drinking water [Sunderland 2019].

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

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

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

After PFAS enter the human body, some PFAS can remain there for a long time. Most studies estimate a half-life of PFHxS between 4.7 and 8.5 years, although some have estimated half-lives as long as 35 years [ATSDR 2021]. Most half-life estimates for PFOS are between 3.3 and 7.4 years, with a maximum of 27 years [ATSDR 2021]. For PFOA, most studies estimate the half-life between 2.1 and 3.9 years with a maximum of 10.1 years [ATSDR 2021].

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

Why Security-Widefield?

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

PFAS and precursors that degrade to other compounds measured in this EA were used in historical AFFF formulations. Two types of PFAS containing AFFF were manufactured before 2016 [ITRC 2020]. Both formulations contained PFAS or PFAS precursors, the use of which resulted in the release of PFOS, PFHxS, PFOA, and PFHxA into the environment. Possibly as early as the 1970s, Peterson Air Force Base (the Base) used AFFF containing PFAS for its firefighter training (AFCEC 2018). Over time, the PFAS from the AFFF moved off site in groundwater and contaminated nearby public drinking water supply wells.

When PFAS first entered Security-Widefield's public water systems is not known. These substances were first detected in municipal wells near the Base in 2013 and 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. The levels measured in the Security Water District (WD) and Widefield Water and Sanitation District (WSD) water systems during UCMR 3 were above EPA's provisional health advisory, which at the time was 400 parts per trillion (ppt) for PFOA and 200 ppt for PFOS.

- In the Security WD system, PFHxS, PFOS, or PFOA were detected in 36 out of 38 samples taken between January 14 and August 11 of 2014. Wells from both the eastern and western parts of the system exceeded EPA's provisional health advisory, and the highest PFOA+PFOS concentration was 1,370 ppt in a well in the eastern part of the system. However, water from this well fed into a tank and mixed with uncontaminated surface water prior to entering the distribution system. According to Security WD engineers, on average, the groundwater would have been diluted with uncontaminated surface water by approximately 90 percent. The highest measurements of finished individual PFAS in finished water (water consumed by customers) in the Security WD system were 590 ppt for PFHxS, 210 ppt for PFOS, and 90 ppt for PFOA.

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

- In the Widefield WSD system, PFHxS, PFOS, or PFOA were detected in 11 out of 17 samples taken between November 12, 2013, and August 11, 2014. PFOA+PFOS exceeded EPA's health advisory in five samples with a maximum concentration of 246 ppt at a well in the western part of the system. Water that entered the eastern part of the Widefield WSD distribution system was less contaminated. The highest measurements of individual PFAS in the Widefield WSD system, detected in western portions of the system, were 330 ppt for PFHxS, 210 ppt for PFOS, and 48 ppt for PFOA.

In 2016, EPA issued a lifetime health advisory (HA) for the sum of PFOA and PFOS levels in drinking water (70 ppt). In 2016 and 2017 (CDPHE, 2019) the Colorado Department of Public Health and Environment (CDPHE) reported the results of PFAS testing in water supplies across El Paso County. The CDPHE data confirmed PFAS contamination throughout the Security WD distribution system and in the western parts of the Widefield WSD system. The CDPHE data showed exceedances of the EPA's HA in a third system, the Security Mobile Home Park (MHP).

- In February 2016, PFAS was detected in an active groundwater well within the Security MHP system at levels of 70 ppt for PFOS and 33 ppt for PFOA.

Between January and November of 2016, Security WD and Widefield WSD inactivated their contaminated groundwater wells and shifted to uncontaminated surface water sources. In 2017, Widefield WSD installed an ion exchange system to treat PFAS in water from its contaminated wells. Security WD currently uses uncontaminated surface water sources. Residents of Security MHP were provided bottled water beginning in the summer of 2016 until a treatment system was installed in November of 2017. By 2016, all three systems had taken active measures to reduce PFAS exposure to customers.

The information available to ATSDR indicates that, when the EA was conducted in 2020, drinking water supplies in Security-Widefield met or were below the EPA's HA for PFAS in drinking water.

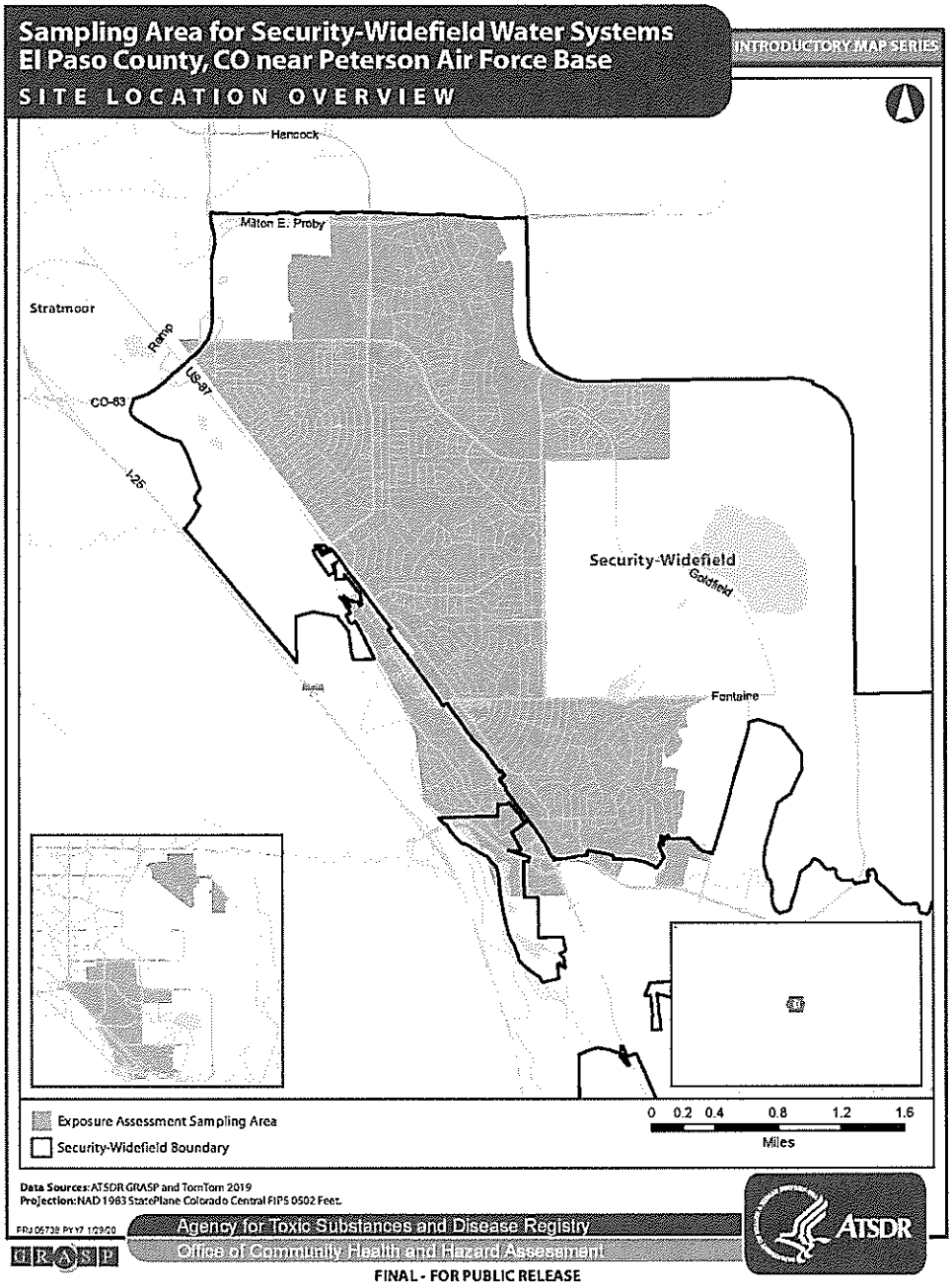
Methods

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 Security-Widefield EA.

Sampling Frame

This EA targeted a specific geographic area, called the sampling frame or sampling area. The sampling frame for this EA was the area served by the drinking water systems of Security WD, Security MHP, and the western portion of the Widefield WSD (see Figure 1). Based on a review of El Paso County land parcel data, ATSDR determined that 10,783 households in the sampling frame were connected to the Security-Widefield water supplies. These households formed the sampling frame from which households were randomly selected for recruitment. Households with private wells were not eligible for participation. 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.elpasocountyhealth.org/news/news-release/2019/resources-for-pfc-water-contamination-and-testing.

Figure 1. Sampling frame for the Security-Widefield Exposure Assessment



Participant Eligibility

Security-Widefield residents who were randomly selected to participate and met the following criteria were eligible to participate in the EA:

- Lived within the sampling frame (i.e., Security-Widefield households in the affected area shown in Figure 1) for at least one year before November 10, 2016, which is when Security-Widefield reduced PFAS drinking water concentrations below EPA's HA in all three water systems.
- Were at least 3 years old at the time of recruitment. This age criterion was used because national reference values are not available children under the age of three.
- Did not have bleeding disorders and were not anemic, unless they confirmed with their doctor the ability to safely provide a blood sample.

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

Participant Recruitment

ATSDR randomly selected 3,000 households in the sampling frame for recruitment. This number was chosen to attempt to achieve the protocol recruitment target of 395 participants. Every household had an equal chance of being selected, and all members of randomly selected households who met eligibility criteria were invited to participate. This type of recruitment, called a one-stage cluster sampling design, means that a single household may have multiple participants.

Measuring PFAS in the blood of people from randomly selected households allowed ATSDR to estimate exposure to PFAS from public drinking water for the entire community (the sampling frame) in the affected area, even those who were not tested.

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. In each attempt, ATSDR called all working phone numbers (cell phone and landline) associated with a household. For calls that went to voicemail, ATSDR staff left messages encouraging residents to call back to schedule appointments. Door-to-door recruitment occurred after each household had received an initial outreach letter and at least one recruitment call attempt.

Results from the randomly selected participants can provide information about community-level exposure. Had ATSDR accepted volunteers, results could not be used to estimate exposure across the Security-Widefield sampling frame. After two waves of recruitment (initially reaching out to 1,162 households and later reaching out to an additional 1,838 households), 384 residents from 200 households scheduled appointments for biological sampling and questionnaire completion.

ATSDR attempted to recruit 10% of the participating households for environmental sampling. ATSDR invited 30 households, and 20 households scheduled environmental sampling appointments.

Data Collection and Analysis

The Security-Widefield 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 at the Security Village Fire Station between September 15 and September

28, 2020. During this same time frame, ATSDR administered questionnaires over the phone and collected environmental samples in a subset of randomly chosen participant homes. All data met the stringent quality control requirements for sample collection and analysis.

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

ATSDR project staff handled all data collected in accordance with the *Standard Operating Procedures of PFAS Exposure Assessment Data Management* [ATSDR 2019b]. These procedures have very strict requirements for handling any personally identifiable information. ATSDR project staff protected this information to the extent required by federal and Colorado law. All signed consent forms were mailed to and are securely archived at ATSDR headquarters. Participant responses to phone questionnaires were logged directly into 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 384 residents who scheduled data collection appointments, 359 (93%) participated in the EA. ATSDR administered exposure history questionnaires to 355 EA participants: 321 for adults 18 and older, and 34 for children between the ages of 3 and 17. Four participants that provided blood samples did not complete a questionnaire. ATSDR used one questionnaire for adults and another for children. Both addressed topics relevant to PFAS exposure, such as residential and work histories, drinking water habits, and use of PFAS-containing consumer products.

A phlebotomist collected blood samples from all 359 participants. ATSDR processed the blood samples in the field, aliquoting the serum portion of the blood.

After the sampling was complete and upon further review of each participant's residential history, ATSDR determined that 13 participants had not lived in the sampling frame for at least one full year before November 10, 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 346 blood samples (318 adults and 28 children) were considered in the community exposure summary. These samples were collected from participants residing in 188 unique households. This represents a household participation rate of 6.3% (i.e., 6.3% of the 3,000 recruited households had at least one person participate in the EA).

Urine samples were collected from 354 participants (324 adults and 30 children). Per the EA protocol, 10% of the urine samples were randomly selected for initial analysis. ATSDR randomly selected 36 samples for analysis. These samples were collected from participants (34 adults and 2 child) who resided in 36 unique households.

CDC's National Center for Environmental Health laboratory analyzed the serum portion of blood and urine samples for the suite of PFAS measured in the 2015–2016 National Health and Nutrition

Examination Survey (NHANES) [CDC 2019]. As part of NHANES, CDC takes biological samples and tests them for chemicals, including PFAS, from a representative sample of 5,000 people across the country during each two-year cycle. All laboratory analyses followed established procedures for quality assurance and control according to the Center's methodology.

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

Environmental Sampling

ATSDR collected tap water and dust samples from 18 of the 20 households that had initially scheduled appointments. Two households were unavailable to complete their environmental sampling appointment. At each participating household, ATSDR collected a drinking water sample from the kitchen tap. If point-of-use filtration was in place, ATSDR project staff attempted to collect a sample before and after filtration. Tap water samples were collected and analyzed in accordance with EPA's *Method 537.1: Determination of Selected Per- and Polyfluorinated Alkyl Substances in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry* [Shoemaker and Tettenhorst 2018].

Project staff also collected a composite dust sample from the floor at a minimum of three locations inside each selected home: the primary living space as identified by the homeowner (e.g., living room, family room, television room), the kitchen, and the bedroom in which participants reported spending the most time. Dust collection was intended to generate more information about the contribution of non-drinking-water exposures to overall PFAS exposure. Participants were instructed not to vacuum carpeting or sweep floors for five days prior to the scheduled visit. Adapting methods described in Scher et al. [2018], ATSDR collected dust samples using a high-volume air sampler connected to an open-faced 37 millimeter filter cassette with an 0.8 micron filter. A wooden 2 square foot (ft^2) sampling template was used to mark off each sampling area. ATSDR project staff attempted to collect at least 1 gram of dust in the open-faced cassettes from each home by vacuuming the same 2 ft^2 surface at least four times with the cassette (vertically, horizontally, and in circles). Samples were taken preferentially from mats, carpets, and area rugs. Household dust samples were analyzed in accordance with SGS AXYS Method MLA-110 (revision 01, version 06), *Analytical Procedure for the Analysis of Per- and Polyfluoroalkyl Substances (PFAS) in Aqueous Samples, Solids and Solvent Extracts by LC-MS/MS* [SGS AXYS 2019].

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

Table 1. Summary of recruitment and data collection efforts

Recruitment	
Households invited to participate by mail	3,000
Wave 1 of recruitment	*1,162*
Wave 2 of recruitment	*1,838*
Households reached by mail	2,567
Households reached by phone	1,147
Household door-to-door visits	2,640
Biological sampling:	
Individuals enrolled	384
Households enrolled	200
Environmental sampling:	
Households invited	30
Households enrolled	20
Data Collection	
Completed questionnaires	355
Adults	*321*
Children	*34*
Blood samples	
Included in community statistics (188 households)	346
Adults	*318*
Children	*28*
Urine samples	
Collected	354
Adults	*324*
Children	*30*
Included in community statistics (36 households)	36
Adults	*34*
Children	*2*
Dust samples collected and analyzed (one composite sample per household)	18
Tap water samples collected and analyzed (18 households)	34
Filtered	17
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 target of at least 15% and a 5% level of significance for PFOS), (2) compare community level data to national levels, and (3) explore relationships between questionnaire data and measured biological and environmental data.

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

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

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

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 dataset 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 dataset 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 defines a range of values that's likely to include a specific value with a certain degree of confidence (probability). It provides a measure of how much uncertainty there is with any particular 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.

means would be calculated if >=60% of samples had detections. 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. While random recruitment at the household level helps allow for such an estimation, ATSDR evaluated demographic differences between the Security-Widefield 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 (on log-transformed data) 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*. This level specifies less than a 5% probability of being due to chance alone.

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

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

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

To account for the one-stage cluster design, 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 0.26 to 0.81, suggesting weak to strong correlation of PFAS blood levels within a household. Appendix B provides more information on clustering, as well as further details on the statistical methods used for this EA and how results from this EA compared to the assumptions used to estimate the target sample size of 395 participants.

Results

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

Most analyses in this section reflect the entire Security-Widefield 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 Security-Widefield (El Paso 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 Security-Widefield EA participants

Characteristics	Count of EA Participants (n)*	Percent of EA Participants (%)‡
Adults and children combined		
Age (years)	(mean = 53.4)	
<18	28	8.1
18 to <50	97	28
50+	221	64
Sex		
Male	153	44
Female	193	56
Race and ethnicity†		
White, non-Hispanic	239	71
non-White or Hispanic	99	29
Adults only		
Years lived at current address	(mean = 20.8)	
<10	80	25
10 to <20	82	26
20 to <30	77	24
30+	79	25
Current primary drinking water source		
Public water system	217	68
Bottled water	101	32
Average tap water consumption while living at current home (8-ounce cups per day)	(mean = 6.4)	
0	45	14
>0 to <2	13	4.1
2 to <4	40	13
4 to <6	60	19
6 to <8	44	14
8+	114	36
Current use of treatment or filtration device		
One or more filter/treatment device(s)	190	60
None	128	40
Occupational exposures to PFAS in the past 20 Years		
One or more occupational exposure(s)	41	13
None	227	87

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

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

‡ The 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 53.4 years, and 71% of the participants identified themselves as White, non-Hispanic. Of EA participants, 56% identified as female, 44% identified as male, and 92% were adults, aged 18 years or older. The age cutoff is important because adults were administered a different exposure history questionnaire with more detailed questions. Among the adult participants, 75% reported living in their current homes for more than 10 years.

Adults were also asked about their current primary source of drinking water: 68% said public water system (Security WD, Widefield WSD, or Security MHP), and 32% said bottled water. Adults reported drinking an average of 6.4 8-ounce cups of water a day at home, and 60% said they currently use some type of filtering or treatment device for their drinking water. Examples include filters on refrigerators, pitchers, and faucets; whole-house carbon filtration systems; and reverse osmosis treatment systems. The questionnaire asked adults for their occupational histories over the past 20 years; 13% reported holding one or more jobs with potential PFAS exposures (e.g., firefighting, military, aviation).

Comparison of Security-Widefield 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., Security-Widefield households in the affected 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 had an equal chance of being chosen to participate. 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. The comparison revealed the following:

- **Age distribution.** The EA participants included a higher proportion of older adults (age 50+ years), a lower proportion of younger adults (18–50 years), and a lower proportion of children (age <18 years) than the sampling frame population (Table 4). Specifically, 64% of the EA participants reported being 50 or older, but 29% 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, 28% of the EA participants reported being 18–50, but 43% of the sampling frame population falls in that age range. Finally, 8.1% of the EA participants reported being <18 years, but 28% of the sampling frame population falls in that age range.
- **Race/ethnicity.** Among the race/ethnicity characteristics, only the percent of residents who identify as White and more than one race showed a significant difference between the EA participants and the sampling frame population (Table 4). Specifically, the EA population had statistically more White participants (79%) than the sampling frame population (74%) and fewer participants who identified as more than one race (3.5%) than the sampling frame (8.3%). For this comparison, combined race and ethnicity were not available at the block level from the Census. Therefore, only ethnicity and the race categories of White, Black, and More than one race were compared because of the small number of respondents in other categories.

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	8.1	28.1	<0.001
18–50	97	28.0	43.2	<0.001
50+	221	63.9	28.7	<0.001
Race				
White	275	79.5	73.7	0.017
Black or African American	28	8.1	9.2	0.52
Am. Indian & AK Native	<10	—	1.1	—
Asian	<10	—	2.8	—
Nat. Hawaiian/Pacific Islander	<10	—	0.88	—
More than one race	12	3.5	8.3	0.0016
Ethnicity				
Hispanic or Latino (of any race)	57	16.5	18.5	0.38

* 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.

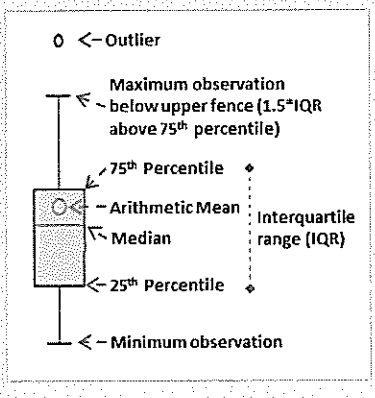
† Sampling frame data are based on the 2010 U.S. Census. Demographic characteristics of the sampling frame may have changed between 2010 and 2020, the time of this EA.

‡ 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 346 blood samples provided by eligible participants. Results are summarized in tables and 'box and whisker' plots (see text box).

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.



Unadjusted Community Statistics for PFAS in Blood

ATSDR first calculated the geometric mean levels of PFAS without accounting for the possible effect of age. Table 5 summarizes results for the seven PFAS measured in Security-Widefield EA participants' blood for all ages. Six of the seven PFAS—PFHxS, PFOS, PFOA, PFNA, PFDA, and MeFOSAA—were detected in more than 67% of the blood samples. ATSDR's statistical analyses throughout this section focus on these six chemicals, and Figure 2 shows the distributions of the individual measurements on a $\log_{10}$ scale. The $\log_{10}$ scale allows for more easily visualizing the wide range of serum concentrations as it uses equal spacing for each factor of 10 increase. The PFAS found at highest levels were PFHxS

(geometric mean = 10.6 micrograms per liter (or µg/L)), PFOS (6.22 µg/L), and PFOA (2.14 µg/L).

One PFAS—PFUnA—was detected in fewer than 60% of the samples. Low frequency of detection for PFUnA is consistent with NHANES data. Detailed statistics are not included for this chemical, 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 0.2% to 16% depending on the PFAS (Appendix B, Table B2). Except for Sm-PFOS, 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	138.2	10.6	9.19–12.3	4.93	11.6	24.4	43.2	55.9
PFOS	NA*	42.5	6.22	5.53–6.99	3.65	6.50	11.5	18.1	23.8
PFOA	NA*	16.8	2.14	1.96–2.34	1.28	2.18	3.45	5.25	6.41
PFNA	95.1	2.4	0.286	0.262–0.312	0.135	0.243	0.390	0.680	0.845
PFDA	68.5	0.9	0.123	0.113–0.133	NA†	NA†	0.138	0.241	0.361
PFUnA	41.3	1.6	NA‡	NA‡	NA†	NA†	NA†	0.138	0.183
MeFOSAA	67.1	2.3	0.134	0.121–0.148	NA†	NA†	0.169	0.293	0.557

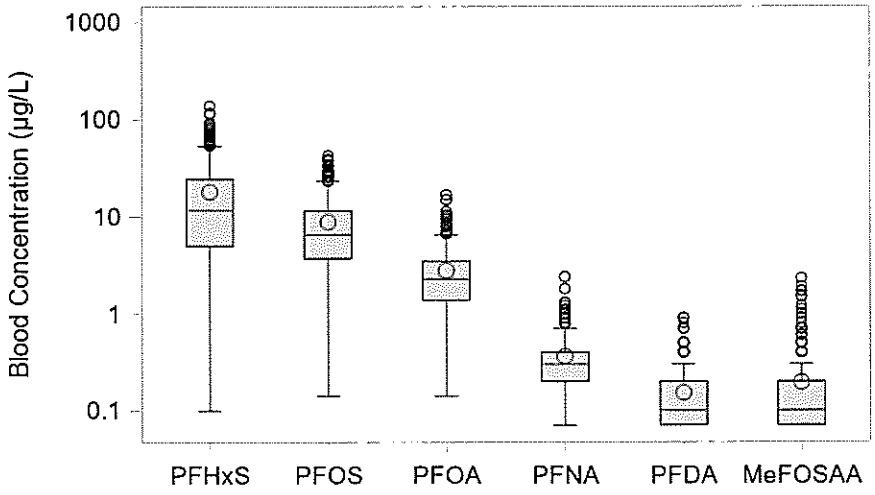
FOD = frequency of detection, CI = confidence interval, NA = not applicable

* PFOA and PFOS are calculated sums of branched and linear subsets and are not measured directly. Linear PFOA was detected in 99.4% of samples with a geometric mean of 2.04 micrograms per liter (µg/L); branched PFOA was detected in 0.3% of samples. Linear PFOS was detected in 99.1% of samples with a geometric mean of 3.98 µg/L; branched PFOS was detected in 99.4% of samples, with a geometric mean of 2.11 µg/L.

† Percentile is below the LOD.

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

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



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

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

Since the demographic profile comparison reported above showed that EA participants were significantly older than the sampling frame as a whole, ATSDR also calculated geometric means that were age-adjusted to the sampling frame population based on 2010 Census data for comparison. Age-adjusted geometric means correct for the participation bias discussed earlier and are more generalizable to the sampling frame community. Table 6 shows that age-adjusted blood geometric means for all PFAS are lower than unadjusted values. Of the three PFAS with the highest concentration (PFHxS, PFOS, and PFOA), age-adjusted geometric means are between 20% and 35% 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	10.6	9.19–12.3	6.88	5.70–8.29
PFOS	6.22	5.53–6.99	4.55	3.93–5.26
PFOA	2.14	1.96–2.34	1.72	1.54–1.93
PFNA	0.286	0.262–0.312	0.242	0.222–0.263
PFDA	0.123	0.113–0.133	0.118	0.108–0.130
PFUnA	NA*	NA‡	NA*	NA*
MeFOSAA	0.134	0.121–0.148	0.112	0.101–0.124

CI = confidence interval, NA = not applicable

* 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 Security-Widefield 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 population, ATSDR calculated both unadjusted geometric means of all EA participants and geometric means adjusted to the age distribution of the U.S. population in NHANES 2015–2016.

Table 7 shows the unadjusted comparison for the entire pool of EA participants to the data available from NHANES, which are the geometric means for the 2015–2016 survey [CDC 2019]. For PFHxS, PFOS, PFOA, unadjusted geometric mean blood levels among Security-Widefield EA participants were statistically ($p<0.05$) higher than the national geometric mean. For PFNA and PFDA, the unadjusted blood levels among Security-Widefield EA participants were statistically lower than the national geometric mean. Per protocol, geometric means were not calculated during NHANES for PFAS detected in less than 60% of samples, which included MeFOSAA. In this EA, MeFOSAA was detected in more than 60% of samples and geometric means were calculated.

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 Security-Widefield EA participants was 9.0 times the national level. Blood PFHxS levels were above the national geometric mean for 96% of EA participants and above the NHANES 95th percentile for 75% of EA participants (Table 7). The unadjusted geometric mean blood PFOS level among Security-Widefield EA participants was 1.3 times the national level. Blood PFOS levels were above the national geometric mean for 65% of EA participants and above the NHANES 95th percentile for 9.8% of EA participants. The unadjusted geometric mean blood PFOA level among Security-Widefield EA participants was 1.4 times the national level. Blood PFOA levels were above the national geometric mean for 69% of EA participants and above the NHANES 95th percentile for 19%.

On average, total PFOS measurements were composed of 65% linear PFOS (n-PFOS) and 35% 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 97% linear PFOA (n-PFOA) and 3% 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 total PFOS rather than treating the 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 the 337 EA participants. Table 7 and Figure 3 show blood PFAS geometric means adjusted to the NHANES population differ from unadjusted values. The adjusted geometric mean blood PFHxS level among Security-Widefield EA participants was 6.8 times the national level. The age-adjusted geometric mean blood PFOA level among Security-Widefield EA participants was 1.2 times the national level. Even when controlling for the age-distribution in the population, EA participants had statistically higher blood levels of PFHxS and PFOA than the U.S. population. After adjusting for age, blood levels of PFOS in EA participants were higher than the U.S. population, but the difference was not statistically significant.

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

PFAS	NHANES GM (CI)*	Security-Widefield GM (CI)†: Unadjusted	Security-Widefield GM (CI)†: Age-Adjusted to NHANES 2015-2016	Percent of Security-Widefield Results over NHANES GM (%)	NHANES 95th Percentile*	Security-Widefield 95th Percentile	Percent of Security-Widefield Results over NHANES 95th Percentile (%)
PFHxS	1.18 (1.08–1.30)	10.6 (9.19–12.3) *p<0.001*	8.08 (6.88–9.50) *p<0.001*	96.0	4.90	55.9	75.1
PFOS	4.72 (4.40–5.07)	6.22 (5.53–6.99) *p<0.001*	5.15 (4.48–5.91) *p=0.27*	65.3	18.3	23.8	9.83
PFOA	1.56 (1.47–1.66)	2.14 (1.96–2.34) *p<0.001*	1.82 (1.65–2.02) *p=0.009*	68.5	4.17	6.41	18.8
PFNA	0.577 (0.535–0.623)	0.286 (0.262–0.312) *p<0.001*	0.245 (0.223–0.270) *p<0.001*	18.2	1.90	0.845	0.290
PFDA	0.154 (0.140–0.169)	0.123 (0.113–0.133) *p<0.001*	0.119 (0.1.08–0.131) *p<0.001*	33.0	0.700	0.361	1.16
PFUnA	NA‡	NA‡	NA‡	NA	0.400	0.183	1.45
MeFOSAA	NA‡	0.134 (0.121–0.148)§	0.122 (0.110–0.136)§	NA	0.600	0.556	4.62

CI = 95% confidence interval, NA = not applicable

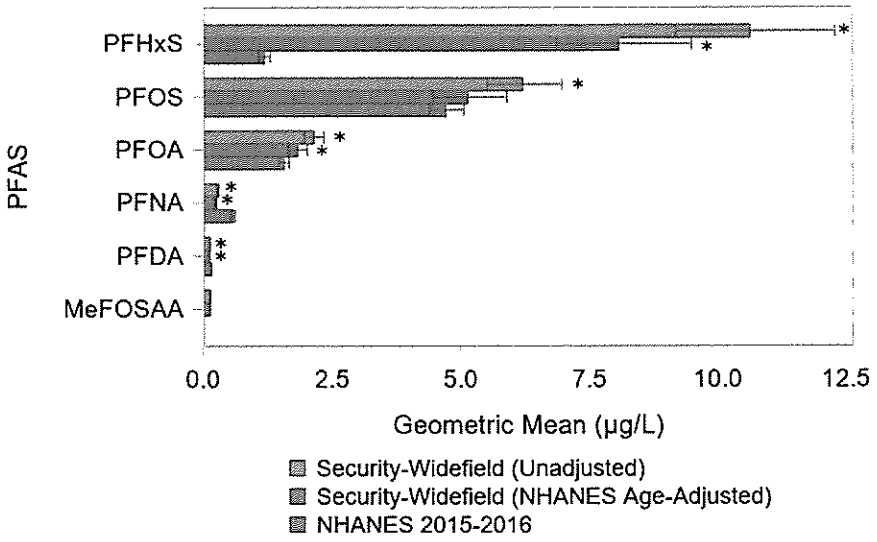
* Source: CDC 2019

† P-values represent a t-test comparison between Security-Widefield GM and NHANES GM.

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

§ No statistical comparison could be made with NHANES because NHANES did not calculate a geometric mean for this PFAS because this PFAS was detected in less than 60% of NHANES samples.

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



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 Security-Widefield EA participants. ATSDR used Pearson correlation coefficients (*r*) for this analysis. An *r* of 0 means two data sets are uncorrelated, and an *r* of 1 means two data sets are exactly correlated (i.e., they rise and fall in proportional amounts). The higher the coefficient, the closer the correlation. Table 8 shows the Pearson correlation coefficients for the five most frequently detected PFAS.

PFHxS, PFOS, and PFOA blood levels showed the strongest correlations (Table 8). All pairings of these chemicals had Pearson correlation coefficients relatively close to 1 (*r* = 0.71–0.73). On the other hand, PFNA and PFDA were correlated with each other (*r* = 0.68) and had weak to moderate correlations with other compounds (*r* = 0.13-0.61). MeFOSAA had weak or no correlations with all other compounds (r=-0.038-0.29).

Table 8. Pearson correlation coefficients between PFAS in blood (log)

	PFHxS	PFOS	PFOA	PFNA	PFDA	MeFOSAA
PFHxS	1.00	0.72	0.73	0.32	0.13	0.22
PFOS	0.72	1.00	0.71	0.61	0.41	0.29
PFOA	0.73	0.71	1.00	0.57	0.35	0.19
PFNA	0.32	0.61	0.57	1.00	0.68	0.19
PFDA	0.13	0.41	0.35	0.68	1.00	-0.038*
MeFOSAA	0.22	0.29	0.19	0.19	-0.038*	1.00

* Correlations not significant, i.e., p>0.05.

PFAS Blood Levels by Demographics and Other Exposure Characteristics

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

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

- age,
- sex,
- tap water consumption,
- drinking water source,
- use of a water filtration or treatment device,
- drinking water consumption rate,
- length of residence in the sampling frame,
- public water supply,
- kidney disease history,
- occupational exposure,
- consumption of selected local food items,
- cleaning frequency,
- breastfeeding (adult females and children), and
- childbirth (adult females).

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

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

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

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

Parameter	PFHxS			PFOS			PFOA		
	All Adult	Adult Female	Adult Male	All Adult	Adult Female	Adult Male	All Adult	Adult Female	Adult Male
Age (continuous)	✓	✓	✓	✓	✓	✓	✓	—	✓
Sex (categorical)	✓	NA	NA	✓	NA	NA	—	NA	NA
Age × sex (continuous)*	✓	NA	NA	—	NA	NA	—	NA	NA
Years in sampling frame in the past 20 years (continuous)	✓	✓	✓	✓	—	✓	✓	—	✓
Kidney disease history (categorical)	✓	—	✓	—	—	—	—	—	—
Occupational Exposure (categorical)	✓	—	✓	—	—	—	—	—	—
Filter use (categorical)	✓	✓	—	✓	✓	—	✓	—	—
Consumption of fruits and vegetables (categorical)	—	—	—	✓	—	✓	—	—	—
Home cleaning frequency (categorical)	—	—	—	✓	✓	—	—	—	—

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

* This variable is an interaction term between age and sex.

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, PFDA, and MeFOSAA. While blood levels of PFNA, PFDA, and MeFOSAA were not found to be statistically higher than the national geometric means, both PFAS were detected at a high enough frequency (greater than 60%) to present meaningful results. Summary statistics are therefore 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 six PFAS, as data allow. Data are presented only

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.

when a category had at least 10 responses. Some categories were collapsed to meet this threshold.

- Tables C5–C12 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 0.13 to 0.30. 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 were only significant for PFHxS and PFOA; the best model for PFOS was a univariate model consisting of only a single significant variable. The final female-only models were only significant for PFHxS and PFOS. ATSDR did not develop multivariate models for children because of the small sample size for this population (n=28).
- Figures C1–C36 present box and whisker plots for unadjusted blood levels by each demographic and exposure characteristic included in the statistical analyses.

Blood PFAS Levels and Age

Because many studies have found that older people have higher blood PFAS levels, ATSDR investigated how Security-Widefield EA participants' ages related to their blood levels. As Figure 4 illustrates, the blood levels for PFHxS, PFOS, and PFOA increased with age in adults, but trends were inconsistent in 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 Security-Widefield EA participants increased 2.5% for every year of participant age in adults. This suggests a 28% increase in blood PFHxS levels for every 10 years of participant age in adult participants. The calculated age-related increases for PFOS (1.9% per year of participant age) and PFOA (1.3% per year of participant age) were lower.

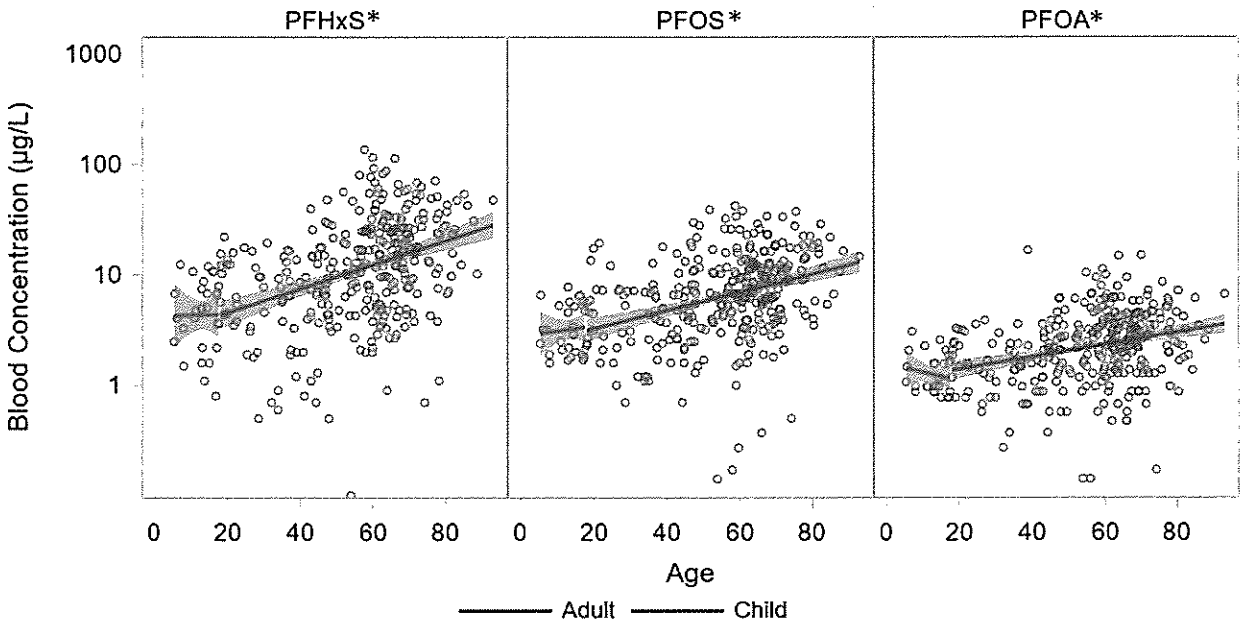
Variability describes the spread or dispersion of data values. If the values are similar to each other there is little variability, if the values are spread out there is more variability.

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.

ATSDR's multivariate analysis provided further perspective on this trend, showing that the age dependence was generally stronger for women than men among adults for PFHxS. For example, the all-adult model for PFHxS (Appendix C, Table C5) suggests a 2.5% increase in blood PFHxS for every additional year of participant age in female participants, and a 1.3% increase in blood PFHxS levels for every additional year of participant age in males, when controlling for other characteristics; these findings were statistically significant. Similar results were observed in the stratified male-only and female-only models. Age also remained a significant predictor of blood levels for PFOS (1.7% per year) and PFOA (1.0% per year) in all-adult multivariate models.

Age was not statistically associated with blood PFAS levels in children under 18 in univariate analyses. Note that multivariate models were not explored for children because of the 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*

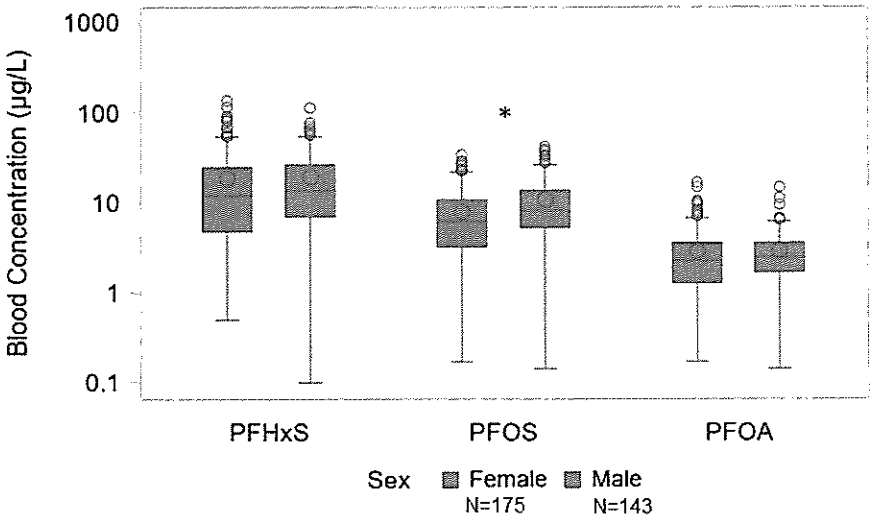
Blood PFAS Levels by Sex

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 analyses showed that PFAS levels were higher in adult males than in adult females for PFOS. Modeled blood levels in adult males were 43% higher for PFOS (Figure 5). This estimate for PFOS was similar when controlling for other variables in multivariate models (42%).

When controlling for other variables, sex was also a significant predictor of blood PFHxS levels, and the difference between males and females was larger in younger people. For example, 30-year-old males had higher modeled blood PFHxS levels than 30-year-old females by 70%. For 50-year-old males, this difference was reduced to 35% 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)



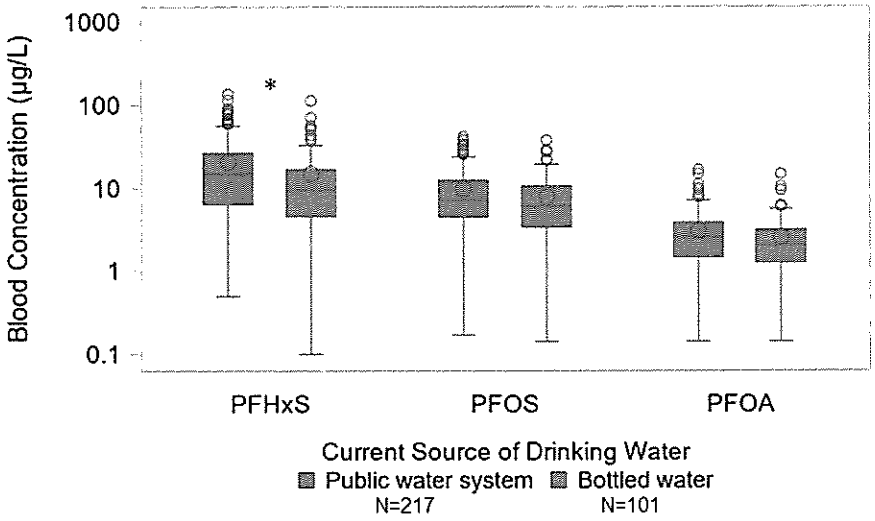
See 'How to read a box and whisker plot' earlier in the PFAS in Blood section.
A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically Significant Difference (p<0.05)*

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. ATSDR also considered the effect of each participant's public drinking water system.

Drinking water source. 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?" All of the responses were tap water (68%) or bottled water (32%). In univariate analyses, adults who primarily drank bottled water had significantly lower PFHxS (31%) blood levels when compared to adults who primarily drank from a public water system. (Figure 6). However, when controlling for other variables in multivariate analyses, this association did not remain statistically significant. Note that the exposure history question asked about current drinking water sources. It is possible that some participants who reported currently drinking bottled water previously drank tap water when their drinking water was contaminated.

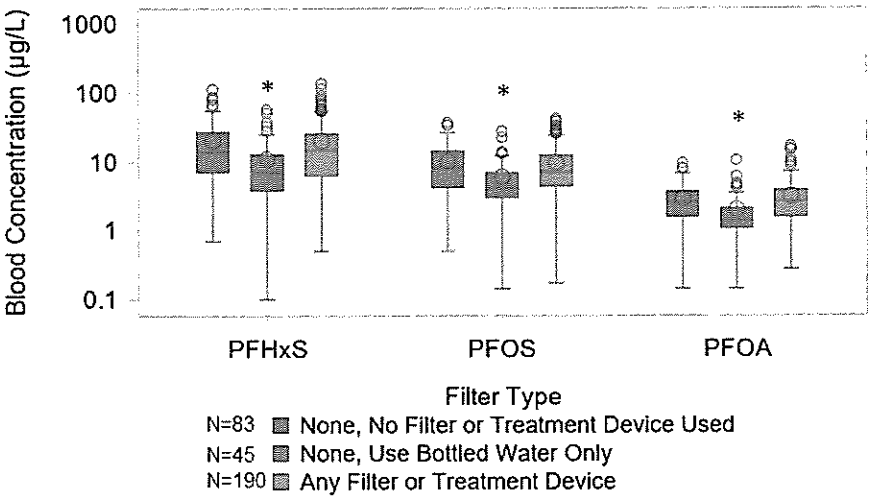
Figure 6. PFAS blood level in adults by drinking water source (log scale)



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)*

Use of filtration device. ATSDR also considered relationships between blood PFAS levels and current use of drinking water filtering and water treatment devices. As Figure 7 shows, 60% of participants reported using a filter or treatment device on the tap water that they drink at home, 26% of participants reported no filter or treatment device on the tap water that they drink at home, and 14% reported not drinking tap water at all. In ATSDR's univariate analyses, participants who reported not drinking tap water at all had significantly lower PFHxS (52%), PFOS (43%), and PFOA (32%) blood levels when compared to those who drank tap water with no treatment of filter device. When controlling for other variables in multivariate analyses, not drinking tap water remained statistically significant in the all-adult multivariate models with lower concentrations for PFHxS (36%), PFOS (32%), and PFOA (24%). This association also remained statistically significant in the PFHxS and PFOS female-only multivariate models.

Figure 7. PFAS blood level in adults by filter type (log scale)



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

Consumption rates. ATSDR also considered participants' self-reported tap water consumption rates (Figure 8). Adult participants were asked, "During the time you lived in a home served by the water source identified above [i.e., for the question quoted three paragraphs ago], on average how many 8-ounce cups of water or beverages prepared with tap water did you drink while at home per day?" In univariate analyses, for every additional cup of tap water an adult reported drinking at home per day, blood PFHxS, PFOS, and PFOA increased by 3.7%, 2.0%, and 1.7%, respectively. However, these associations did not remain significant in multivariate analyses, which controlled for other potential confounders.

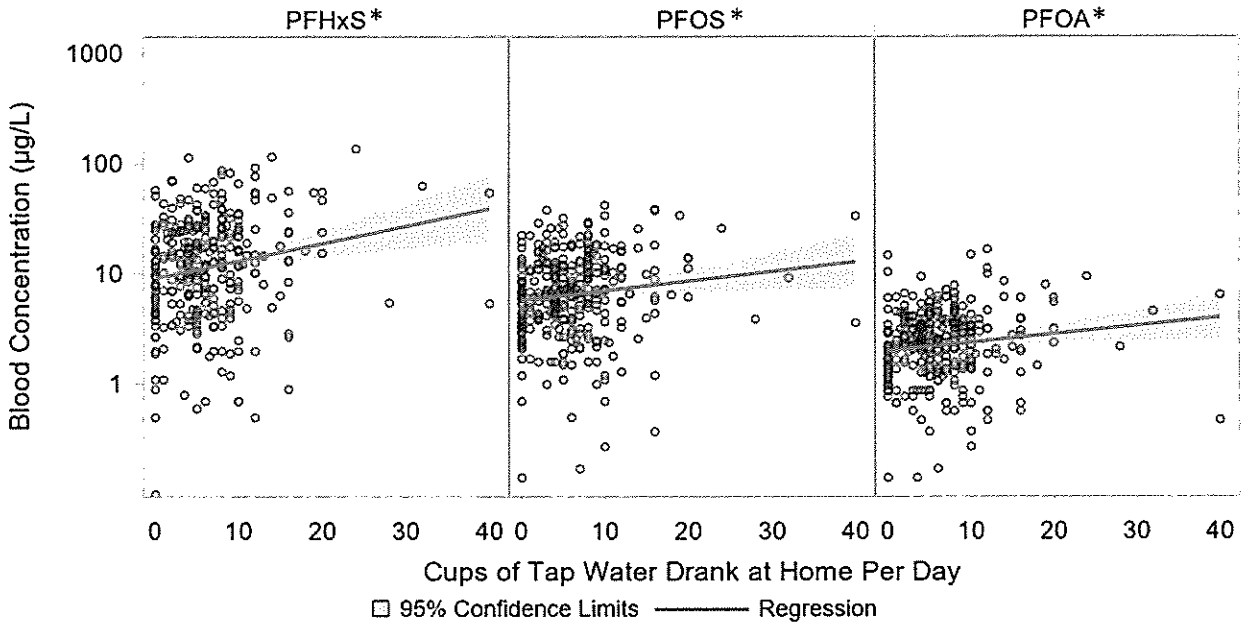
As can be seen in Figure 8, 8% of participants reported consumption rates that fall above the higher end values (95th percentile) reported in EPA's Exposure Factors Handbook of 3,292 milliliters per day (approximately 14 cups) [EPA 2019]. This relatively small percentage of participants may have overestimated their drinking water consumption, but this is not expected to alter conclusions.

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.

Figure 8. PFAS blood level in adults by tap water consumption rates (log scale)

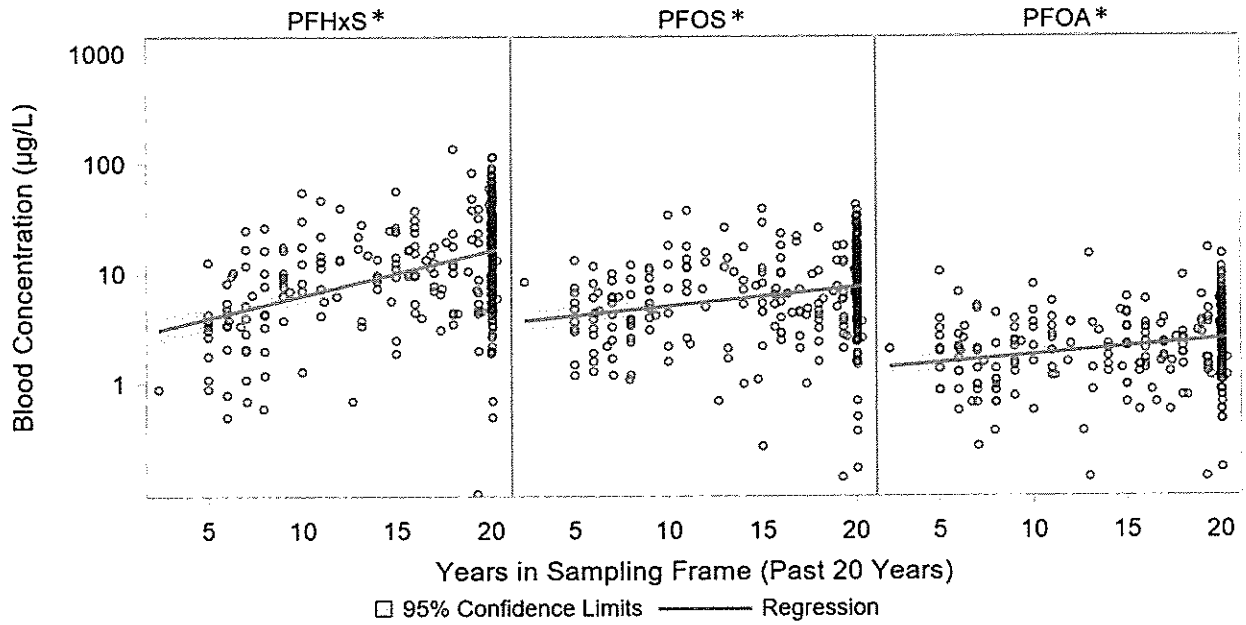


A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically Significant Trend (p<0.05)*

Length of residency. For adults, ATSDR also considered the length of residency. The exposure history questionnaire asked adults where they had lived for over the past 20 years. ATSDR calculated the total amount of time participants reported living in the sampling frame over this period. These responses can serve as a proxy for potential exposure to PFAS-contaminated drinking water in the community. That is, the longer the residency within the sampling frame, the greater the likelihood of past PFAS exposure from contaminated drinking water. Any resident reporting prior residences with addresses in Security, Widefield, or Security-Widefield were assumed to fall within the sampling frame. Any addresses in question (e.g., addresses in Colorado Springs or Fountain) were mapped and categorized as within or outside of the sampling frame accordingly.

Figure 9 shows the relationship between reported residence duration in Security-Widefield for the past 20 years and blood PFAS levels. A consistent relationship was observed for PFHxS, PFOS, and PFOA: blood levels statistically increased with the number of years participants lived in the sampling frame in the past 20 years for PFHxS (9.8% per year), PFOS (4.1% per year), and PFOA (3.3% per year). The multivariate analysis showed that all three PFAS continued to have a statistically significant relationship with residency duration, and this effect was most pronounced for PFHxS. For every additional year that an adult participant lived in Security-Widefield, blood PFHxS increased by 7.1%, while PFOS and PFOA increased by 2.0%. This relationship continued to be significant for all PFAS in male-only models and for PFHxS in female-only models.

Figure 9. PFAS blood levels in adults by length of residence in sampling frame (log scale)

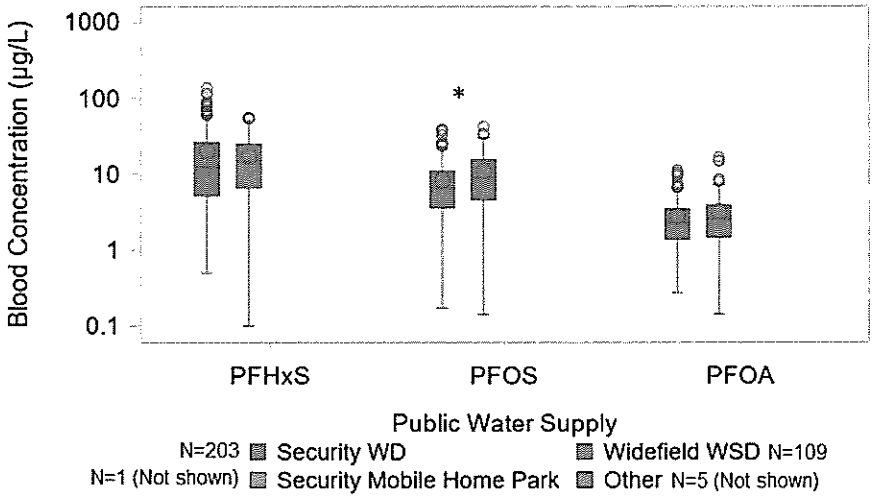


A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically Significant Trend (p<0.05)*

Public Water Supply

ATSDR also consider participants' public water supplies (Figure 10). Participants were asked which public water supply that were served by. For participants who did not know which public water supply they were served by, ATSDR mapped their addresses to identify the appropriate public water supply. In the sampling frame, adult participants generally lived in homes that received drinking water from the Security WD (n=203) or from Widefield WSD (n=109). One EA participant received water from Security MHP. In univariate analyses, adult participants connected to Widefield WSD had blood PFOS levels 33% greater than adult participants connected to Security WD. However, this association did not remain significant in a multivariate model.

Figure 10. PFAS blood level in adults by public water supply (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)*

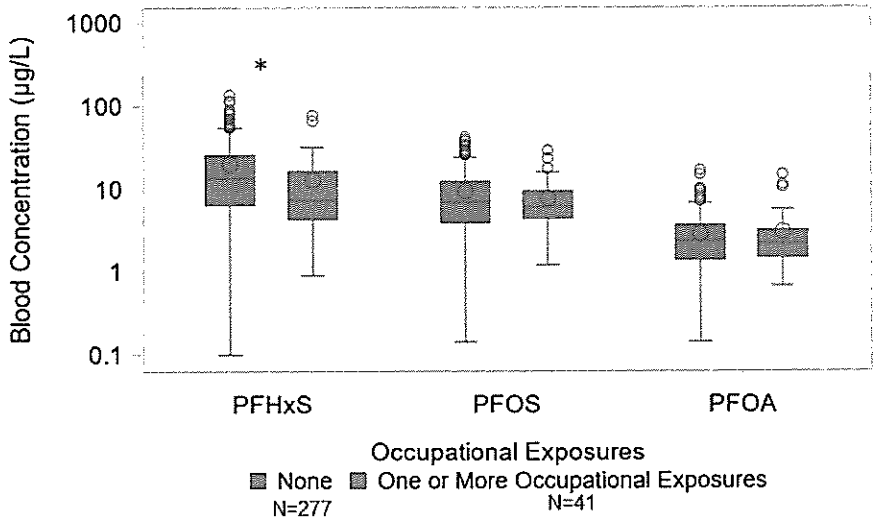
Blood PFAS Levels and Kidney Disease

Adult participants were asked about whether they had a history of kidney disease, because it can affect blood PFAS levels [Barry et al. 2013; Watkins 2013]. The questionnaire results indicated that only 6% of adults (n=20) 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 PFHxS blood levels that were 39% lower than those who did not. This variable was also statistically significant in the male-only multivariate model. The results for kidney disease for this EA are based on limited data and should be interpreted with caution. Note also that kidney disease was self-reported and there may be misclassification with this variable.

Blood PFAS Levels and Occupational Exposures

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. Forty-one (13%) adult participants reported at least one occupational exposure in the past 20 years. All 41 participants reported working in either military, aviation, or firefighting. In univariate analyses, participants with occupational exposures on average had lower blood PFHxS (33%) than adult participants who reported no occupational exposures in the past 20 years (Figure 11). In multivariate models, participants with any occupational exposure continued to have significantly lower blood PFHxS levels (28%). The direction of this association is the opposite of what was expected, but results are based on a small number of participants and should be interpreted with caution.

Figure 11. PFAS blood level in adults by occupational history (log scale)



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

Blood PFAS Levels and Consumption of Selected Local Food Items

Some PFAS accumulate in plants, fish, and animals. The questionnaire asked adult and child EA participants how often they consume locally grown fruits and vegetables, locally caught fish, and milk from animals in the sampling frame. Too few adult EA participants reported consuming locally produced milk (n=5) to allow for meaningful statistical analyses, and a statistically significant relationship was not observed between consumption of locally caught fish and blood PFAS levels, though only 11 adults reported consuming locally caught fish.

Blood PFAS levels were not associated with consumption of locally grown fruits and vegetables in univariate analyses. However, in multivariate analyses, blood PFOS levels were higher by 52% among adult EA participants who reported any consumption of locally grown fruits or vegetables (n=161) compared to participants who reported no such consumption (n=154). Note that sex-specific models showed that this relationship was primarily observed in males. While levels of PFOS were higher in participants who consumed local produce, PFOS blood levels were not elevated in the community.

Blood PFAS Levels and Cleaning Fequency

Adult participants were asked about the frequency at which they clean their homes. In univariate models, adult participants who reported cleaning their homes three times per week or more on average did not have statistically different blood PFAS levels than adult participants who reported cleaning their homes a few times per month or less. However, in all adult multivariate models, adult participants that reported cleaning their homes three times per week or more on average had PFOS blood levels 24% higher than adult participants that reported cleaning their homes a few times per month or less. Sex-specific models showed that this relationship was primarily observed in females. While levels of PFOS were higher in participants who cleaned their homes more frequently, the community's average PFOS blood level was not elevated.

Blood PFAS Levels and Past PFAS Blood Levels

Adult participants were asked if they previously had their blood tested for PFAS. Four EA participants from three households submitted blood PFAS test results from the PFAS Assessment of Water and Resident Exposure (PFAS-AWARE) health study, which tested PFAS levels in approximately 200 people in El Paso County in 2018. Approximately 50 participants were retested in 2019 as part of the PFAS-AWARE study. Information can be found online at https://pfas-aware.org. Two additional participants from one household submitted results from independent testing conducted in 2017.

ATSDR compared the change in PFAS blood levels between the first submitted test results for each participant and the levels measured in this EA. Blood PFHxS and PFOS levels decreased in five of the six participants between 8.0% and 13% per year and between 7.7% and 20% per year, respectively. In one participant, PFHxS increased by 11% per year and in a different participant PFOS increased by 13% per year. In all six participants, blood PFOA levels decreased by between 0.3% and 19% per year.

Blood PFAS Levels and Breastfeeding

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

Among adult female EA participants, 52% reported that they had breastfed a child, with an average breastfeeding duration across all pregnancies of 17 months. In univariate and multivariate models for adult females, neither having ever breastfed a child (yes/no) nor breastfeeding duration was associated with PFAS serum levels.

Among child EA participants, ATSDR was unable to evaluate the association between having been breastfed (yes/no) and blood PFAS levels because of the small sample. However, in univariate models for children, the longer a child breastfed, the greater their blood levels of PFOS and PFOA. Each month of reported breastfeeding was associated with an increase of 2.4% in blood PFOS and 2.2% in blood PFOA. For example, 6 months of breastfeeding was associated with an infant's modeled PFOS blood level increasing from 2 µg/L to 2.3 µg/L.

Approximately one-third of the children in the Security-Widefield EA (36%) consumed infant formula reconstituted with tap water (some of these children were also breastfed). In univariate models, children that reported ever drinking formula reconstituted with tap water on average had blood PFHxS, PFOS, and PFOA levels that were 57%, 44%, and 40% lower than children that reported never drinking formula reconstituted with tap water. Similarly, each month of formula consumption was associated with a decrease of 3% for blood PFOA.

Blood PFAS Levels and Childbirth (adult females and children)

The adult questionnaire asked female participants whether they had any biological children, and if so, how many. Most adult female EA participants (84%) reported having biological children. Adult female participants who reported having children on average had blood PFHxS levels that were 45% greater than adult female participants who reported having no children. Similarly, each child was associated with 17% increased PFHxS blood levels and 11% increased PFOS levels in univariate models. However, these relationships were not significant in multivariate models.

Blood PFAS Levels and Other Variables

Through the exposure history questionnaires, ATSDR gathered information on several other possible contributing factors to PFAS exposures. The variables listed below were not statistically associated with blood levels of PFHxS, PFOA, and PFOS among EA study participants in univariate or multivariate analyses. In some cases, ATSDR was not able to assess particular relationships because of small number of participant responses.

- **Race/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 Security-Widefield 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.
- **Blood donation frequency.** Adult participants were asked how often they donate blood or plasma, because frequent blood and plasma donations might result in decreasing blood PFAS levels. Relatively few participants (n=12) reported donating blood once or more a year, and no statistically significant relationship was observed with blood PFAS levels in adults.
- **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. Security-Widefield 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.
- **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.
- **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 Security-Widefield 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. This shift may make it more challenging to link PFAS exposure to fast food consumption.
- **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.

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

Information on urinary concentrations of PFAS in humans is limited, yet it may be important to understand exposure to short-chain and alternative PFAS. Because urine is the primary route of

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

For the Security-Widefield EA, ATSDR randomly selected 36 participants' urine samples for analysis. These samples were provided by 34 adults and 2 children, and these individuals lived in 36 different households. PFBA was the only PFAS detected in any of the 36 urine samples. Of note, the measurement 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. One of the 36 samples had PFBA urine concentrations higher than the NHANES 95th percentile. The protocol specified that all urine samples would be analyzed if the geometric mean exceeded the 95th percentile from NHANES. Since no PFAS were detected in more than 60% of the analyzed samples, no geometric means were calculated for any PFAS in urine and ATSDR did not analyze the remainder of the urine samples.

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

PFAS	Frequency of Detection (%)	Range of Concentrations (µg/L)	Security-Widefield Geometric Mean (µg/L)	Security-Widefield 95th Percentile (µg/L)	NHANES Geometric Mean (µg/L)	NHANES 95th Percentile (µg/L)
PFBA	2.8	ND–0.4	NA*	NA**	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]).

** 95th percentile is below the limit of detection.

PFAS in Tap Water

As noted previously, ATSDR collected tap water samples from 18 randomly selected participant households and analyzed these samples for PFAS. One household provided two filtered samples, two households provided only an unfiltered sample, and 15 households provided both filtered and unfiltered samples. Detection limits were 2 ppt for all PFAS, except for HFPO-DA (5 ppt).

PFAS were detected in three of the 17 filtered samples. In one of the filtered samples, PFBS, PFHxS, PFHxA, PFOS, and PFOA were detected. In the second sample, PFHxA and PFHpA were detected and in the third sample, only PFHxA was detected. The maximum concentrations in these filtered samples were 2.1 ppt PFBS, 3.5 ppt PFHxS, 51 ppt PFHxA, 2.3 ppt PFHpA, 11 ppt PFOS, and 3.0 ppt PFOA.

PFHxA was detected in seven of the 17 unfiltered samples. Four of those samples also had a detected concentration of PFHpA, and one of those samples also had a detected concentration of PFOS. The maximum concentrations in these unfiltered samples were 57 ppt PFHxA, 2.5 ppt PFHpA, and 3.0 ppt PFOS.

Geometric means were not calculated for any PFAS in filtered or unfiltered tap water because 40% or more of the results were non-detect. The detection limit, and measured concentrations were below EPA's HA of 70 ppt for PFOA and PFOS combined. There are no EPA health advisory levels for PFBS, PFHxS, PFHxA, or PFHpA.

The reason that a larger number of PFAS were detected in filtered samples 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.

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 18 randomly selected participant households where tap water samples were collected and analyzed these samples for PFAS. These samples were taken from multiple locations in each household, including the primary living space as identified by the homeowner (e.g., living room, family room, television room), the kitchen, and the bedroom in which participants reported spending the most time. When necessary, additional sampling was performed in other rooms to allow ATSDR to collect the proper amount of dust for testing.

Table 11 lists the specific PFAS that were measured in dust along with detailed summary statistics (i.e., frequency of detection, geometric means, 95% confidence intervals around the geometric means, and percentiles). Note that several PFAS were not detected in any sample and are therefore not included in Table 11 (i.e., PFNS, N-EtFOSA, FtS 4:2, HFPO-DA, ADONA, 9CL-PF3ONS, and 11CL-PF3OUdS).

Table 11. Summary statistics for dust samples (n=18) collected in Security-Widefield

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	72	67.9	3.25	1.56–6.80	2.91	21.9	54.0
PFPeS	11	28.0	NA*	NA*	1.05	2.90	5.64
PFHxS	72	267	3.53	1.82–6.86	2.82	9.05	42.2
PFHpS	11	3.25	NA*	NA*	0.884	2.88	3.14
PFOS	100	96.0	12.2	7.20–20.7	10.9	48.8	81.5
PFDS	56	9.83	NA*	NA*	1.35	5.00	7.63
PFDoS	28	16.3	NA*	NA*	1.34	5.13	7.76
PFBA	67	160	11.0	5.76–20.9	7.88	53.2	141
PFPeA	56	10.6	NA*	NA*	2.69	6.36	7.12
PFHxA	100	34.2	6.54	4.07–10.5	6.16	24.1	26.4
PFHpA	78	22.2	3.51	1.91–6.44	2.33	16.5	21.7
PFOA	89	65.1	7.99	4.47–14.3	6.52	34.7	39.5
PFNA	94	36.8	6.70	4.04–11.1	5.74	22.9	33.7
PFDA	89	13.4	3.92	2.57–5.97	3.48	11.5	11.8
PFUnA	44	12.2	NA*	NA*	1.35	7.79	10.6
PFDoA	56	10.9	NA*	NA*	1.88	6.83	8.20

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
PFTrA	44	5.10	NA*	NA*	1.35	3.19	3.57
PFTA	39	8.31	NA*	NA*	1.35	3.14	3.69
PFOSA	17	3.13	NA*	NA*	1.29	2.45	2.85
N-MeFOSA	6	5.20	NA*	NA*	1.20	3.32	3.77
MeFOSAA	61	38.7	2.35	1.33–4.16	1.98	9.66	24.4
N-MeFOSE	61	1,440	26.8	14.0–51.2	19.0	96.1	383
EtFOSAA	72	12.9	3.08	1.92–4.96	2.82	11.1	12.4
N-EtFOSE	17	150	NA*	NA*	7.85	21.6	36.1
FtS 6:2	44	54.7	NA*	NA*	4.88	42.5	48.5
FtS 8:2	6	12.6	NA*	NA*	4.19	9.79	11.4

FOD = frequency of detection, ng/g = nanograms per gram, NA = not applicable
A total of 18 dust samples are summarized in this table.
* Per the EA protocol, geometric means were not calculated for PFAS detected in less than 60% of samples.

Multiple PFAS (PFHxS, PFOS, PFOA, PFBA, PFNA, PFHxA, PFDA, PFHpA, PFBS, EtFOSAA, N-MeFOSE, and MeFOSAA) were detected in greater than 60% of samples. N-MeFOSE and PFOS were detected with the highest average concentration. N-MeFOSE and PFOS had geometric mean values of 26.8 nanograms/gram (ng/g)[4] (95% confidence interval = 14.0–51.2 ng/g) and 12.2 ng/g (95% confidence interval = 7.2–20.7 ng/g). PFHxS and PFOA had geometric mean values of 3.5 nanograms/gram (ng/g) (95% confidence interval = 1.8–6.9 ng/g) and 8.0 ng/g (95% confidence interval = 4.5–14.3 ng/g), respectively.

To provide some context to the results summarized above, average levels of PFAS measured in the 18 samples collected as part of this EA were compared to average dust levels reported in other U.S.-based studies (in communities with or without 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, 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 18 samples collected as part of this EA were lower than what was reported from these four studies. Details on these studies and comparisons with all other measured PFAS can be found in Appendix A, Table A1.

While these results suggest that PFOS and PFOA measured in the dust samples collected in Security-Widefield were found at lower levels than reported elsewhere in the United States, note that the studies referenced here do not necessarily provide representative comparisons and are provided only for

[4] 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.

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 18 dust samples and from the 35 blood samples collected from participants residing in the same homes. Using log-transformed data, ATSDR calculated Pearson correlation coefficients for the PFAS measured in at least 60% of the dust and the same PFAS measured blood samples for this assessment. Data were log-transformed because dust and blood concentrations were log-normally distributed.

PFOA measured in dust was statistically correlated (r=0.46, p=0.0053) with PFOA measured in blood. MeFOSAA measured in dust was statistically correlated (r=0.57, p=0.0004) with MeFOSAA measured in blood. None of the other PFAS measured in dust were statistically correlated ($p<0.05$) with the same PFAS measured in blood. Note that the sample size for dust measurements in Security-Widefield 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 report analyzing data across 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 Security-Widefield 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, PFDA, and MeFOSAA were the most frequently detected compounds in Security-Widefield EA participants (detection frequencies above 67%).

Results from this EA were compared to the NHANES data from 2015–2016.[5] Age-adjusted geometric mean blood levels of PFHxS and PFOA were statistically higher than these national geometric means (6.9 and 1.2 times, respectively), and age-adjusted blood concentrations of PFOS, PFNA, and PFDA were similar to or lower than national geometric means. ATSDR was unable to compare blood levels of MeFOSAA because this PFAS was detected in less than 60% of NHANES samples.

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 Security-Widefield EA blood levels, collected in 2020, and the NHANES 2019-2020 geometric mean (not yet available) could be greater than the differences between geometric mean Security-Widefield EA blood levels and the NHANES 2015-2016 geometric mean presented here.

[5] 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.

ATSDR compiled blood PFAS levels for the three most prevalent PFAS (PFHxS, PFOS, and PFOA) to provide further context on the current (2020) Security-Widefield EA blood levels (Appendix A, Table A2):

- For PFHxS, Security-Widefield EA participants' blood levels are higher than the national geometric mean from 1999–2000 (2.1 ppt), the time NHANES first measured PFAS and the time the highest PFAS levels were observed [CDC 2019]. EA participants blood PFHxS levels are also higher than levels observed in other communities with contaminated drinking water [PA DOH 2019; ATSDR 2013; Frisbee et al. 2009; NH DHHS 2016; NYDOH 2019].
- For PFOS and PFOA, blood levels among Security-Widefield EA participants are within the range of those observed in other communities with contaminated drinking water (Appendix A, Table A2). The levels reported here are lower than the national geometric mean PFOS and PFOA levels for 1999–2000 (30.4 ppt and 5.2 ppt, respectively) [CDC 2019].

Generalizability of Security-Widefield EA Community Statistics

The random sampling 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., Security-Widefield households in the area shown in Figure 1). Although the population invited to participate was likely representative of the sampling frame, the population that ultimately enrolled was older. Specifically, adults aged 50 or older represented 64% of the EA population compared with 29% of the sampling frame. The EA population and the sampling frame as a whole also statistically differed in the proportion of people who identify as White and as more than one race. Given the 6.3% 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 believes that any bias caused by differences in ethnicity would be minimal because race and ethnicity were not statistically significant in multivariate analyses for PFHxS, PFOS, and PFOA. However, ATSDR was concerned about the potential bias caused by the older age of EA participants since levels of PFAS are known to vary depending on people's age. Therefore, ATSDR quantified the magnitude of the bias introduced by age by calculating geometric means that were adjusted to the age distribution of the sampling frame (Table 6). This analysis showed that the unadjusted geometric means for blood PFHxS, PFOS, and PFOA biased high by 20% to 35%. Therefore, the sampling frame age-adjusted geometric means for PFAS are more representative of the average levels in the community.

Relationships Between Demographics and PFAS Blood Levels

When evaluating differences in demographic factors by PFAS levels, adult males had statistically higher geometric mean blood levels for PFHxS and PFOS, based on results from the all-adult multivariate models, but did not have statistically elevated differences for other PFAS. In other studies in communities with contaminated drinking water and for the general U.S. population [e.g., ATSDR 2013; NH DPHS 2016; CDC 2019], sex-based differences are likely due to additional excretion routes in females including through menstrual fluid, breastfeeding, pregnancy, and renal clearance rate differences [ATSDR 2021]. PFAS have been demonstrated to pass through the placental barrier and into the developing fetus during gestation, and have been measured in maternal serum, cord blood, breast milk [Cariou et al. 2015], placenta [Chen et al. 2017], fetal tissue [Mamsen et al. 2019], and neonates [Wang et al. 2014]. These studies suggest gestation, birth, and breastfeeding as excretion pathways for mothers and gestation and breastfeeding as potential exposure pathways for infants. In this EA, the effect of gestation (as measured by the number of children a female reported having had) and the duration of

breastfeeding were not significant predictors of PFAS blood levels in adult females. However, in univariate models of child participants, breastfeeding duration was associated with increased PFOS and PFOA blood levels, formula consumption (yes/no) was associated with decreased PFHxS, PFOS, and PFOA blood levels, and formula consumption duration was associated with decreased PFOA blood levels.

Blood PFAS levels were statistically higher in older adults than younger adults, and the effect of age was stronger in female participants than males for PFHxS. Blood PFAS levels were found to 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. Most studies estimate a half-life of PFHxS between 4.7 and 8.5 years, although some have estimated half-lives as long as 35 years [ATSDR 2021]. Most half-life estimates for PFOS are between 3.3 and 7.4 years, with a maximum of 27 years [ATSDR 2021]. For PFOA, most studies estimate the half-life between 2.1 and 3.9 years with a maximum of 10.1 years [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 PFAS levels were not associated with age in children under 18. Although this trend was not statistically significant, in other studies PFAS blood levels and age have been associated with multiple factors including early life exposures and growth dilution. Early-life exposures may have occurred since PFAS can cross the placenta and are found in breast milk [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:

- The two PFAS (PFHxS and PFOA) with statistically elevated blood levels in comparison to national levels were detected in Security-Widefield's water supplies as early as 2013. We do not know if contamination began earlier because no data are available before 2013. The maximum concentrations observed in finished drinking water in any of the three affected water systems were 590 ppt for PFHxS, 210 ppt for PFOS, and 90 ppt for PFOA. In 2016, all three water systems mitigated the contamination; however, these PFAS have very long biological half-lives (on the order of years). Therefore, even though drinking water PFAS exposures in the Security-Widefield were significantly reduced in November 2016, past drinking water exposures were likely a contributing factor to the EA participants' elevated blood PFAS levels, observed 3 years and 10 months later. Furthermore, in this EA, PFHxS had the largest deviation from the national average and showed the greatest association with reported drinking water consumption, which is what would be expected given that PFHxS has the longest half-life of the three PFAS.

- PFHxS, PFOS, and PFOA were highly correlated in blood (*r* between 0.71 and 0.73), 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 correlations observed between these three PFAS in this EA are much higher than those observed in the general U.S. population (*r* between 0.46 and 0.66) [Calafat et al. 2007b]. Instead, the high correlation between PFHxS, PFOS, and PFOA is 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 likely a contributing source of exposure among Security-Widefield EA participants. In addition, the correlations between PFHxS, PFOS, and PFOA in this study are much higher than the correlations observed for PFNA, PFDA, and MeFOSAA, three compounds that were detected in Security-Widefield's drinking water, providing further evidence of a distinct exposure pathway for these three compounds.
- 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 Security-Widefield. ATSDR considered residency duration to be a suitable surrogate for drinking water exposures because only residents who lived in the sampling frame before November 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 correlated (*r = 0.31)* with age in adults. Because of this, it was unclear from univariate models alone whether the association between the time someone lived in the sampling frame and PFAS blood levels was primarily due to age. After controlling for age, sex, and other data characteristics, the multivariate statistical analysis found that residency duration remained statistically associated with blood PFHxS, PFOS, and PFOA levels, and tap water consumption did not remain statistically associated with blood PFAS levels. However, multivariate models conducted separately for males and females suggest that these relationships were primarily observed in male participants for PFOS and PFOA. Furthermore, multivariate regression models did not explain a large portion of the variability in participants' blood PFAS levels (R^2 ranged between 0.13 and 0.30 in the "all adult" models), indicating that many factors are not accounted for.
- ATSDR investigated several questions from the adult and child questionnaires to characterize relationships between blood PFAS levels and consumption of PFAS-contaminated drinking water. In ATSDR's univariate analysis, increased tap water consumption at home was associated with increased PFHxS, PFOS, and PFOA. However, these associations did not remain significant in multivariate models. In ATSDR's univariate and multivariate analyses, participants who reported drinking only bottled water on average lower PFHxS, PFOS, and PFOA blood levels than participants who reported drinking tap water with no filter or treatment device. Even though drinking water consumption rates were not statistically associated with blood PFAS levels as expected, the associations with bottled water consumption provided further evidence for a drinking water exposure route.
- ATSDR also considered which public water system served EA participants. In ATSDR's univariate analyses, adult participants connected to Widefield WSD had blood PFOS levels greater than adult participants connected to Security WD. However, this association did not remain significant in a multivariate model.

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

Other Exposure Characteristics

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

- **Kidney disease.** Previous research shows that kidney disease can affect blood PFAS levels [Barry et al. 2013; Watkins 2013]. Six percent of adults (n=20) 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 PFHxS blood levels that were 39% lower than does who did not. The results for kidney disease for this EA are based on limited, self-reported data and should be interpreted with caution.
- **Occupational Exposure.** Workers can be exposed to PFAS through job tasks that involve manufacturing or working with PFAS. In both univariate and multivariate models, adult participants who reported at least one occupational exposure in the past 20 years on average had lower blood PFHxS levels that those who reported no occupational exposure. Although this result was the opposite of expected, it is based on a relatively small sample of participants with occupational exposure (n=41).
- **Local fruits and vegetables.** In multivariate analyses, blood PFOS levels were higher among adult EA participants who reported any consumption of locally grown fruits or vegetables compared to participants who reported no such consumption.
- **Cleaning frequency.** In multivariate analyses, adult participants that reported cleaning their homes three times per week or more on average had higher PFOS blood levels than adult participants that reported cleaning their homes a few times per month or less.

While these two last exposure characteristics showed significant associations with PFOS, PFOS blood levels were not elevated in the community. All of these observations are based on limited data and should be interpreted with caution; they will be re-examined in the report analyzing results across all EA sites.

Security-Widefield Community-Wide Findings

Finding 1. Average blood levels of PFHxS and PFOA in the Security-Widefield EA site participants are higher than national levels. Averages of other PFAS were not higher than the national levels or were detected too infrequently to compare to national levels.

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

Of the PFAS analyzed in blood, PFHxS had the largest elevations when compared to national levels. The age-adjusted geometric mean blood PFHxS level among EA participants was 6.8 times the national level. Blood PFHxS levels were above the national geometric mean for 96% of the Security-Widefield EA

participants and above the NHANES 95th percentile for 75% of the participants. The age-adjusted geometric mean blood PFOA level was 1.2 times the national level.

Other PFAS measured in this EA (PFOS, PFNA, PFDA) were not higher than national levels. ATSDR was unable to compare the geometric mean MeFOSAA levels because MeFOSAA was detected in less than 60% of NHANES samples. PFUnA was detected in fewer than 60% of the EA participant samples; due to the large percentage of samples below the limit of detection, geometric means were not calculated.

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

PFHxS, PFOS, and PFOA were detected in Security-Widefield water systems as early as 2013, though contamination likely began earlier. Two of these PFAS (PFHxS and PFOA) had statistically elevated blood levels compared to national geometric means. The maximum concentrations observed in finished water in Security-Widefield water systems were 590 ppt for PFHxS, 210 ppt for PFOS, and 90 ppt for PFOA.

By November 2016, actions taken by the three affected water systems reduced PFAS levels in drinking water below EPA's HA for PFOS and PFOA. Before 2016, PFAS-containing AFFF were primarily formulated with PFOS, but also contained various PFAS precursors that could break down in the environment into other PFAS, such as PFHxS, which could explain the elevated blood PFHxS levels. PFHxS and PFOA have very long biological half-lives (on the order of years). There were 3 years and 10 months between when the water systems took action to reduce exposure to contaminated drinking water and collection of biological samples during the EA. Because of the long half-lives of PFHxS and PFOA, past drinking water exposures may have contributed to the EA participants' blood levels. PFHxS has the longest estimated half-life of the three compounds (up to 35 years), which may contribute to why it exceeded the NHANES 2015-2016 geometric mean by the largest margin.

PFHxS and PFOA were highly correlated in Security-Widefield EA participant's blood (Pearson correlation coefficient, $r = 0.73$). This means that, typically, residents who had elevated blood PFHxS levels also had elevated blood PFOA levels. This correlation suggests a common exposure source, such as the pre-2017 Security-Widefield public drinking water supplies, though other sources of exposure may also have contributed to the observed blood levels.

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

- First, a consistent and statistically significant predictor of participant blood levels for PFHxS and PFOA was how long the resident had lived in Security-Widefield during the past 20 years. Each year of residence in the sampling frame over the past 20 years was associated with a 7.1% increase in PFHxS levels and a 2.0% increase in PFOA levels.
- Second, adults who reported not drinking tap water at all at home on average had statistically lower PFHxS (36%) and PFOA (24%) blood levels when compared to those who reported drinking tap water at home with no filter or treatment device.

Multivariate models conducted separately for males and females suggest differences in the associations (between blood levels and residency duration/tap water consumption) between males and female participants.

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

Finding 3. Age, sex, occupational exposure, kidney disease history, local fruit and vegetable consumption, and home cleaning frequency were associated with some PFAS blood levels.
PFAS blood levels varied with different demographic and exposure characteristics of the participant population. The following relationships were statistically significant in multivariate analyses in the Security-Widefield EA data set in adult participants:

- Blood levels of PFHxS, PFOS, and PFOA were higher in older participants, and the size of the effect varied by sex for PFHxS. In males, blood levels for these compounds increased by 1.0% to 1.7% for every year of participant age. In females, blood levels for these compounds increased by 1.0% to 2.5% for every year of participant age.
- Males had statistically higher blood levels of PFHxS and PFOS than females. PFOS blood levels in males were 42% higher than in females. For PFHxS, the difference between males and females was larger in younger people. For example, 30-year-old males had higher blood PFHxS levels than 30-year-old females by 70%. For 50-year-old males, this difference was reduced to 35%.
- Adult participants who reported at least one occupational exposure in the past 20 years on average had lower PFHxS (28%) than adult participants who reported no occupational exposures in the past 20 years. Although this result was the opposite of expected, it is based on a relatively small sample of participants with occupational exposure and should be interpreted with caution.
- Adult participants who reported a history of kidney disease had PFHxS blood levels that were 39% lower than those who did not. This result is based on a relatively small sample of participants self-reporting a history of kidney disease and should be interpreted with caution.
- Adult EA participants who reported any consumption of locally grown fruits or vegetables had blood PFOS levels that were 52% higher compared to participants who reported no such consumption. While PFOS levels were higher in participants who reported consuming local produce compared to those who did not, PFOS blood levels were not elevated in the community.
- Adult participants who reported cleaning their homes three times per week or more on average had 24% higher PFOS blood levels than adult participants who reported cleaning their homes a few times per month or less; however, PFOS blood levels were not elevated in the community.

A few associations were observed in children (<18 years) in univariate analyses, though many variables could not be examined because of the small number of child participants (n=28). Because of the small sample size, results should be interpreted with caution. Specifically, the longer a child was breastfed, the higher blood levels of PFOS and PFOA compared to non-breastfed children, and children that reported ever drinking formula reconstituted with tap water on average had blood PFHxS, PFOS, and PFOA levels that were lower than children that reported never drinking formula reconstituted with tap water. Infants born to mothers exposed to PFAS can be exposed in utero and while breastfeeding. However, based on current science, the benefits of breastfeeding outweigh the risks for infants exposed to PFAS in breast milk. The final report on all EA sites will include a more robust analysis of children.

Finding 4. Only one PFAS was detected in urine and at relatively low concentrations.
ATSDR analyzed 36 (10%) of the urine samples collected. Only PFBA was detected; it was detected in 2.8% of the 36 samples that were analyzed. ATSDR did not analyze all participants' urine samples because none of the species were detected in more than 60% of the samples analyzed.

Finding 5. All Security-Widefield drinking water samples collected during the EA in 2020 met the EPA's HA for specific PFAS in drinking water.

This is based on 17 filtered and 17 unfiltered water samples collected in 18 households during the EA. These results are consistent with recent data collected from the Widefield WSD, Security WD, and Security MHP water systems.

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

Among the PFAS detected most frequently in household dust samples, N-MeFOSE and PFOS were measured at the highest average concentrations. No nationally representative comparison values are available, but geometric mean and median concentrations for PFAS measured in dust collected in the small subset of participating households (n=18) were within the range of levels reported in a few published studies of other U.S. communities (with or without known PFAS contamination). Of the PFAS measured in this EA's household dust samples, PFOA (r=0.46) and MeFOSAA (r=0.57) 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 random sampling recruitment method used for this EA was designed to measure blood PFAS concentrations that were generalizable to all Security-Widefield residents who were customers of the Security WD, Widefield WSD, or Security MHP. However, the EA participant sample may not be fully representative of the community. Only 6.3% of the households from the random sample participated in the EA. Participant characteristics were different than those of the area's overall population. Participants were older, more likely to identify as White, and less likely to identify as more than one race. ATSDR addressed some of these differences by calculating geometric mean estimates that were adjusted to the age distribution of the community.
- Measurement of blood, urine, and environmental PFAS concentrations 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 potential confounding exposure is not possible.
- There are challenges in measurement of trace levels of PFBA in urine, including selectivity of the analytical instrumentation and potential for external contamination. Therefore, we advise caution when interpreting the PFBA results in urine.
- Multivariate regression models did not explain a large portion of the variability in participants' blood PFAS levels (R-squared or R^2, a measure of model goodness-of-fit, ranged between 0.13 and 0.30 in all-adult models). This means that other factors not identified could influence the relationships reported in this assessment (see "Statistical Analysis" section for details).
- This EA did not directly assess participants' tap water consumption prior to the reduction of PFAS in the municipal water systems.
- This EA was not designed to investigate health problems associated with exposure to PFAS. Without additional information about exposure-response relationships, the results of this EA cannot be used to assess current or past health problems or predict the future occurrence of disease. PFAS found in a person's blood or urine means that exposure has occurred. The presence of PFAS in blood or urine does not tell us how, where, when, or for how long a person

was exposed to PFAS. Exposure to PFAS does not mean adverse health effects will result, either now or in the future.

- The dust results are exploratory and should be interpreted with caution. They are based on a limited set of samples, and in some cases those samples are based on a small sample mass.

Recommendations

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

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

Based on the PFAS drinking water test results from drinking water wells in Security-Widefield, ATSDR does not recommend an alternate source of drinking water at this time.

1. What the Security WD, Widefield WSD, and Security MHP can/should do:
    a. Operators of these three public water systems should continue to monitor concentrations of PFAS in drinking water delivered to the Security-Widefield community to ensure that concentrations of PFAS remain below the EPA's HA or other applicable guidelines for specific PFAS in drinking water. Results of PFAS monitoring should be shared with community members through appropriate communication channels (Consumer Confidence Reports for Security WD: http://securitywsd.com/water-quality/; Consumer Confidence Reports for the Widefield WSD, https://www.wwsdonline.com/consumer-confidence-report).
    b. All treatment systems to remove PFAS from the municipal drinking water in Security-Widefield should be maintained appropriately to ensure that PFAS concentrations remain below the EPA's HA or other applicable guidelines for specific PFAS in drinking water.
2. What community members can/should do:
    a. Become familiar with Consumer Confidence Reports for information on water quality in Security-Widefield (Consumer Confidence Reports for Security WD: http://securitywsd.com/water-quality/; Consumer Confidence Reports for the Widefield WSD, https://www.wwsdonline.com/consumer-confidence-report).
    b. Private well owners living in the area affected by PFAS should consider having their wells tested for PFAS if testing has not been conducted before. To learn more about testing wells for PFAS visit: https://www.elpasocountyhealth.org/news/news-release/2019/resources-for-pfc-water-contamination-and-testing. Global public health organization NSF International has developed a test method to verify a water filter's ability to reduce PFOA and PFOS to below the health advisory levels set by the EPA. NSF International-approved devices can be found at: https://info.nsf.org/Certified/DWTU/ Click on "reduction devices" at the bottom of the page for PFOA and PFOS.

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

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

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

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

g. At this time, ATSDR does not have plans to conduct additional blood testing for PFAS nor recommend PFAS EA participants get individually retested for PFAS in blood. The biological half-lives of many of the PFAS measured in people's blood are long. PFHxS has one of the longest half-lives. This means that PFAS blood levels are not expected to change significantly in the near-term, even if exposure stops. Additionally, it is unclear what an individual's PFAS test results mean in terms of possible health effects.

   For the general population, blood tests for PFAS are most useful when they are part of a scientific investigation like this 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. 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. ATSDR is funding a multi-site health study, including one site in the El Paso County area called the Colorado Study on Community Outcomes from PFAS Exposure (CO-SCOPE). The CO-SCOPE is being conducted by the same investigative team that completed the PFAS AWARE study. The study will evaluate PFAS levels in serum as well as health markers and neurobehavioral outcomes in children. If you are interested in being included in the study or want further information, please contact Fountain Valley PFAS Study | PFAS Multi-Site Study Colorado: CO SCOPE (co-scope.org)

i. 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. Follow the advice of your health care provider and the recommendations for checkups, vaccinations, and health screening tests.

j. 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 Security-Widefield EA site, call 800-CDC-INFO or email pfas@cdc.gov. For more information on the work CDC/ATSDR is doing to address PFAS exposure, visit ATSDR's PFAS website: https://www.atsdr.cdc.gov/pfas/. For other EA or PFAS-related questions, email pfas@cdc.gov.

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

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