

# Lubbock County

Texas | near Reese Technology Center



INFORMATION TO PROTECT OUR COMMUNITIES

## Per- and Polyfluoroalkyl Substances (PFAS) Exposure Assessment

# REPORT



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

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### About ATSDR

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

## Abbreviations

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

PFNS	perfluorononane sulfonic acid
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonic acid
PFOSA	perfluorooctanesulfonamide
PFPeA	perfluoropentanoic acid
PFPeS	perfluoropentane sulfonic acid
PFTA	perfluorotetradecanoic acid
PFTrA	perfluorotridecanoic acid
PFUnA	perfluoroundecanoic acid
ppt	parts per trillion (same as 1 nanogram per liter)
Sb-PFOA	branched isomers of PFOA
Sm-PFOS	branched isomers of PFOS
TCEQ	Texas Commission on Environmental Quality

# Executive Summary

## Background and Purpose

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

PFAS do not occur naturally but are widespread in the environment. They have been found in soil, water, air, and animal and plant life. Most PFAS (including PFOA, PFOS, PFHxS, and PFNA) are either very resistant to breaking down or degrade into other PFAS that do not degrade further. Certain PFAS will therefore remain in the environment indefinitely. Major exposure routes for PFAS include drinking contaminated water and eating contaminated food, but exposure can also occur through other routes (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 since 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 an area in Lubbock County, Texas, near Reese Technology Center, formerly Reese 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 private wells. PFAS were first detected in private wells downgradient of the Base in September 2017. To reduce levels of PFAS in drinking water, the Air Force installed whole-house treatment systems in affected homes and supplied bottled water. Based on information available to ATSDR, all households tested by the Air Force now have a drinking water supply that meets or is below the U.S. Environmental Protection Agency's (EPA) 2016 health advisory (HA) and state public health guidelines for PFAS in drinking water. Households that receive bottled water and/or have water filtration systems installed by the Air Force should continue to use them. Note that a small number of households in the sampling frame refused testing for PFAS in private wells offered by the Air Force. Additionally, private well testing for PFAS has continued in phases with small numbers of additional wells identified with PFAS concentrations exceeding either EPA's HA or state guidelines for PFAS. Because of these factors, ATSDR is unable to definitively conclude that all drinking water exposures in the area have been mitigated; however, all known drinking water exposures have been mitigated and the Air Force has continued to take action to mitigate exposures when new data become available.

This EA assessed PFAS levels in the blood and urine of Lubbock County residents living near the Reese Technology Center, formerly Reese Air Force Base where many private wells had PFAS levels above state or federal guidelines. 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. Because only

households with private wells were included in the EA, the use of “tap water” throughout this report is used to refer to drinking water from a private well. 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 all Lubbock County residents who met eligibility criteria to participate in the EA. To be eligible to participate, household residents must have (1) received their drinking water from a private well in the affected area in Lubbock County for at least 1 year before September 30, 2019 (these residents have the greatest likelihood of past exposures to PFAS via their private wells 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. Residences served by the City of Lubbock Water Department were not included in the exposure assessment.

In February and March 2020, 214 eligible people (190 adults and 24 children) from 96 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 12 randomly selected participants
- tested for 7 PFAS in blood, 14 in urine, 18 in water, and 33 in dust<sup>1</sup>
- measured PFHxS, PFOS, PFOA, PFNA, PFDA, and PFUnA across all media
- mailed individual biological and environmental results to participants in November 2020

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

The samples were collected and analyzed in strict accordance with ATSDR’s *Exposure Assessment Protocol: Biological and Environmental Sampling of PFAS* (EA protocol) to ensure their quality. This EA was designed to estimate geometric mean concentrations of PFOS in blood for the sampling frame

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<sup>1</sup> The laboratory reports concentrations of branched and linear isomers of PFOA and PFOS in blood and urine. ATSDR reports the sum of the individual isomer concentrations of PFOA and PFOS.

(Lubbock County households with private wells in the affected area near Reese Technology Center) population, with a precision goal of at least 15%. The precision is a measure of how wide the confidence interval is around the estimated geometric mean. ATSDR met this goal for PFOS, and precision for all PFAS measure in this EA ranged from approximately 5% to 24%. 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.<sup>2</sup>

## **Lubbock County Community-Wide Findings**

### **Finding 1. Average blood levels of PFHxS and PFOA in the Lubbock County 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 Lubbock County EA participants when compared to CDC's NHANES (2015–2016) testing, which was limited to people over 12 years old. The statistically higher blood PFAS levels were observed for both unadjusted geometric means for all EA participants and geometric means adjusted to the age distribution of the U.S. population from NHANES 2015–2016.

Of the PFAS analyzed in blood, PFHxS had the largest elevations when compared to national levels. The age-adjusted geometric mean blood PFHxS level among all Lubbock County EA participants was 4.2 times the national level. Blood PFHxS levels were above the national geometric mean for 86% of the Lubbock County EA participants and above the NHANES 95<sup>th</sup> percentile for 81% of the Lubbock County EA participants. The age-adjusted geometric mean blood PFOA level was 1.2 times the national level.

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

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

The two PFAS (PFHxS and PFOA) with statistically elevated blood levels compared to national geometric means were detected in Lubbock private wells as early as 2017. It is likely that contamination began earlier, but no data are available before 2017. The maximum concentrations measured by the Air Force in private drinking water wells in Lubbock County were 1,450 parts per trillion (ppt) for PFHxS, 2,900 ppt for PFOA, and 998 ppt for PFOS (note the maximum PFHxS, PFOA, and PFOS concentrations measured in EA participant drinking water wells was 1,410 ppt, 2,890 ppt, and 946 ppt, respectively). Between 2017

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<sup>2</sup> A confounding variable is a factor that may distort or mask the relationship between a potential predictor and measure of exposure. 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 variables of interest.



and 2019, actions taken by the Air Force reduced PFAS levels in drinking water in the affected area below EPA health advisory for PFOS and PFOA and Texas Commission on Environmental Quality's (TCEQ's) protective concentration levels (PCLs) for multiple PFAS. Before 2016, PFAS-containing AFFF were primarily formulated with PFOS but also contained various PFAS precursors that could break down into other PFAS, such as PFHxS, which could explain the elevated blood PFHxS levels. PFHxS and PFOA have long biological half-lives (on the order of years). There was 1 year and 4 months between when concentrations of PFAS in private wells were reduced 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 two 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 Lubbock County residents' blood (Pearson correlation coefficient,  $r = 0.85$ ). 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 contaminated groundwater that supplies drinking water to private wells in the area, though other sources of exposure may also have contributed to the observed blood levels.

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

- First, a consistent and statistically significant predictor of participant blood levels for PFHxS and PFOA was how long the resident had lived in Lubbock County during the past 20 years. Those who lived in the area longest likely drank, in total, a larger volume of contaminated water. For every year a participant reported having lived in the affected area of Lubbock County, there was an increase in blood PFHxS (6.2%) and PFOA (2.4%) levels.
- Second, exposure history questions pertaining to drinking water were statistically associated with either PFHxS or PFOA:
  - Adults who reported mainly drinking bottled water at home on average had statistically lower PFHxS blood levels when compared to those who reported mainly drinking private well water.
  - PFOA blood levels in adults statistically increased with the amount of tap water those adults reported drinking.
- Third, blood PFHxS and PFOA levels were statistically associated with corresponding private well water PFAS concentration data measured by the Air Force. Among adults, for every 1% increase in maximum well PFHxS and PFOA concentrations, there was an increase in blood PFHxS (0.54%) and PFOA levels (0.30%). Average blood PFOS levels were not elevated compared to national levels; however, the association observed between levels in drinking water and blood was still significant. This discrepancy can be explained because PFOS was detected in the wells of fewer participants (only 57%) compared to PFHxS (92%) and PFOA (85%).

### **Finding 3. Age, sex, flooring, soil exposure, childbirth, and breastfeeding 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 Lubbock County EA data set in adult participants (and are consistent with those reported in other non-ATSDR PFAS studies):

- Blood levels of PFHxS, PFOS, and PFOA were higher in older participants. Adult blood PFHxS increased by 1.0% and PFOS by 1.7% for every year of age. For PFOA, a difference was observed between males and females. In females, blood levels for PFOA increased by 1.2% for every year of participant age. In male, blood levels for PFOA did not show a change with age.
- Males had statistically higher blood levels of PFOS and PFOA than females. Blood levels in adult males were 70% higher for PFOS. For PFOA, the difference between males and females was larger in younger people. For example, 30-year-old males had higher blood PFOA levels than 30-year-old females by 59%. For 50-year-old males, this difference was reduced to 26% compared to 50-year-old females.
- Participants who reported having carpet in any room (n=37) had blood levels of PFHxS and PFOA that were 100% and 36% higher than those who reported not having carpet in their home, respectively.
- Participants who reported coming in contact with soil a few times per month (63% higher) and three times a week or more (78% higher) had higher blood PFHxS levels than those who reported coming in contact with soil a few times per year or less.
- Female participants reporting having children had lower blood PFHxS (58%) levels than females who did not have children.
- Females who breastfed had lower blood levels of PFOS by 27% than females who did not.

One additional association was observed in children (<18 years), though many variables could not be examined because of the small number of child participants (n=24) and results should be interpreted with caution. Specifically, children who were breastfed had higher blood levels of PFOS compared to non-breastfed children. Infants born to mothers exposed to PFAS can be exposed in utero and while breastfeeding. However, based on current science, the benefits of breastfeeding outweigh the risks for infants exposed to PFAS in breast milk. The final report on all EA sites will include a more robust analysis of children.

**Finding 4. Only two PFAS were detected in urine.**

ATSDR analyzed 22 (10%) of the urine samples collected. Only perfluorobutanoic acid (PFBA) and perfluorohexanoic acid (PFHxA) were detected; they were detected in 4.6% and 9.1%, respectively, of the 22 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 tap water samples from Lubbock County private wells collected during the EA in 2020 met the EPA's HA and the Texas Commission on Environmental Quality's (TCEQ's) protective concentration levels (PCLs) for specific PFAS in drinking water.**

This is based on 6 unfiltered and 10 filtered tap water samples collected in 12 households during the EA.

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

Among the PFAS detected most frequently in household dust samples, PFOS, PFOA, and PFHxA were measured at the highest concentrations. No nationally representative comparison values are available, but geometric mean and median concentrations for PFAS measured in dust collected in the small subset of participating households (n=12) 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, only PFOA was statistically correlated with the same PFAS measured in

participants' blood. The final report on all EA sites will include a more robust comparison of PFAS measured in dust and blood.

## Limitations

There are several limitations associated with this assessment.

- The EA participant sample may not be representative of the community. All households in the study area were invited to participate, and 14% of the households participated in the EA. Participant characteristics were different than those of the area's overall population; specifically, participants were older. ATSDR addressed some of these differences by calculating geometric mean estimates that were adjusted to the age distribution of the community.
- Measurement of blood, urine, and environmental PFAS concentrations for EA participants may improve the understanding of exposure in this community but will not provide information about all sources of exposure. Additionally, identifying every potential confounding exposure is not possible.
- There are challenges in measurement of trace levels of PFBA in urine, including selectivity of the analytical instrumentation and potential for external contamination. Therefore, we advise caution when interpreting the PFBA results in urine.
- While multivariate regression models explained a moderate to large portion of the variability in participants' blood PFAS levels (R-squared or  $R^2$ , a measure of model goodness-of-fit, ranged between 0.43 and 0.56 in the "all adult" models), other factors not identified could still influence the relationships reported in this assessment (see "Statistical Analysis" section for details).
- The correlation between PFOS and PFHxS in blood of EA participants in Lubbock County was lower than observed at other sites with known AFFF contamination. Additionally, concentrations of PFOS in the blood of Lubbock County EA participants were statistically significantly lower than the national reference population from NHANES 2015-2016. These observations differ from other sites where concentrations of PFHxS and PFOS in participants' blood were more highly correlated and both PFHxS and PFOS were elevated relative to NHANES 2015-2016. The measured concentrations in blood do align with the maximum reported concentrations in pre-mitigation drinking water with PFHxS and PFOA present at higher concentrations than PFOS in private wells.
- A small number of households in the sampling frame refused testing for PFAS in private wells offered by the Air Force. Additionally, private well testing for PFAS has continued in phases with small numbers of additional wells identified with PFAS concentrations exceeding either EPA's HA or state guidelines for PFAS. Because of these factors, ATSDR is unable to definitively conclude that all drinking water exposures in the area have been mitigated; however, all known drinking water exposures have been mitigated and the Air Force has continued to take action to mitigate exposures when new data become available.
- This study did not directly assess participants' tap water consumption prior to the reduction of PFAS in private wells.
- This EA was not designed to investigate health outcomes. Without additional information about exposure-response relationships, the results of this EA cannot be used to assess current or past health problems or predict the future occurrence of disease. PFAS found in a person's blood or urine means that exposure has occurred. The presence of PFAS in blood or urine does not tell us

how, where, when, or for how long a person was exposed to PFAS. Exposure to PFAS does not mean adverse health effects will result, either now or in the future.

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

## Recommendations

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

Although the exposure contribution from PFAS in private well water in Lubbock County has been mitigated in most private wells, there are actions community members and other stakeholders can take to further reduce exposures to PFAS and protect public health.

Households that receive bottled water and/or have water filtration systems installed by the Air Force should continue to use them.

1. What the Air Force can/should do:
  - a. With permission from homeowners, test private wells in the affected area that have not been previously tested.
  - b. Continue to provide whole-house water treatment system installation, monitoring, and maintenance. When the Air Force installs a system, continue to monitor it on a routine basis to ensure proper operation.
  - c. Continue to work on developing a cooperative agreement with the City of Lubbock to build water lines to affected homes within the city limits.
2. What community members can/should do:
  - a. The alternative drinking water provided by the Air Force (whether through whole-house filters or bottled water) currently meets all federal and state guidelines for PFAS. Households that receive bottled water and/or have water filtration systems installed by the Air Force should continue to use them. Residents should coordinate monitoring and maintenance of the water filtration systems with the Air Force. All treatment systems to remove PFAS from private well water in Lubbock County should be maintained appropriately to ensure that PFAS concentrations remain below EPA's HA and the TCEQ's PCLs for specific PFAS in drinking water.
  - 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. For more information contact: Air Force Installation and Mission Support Center (AFIMSC) at [AFIMSC.PA.workflow@us.af.mil](mailto:AFIMSC.PA.workflow@us.af.mil) or call Paul Carrol, AFCEC Program Manager at (806) 885-5010.
  - c. All private well owners should follow best public health practices for the testing, operation, and maintenance of their wells:  
<https://www.cdc.gov/healthywater/drinking/private/wells/index.html>
  - d. Nursing mothers should continue breastfeeding. Based on current science, the known benefits of breastfeeding outweigh the potential risks for infants exposed to PFAS in breast milk.

- e. 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>
- f. Pay attention to advisories about food consumption, such as local fish advisories.
- g. 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.
- h. ATSDR does not recommend EA participants get retested for PFAS. At this time, ATSDR does not have plans to conduct additional blood testing for PFAS or recommend PFAS EA participants get individually retested for PFAS in blood. The biological half-lives of many of the PFAS measured in people's blood are long. PFHxS, in particular, has one of the longest half-lives—some estimates range in the decades. This means that PFAS blood levels are not expected to change significantly in the near term, even if exposure stops. Additionally, it is unclear what an individual's PFAS test results mean in terms of possible health effects.  
  
For the general population, blood tests for PFAS are most useful when they are part of a scientific investigation like the EA. Test results tell you how much of each PFAS is in your blood, but it is unclear what the results mean in terms of possible health effects. In addition, blood testing for PFAS is not a routine test offered by most doctors or health departments. 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>).
- 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 Lubbock County EA site, call 800-CDC-INFO or email [pfas@cdc.gov](mailto: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](mailto: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 Lubbock County, Texas. This report summarizes the findings of the Lubbock County EA. When all EAs are complete, ATSDR will prepare a report describing the results across all sites.

EA participants were recruited among Lubbock County residents living in a specific area near the Reese Technology Center, formerly Reese Air Force Base, where many private wells had PFAS levels above state or federal guidelines. For more information and a map of the area see the “Methods” section of the report.

The EA involved collecting responses to exposure history questionnaires, biological samples (blood and urine), and environmental samples (tap water and household dust). Because only households with private wells were included in the EA, the use of “tap water” throughout this report is used to refer to drinking water from a private well. ATSDR collected biological samples and administered questionnaires at Reese Technology Center in Lubbock County between February 26 and March 4, 2020. During the same time frame, ATSDR also took water and dust samples in a subset of randomly chosen participant homes.

The results of the EA

- tell us the amount of PFAS in the blood of individual participants and the Lubbock County community and how these levels compare to the general U.S. population,
- tell us the amount of PFAS in the urine of a subset of individual participants and the EA community and how these levels compare to the general U.S. population,
- provide a better understanding of environmental factors that affect PFAS exposure,
- provide information that may be used to stop or reduce PFAS exposure,
- produce information that public health professionals can use to help communities affected by PFAS, and
- inform future studies looking at the 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; 2020; Wang et al. 2017].

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

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

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

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

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

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

## **Why Lubbock County?**

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

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

When PFAS first entered private wells in Lubbock County is not known. These substances were first detected in private wells near the Base in September 2017, through testing conducted by the Air Force. In November 2017, the Air Force began sampling private wells within 1 mile of the Base [AFIMSC 2018]. This sampling campaign extended in area to approximately 3 miles off base as more private wells were found with PFAS contamination above the U.S. Environmental Protection Agency's (EPA's) health advisory for the sum of PFOA and PFOS levels in drinking water (70 ppt) and the Texas Commission on Environmental Quality's (TCEQ's) protective concentration levels (PCLs) which were available for 16 PFAS [AFIMSC 2019]. By September 2019, Air Force testing indicated that 235 private wells out of the 504 that were tested had PFAS levels above either EPA's health advisory or TCEQ's PCLs.<sup>4</sup> The highest sampling result from a private drinking water well was 2,900 parts per trillion (ppt) for the sum of PFOA and PFOS, though only PFOA was detected in this sample. Across samples, the maximum PFOS concentration detected in a private drinking water well was 998 ppt, and the maximum PFHxS concentration was 1,450 ppt. The private well sampling in Lubbock County detected additional PFAS (e.g., PFHxA).

The Air Force immediately provided bottled water delivery service to households with PFAS levels above EPA's HA and TCEQ PCLs. To reduce concentrations of PFOA and PFOS in drinking water, the Air Force

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<sup>3</sup> 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.

<sup>4</sup> The private well testing data presented here reflect information available to ATSDR prior to recruitment and data collection. As of April 2021, subsequent data posted by the Air Force indicates that 240 private wells out of 517 that were tested had PFAS levels above either EPA's health advisory or TCEQ PCLs [AFIMSC 2021].



installed whole-house treatment systems in affected homes. The last time the Air Force measured PFAS drinking water concentrations in a private well above EPA's health advisory or TCEQ's PCL was in September 2019.

The information available to ATSDR indicates that in 2020 all households tested by the Air Force have a drinking water supply that met or was below the EPA's HA and the TCEQ's PCLs for PFAS in drinking water. Note that a small number of households in the sampling frame refused testing for PFAS in private wells offered by the Air Force. Additionally, private well testing for PFAS has continued in phases with small numbers of additional wells identified with PFAS concentrations exceeding either EPA's HA or state guidelines for PFAS. Because of these factors, ATSDR is unable to definitively conclude that all drinking water exposures in the area have been mitigated; however, all known drinking water exposures have been mitigated and the Air Force has continued to take action to mitigate exposures when new data become available.

## 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 Lubbock County EA.

### Sampling Frame

This EA targeted a specific geographic area, called the sampling frame or sampling area. The sampling frame for this EA was the part of Lubbock County where many private wells had PFAS levels above state or federal guidelines (see [Figure 1](#)). Based on a review of Lubbock County land parcel data, ATSDR identified 701 households in the sampling frame. These households formed the sampling frame from which households were invited to participate. The sampling frame includes all households served by private wells in the affected area. Residences served by the Lubbock Water Department were not included because they have a different source of drinking water.

### Participant Eligibility

Lubbock County residents who met the following criteria were eligible to participate in the EA:

- Lived within the sampling frame (i.e., Lubbock County households in the affected area shown in [Figure 1](#)) for at least one year before September 30, 2019, which was the last time prior to EA recruitment that the Air Force measured PFAS drinking water concentrations in a private well above EPA's HA or TCEQ's PCLs. Note that as of April 2021, additional data provided by the Air Force found five additional wells with PFAS concentrations above EPA's HA or TCEQ PCLs.
- Were at least 3 years old at the time of recruitment. This age criterion was used because national reference values are not available for children under the age of three.
- Did not have bleeding disorders and were not anemic, unless they confirmed with their doctor the ability to safely provide a blood sample.

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

## **Participant Recruitment**

ATSDR invited all 701 households identified in the sampling frame to participate. All households were chosen to attempt to achieve the protocol recruitment target of 395 participants. Initially, ATSDR mailed invitations to 664 households, and identified an additional 37 households during door-to-door canvassing. All members of each household who met eligibility criteria were invited to participate.

Recruitment was done at an ATSDR informational meeting held in Lubbock County and through mailings, phone calls, and in-person visits to households that had not been reached by phone. Every household that did not enroll at the informational meeting and for which ATSDR had a phone number received up to three recruitment call attempts. In each attempt, ATSDR called all working phone numbers (cellphone and landline) associated with a household. For calls that went to voicemail, ATSDR staff left messages encouraging residents to call back to schedule appointments. Door-to-door recruitment occurred after each household had received an initial outreach letter and at least one recruitment call attempt.

After recruitment, 260 residents from 106 households scheduled appointments for biological sampling and questionnaire completion.

ATSDR attempted to recruit approximately 10% of participating households for environmental sampling (i.e., 11 households from which at least one person had scheduled an appointment at the time environmental recruitment calls were made). ATSDR invited 30 households in two waves of recruitment. In total, ATSDR scheduled 14 environmental sampling appointments.



## Data Collection and Analysis

The Lubbock County EA involved collection of three types of data: questionnaires, biological samples (blood and urine), and environmental samples (tap water and household dust). The ATSDR project team collected biological samples and administered questionnaires at the Reese Technology Center in Lubbock between February 26 and March 4, 2020. During the same time frame, ATSDR collected environmental samples in a subset of randomly chosen participant homes. All data met the stringent quality control requirements for sample collection and analysis.

Before any data collection, ATSDR obtained written consent from the participants. The purpose of the consent process was to ensure participants were fully aware of the purpose of the exposure assessment, 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 Texas law. All signed consent forms were mailed to and are securely archived at ATSDR headquarters. Questionnaire data were collected using dedicated encrypted laptops with no internet access, and these data were transferred at program completion to ATSDR's secure data network. All information provided by participants was kept confidential, and no personally identifiable information appears in any of ATSDR's public reports for this site.

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

### Biological Sampling and Questionnaire Administration

Of the 260 residents who scheduled data collection appointments, 219 (84%) participated in the EA. ATSDR administered exposure history questionnaires to these 219 individuals: 195 for adults 18 and older, and 24 for children between the ages of 3 and 17. ATSDR used one questionnaire for adults and another for children. Both addressed topics relevant to PFAS exposure, such as residential and work histories, drinking water habits, and use of PFAS-containing consumer products.

A phlebotomist collected blood samples from all 219 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 five participants had not lived in the sampling frame for at least one full year before September 30, 2019, 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 214 blood samples (190 adults and 24 children) were considered in the community exposure summary. These samples were collected from participants residing in 96 unique households. This represents a household participation rate of 14% (i.e., 14% of the 701 recruited households had at least one person participate in the EA).

Urine samples were collected from 219 participants (195 adults and 24 children). Per the EA protocol, 10% of the urine samples were randomly selected for initial analysis. ATSDR randomly selected 22 samples for analysis. These 22 samples were collected from participants (20 adults and 2 children) who resided in 20 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 12 of the 14 households that had scheduled appointments. At each participating household, ATSDR collected a drinking water sample from the kitchen tap. If point-of-use filtration was in place, ATSDR project staff attempted to collect a sample before 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<sup>2</sup>) 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<sup>2</sup> 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**

<b>Recruitment</b>	
Households invited to participate by mail	664
Households reached by mail	542
Households reached by phone	196
Household door-to-door visits	701
Biological sampling:	
Individuals enrolled	260
Households enrolled	106
Environmental sampling:	
<i>Wave 1 households invited</i>	23
<i>Wave 2 households invited</i>	7
Households enrolled	14
<b>Data Collection</b>	
Completed questionnaires	219
<i>Adults</i>	195
<i>Children</i>	24
Blood samples	
Included in community statistics (96 households)	214
<i>Adults</i>	190
<i>Children</i>	24
Urine samples	
Collected	219
<i>Adults</i>	195
<i>Children</i>	24
Included in community statistics (20 households)	22
<i>Adults</i>	20
<i>Children</i>	2
Dust samples collected and analyzed (one composite sample per household)	12
Tap water samples collected and analyzed (12 households)	16
Filtered	10
Unfiltered	6

**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 25<sup>th</sup>, 50<sup>th</sup> [median], 75<sup>th</sup>, 90<sup>th</sup>, and 95<sup>th</sup> percentiles). The protocol specified that geometric means would be calculated if  $\geq 60\%$  of samples had detections. Geometric means were calculated as the measures of central tendency because of the lognormal distribution

### Statistical Terms

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

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

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

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



of blood and urine measurements. Note that many of the statistics could not be calculated for urine due to the low detection frequency.

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

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

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

ATSDR then used information gathered in the exposure questionnaire to understand and quantify how demographic data and other exposure characteristics relate to PFAS measurements in blood. For this, ATSDR relied on self-reported information, such as age, race/ethnicity, sex, length of residency in the sampling frame, tap water and food consumption patterns, and work/school history. All numerical responses were treated as continuous variables. In some cases, categorical variables were collapsed when there were too few responses (<10) in a given category. In order to explore sex-specific associations (e.g., women having biological children [yes/no], having breastfed children [yes/no], duration of breastfeeding), ATSDR also evaluated multivariate models for males and females only. 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 95<sup>th</sup> percentile from NHANES. The protocol specified that geometric means would be calculated if  $\geq 60\%$  of samples had detections, and the rest of the samples would be analyzed if the calculated geometric mean exceeded the NHANES 95<sup>th</sup> percentile. Since no PFAS were detected in 60% or more of the analyzed samples, no geometric means were calculated for any PFAS in urine and ATSDR did not analyze the remainder of the urine samples. ATSDR did calculate the 95<sup>th</sup> percentile concentration for PFBA and PFHxA, the two PFAS detected in urine samples.

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

ATSDR conducted all statistical analyses in SAS (release 9.4, SAS Institute, Cary, NC) using complex survey procedures (e.g., SURVEYMEANS, SURVEYREG). To do this, ATSDR assigned household IDs to all participants and calculated summary statistics while accounting for clustering at the household level. For blood results across all EA participants, intra-cluster correlation coefficients ranged from 0.20 to 0.76, suggesting weak to strong correlation of PFAS blood levels within a household, depending on the PFAS. 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 Lubbock County EA participants and compares their demographics to those of people in the sampling frame, then reviews the blood, urine, tap water, and household dust measurements that ATSDR collected. Those reviews use exposure history questionnaire data to provide further context on the measurements. (The next section, “Discussion,” further evaluates the observed trends using insights from the broader scientific literature on PFAS drinking water exposures.)

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

### Profile of Lubbock 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.

The average age of EA participants was 51.1 years, and 64% of the participants identified themselves as White, non-Hispanic. Of EA participants, 55% identified as female, 45% identified as male, and 89% 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, 25% reported living in their current homes for less than 10 years.

Adults were also asked about their current primary source of drinking water: 48% said private well, and 49% said bottled water. Adults reported drinking an average of 7.2 8-ounce cups of water a day at home, and 68% 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; 2% reported holding one or more jobs with potential PFAS exposures (e.g., firefighting, military, aviation).

**Table 3. Characteristics of Lubbock County EA participants**

Characteristics	Count of EA Participants (n)*	Percent of EA Participants (%)†
<b>Adults and children combined</b>		
Age (years)	(mean = 51.1)	
<18	24	11
18 to <50	61	29
50+	129	60
Sex		
Male	96	45
Female	118	55
Race and ethnicity†		
White, non-Hispanic	135	64
non-White or Hispanic	76	36
<b>Adults only</b>		
Years lived at current address	(mean = 21.4)	
<10	47	25
10 to <20	38	20
20 to <30	49	26
30+	56	29
Current primary drinking water source		
Private well	92	48
Bottled water	93	49
Average tap water consumption while living at current home (8-ounce cups per day)	(mean = 7.2)	
0	20	11
>0 to <2	8	4
2 to <4	39	21
4 to <6	31	16
6 to <8	19	10
8+	73	38
Current use of treatment or filtration device		
One or more filter/treatment device(s)	129	68
None	60	32
Occupational exposures to PFAS in the past 20 years		
One or more occupational exposure(s)	3	2
None	187	98

\* 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.

## Comparison of Lubbock County EA Participants' Demographics to Sampling Frame Demographics

This EA was designed to estimate PFAS levels in blood that were generalizable to the sampling frame as a whole (i.e., Lubbock County 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 was invited to participate and therefore had an equal chance of doing so. However, ATSDR also explored the potential for participation bias—that is, substantive differences between those who chose to participate and those who did not.

ATSDR used 2010 Census data ([Table 4](#)) [USCB 2010] to compare the EA participants' demographic profile with the profile of all residents in the sampling frame. The comparison revealed the following:

- **Age distribution.** The EA participants included a higher proportion of older adults (age 50+ years) and a lower proportion of younger adults (18–50 years) than the sampling frame population ([Table 4](#)). Specifically, 60% of the EA participants reported being 50 or older, but 25% 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, 29% of the EA participants reported being 18–50, but 43% of the sampling frame population falls in that age range.
- **Race/ethnicity.** Among the race/ethnicity characteristics, the percent of residents who identify as White, Hispanic, and non-White did not show a significant difference between the EA participants and the sampling frame population ([Table 4](#)). For this comparison, combined race and ethnicity were not available at the block level from the Census. Therefore, only ethnicity and the race categories of White and non-White 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	24	11.2	31.5	<0.001
18–50	61	28.5	43.4	<0.001
50+	129	60.3	25.1	<0.001
Race				
White	162	75.7	77.3	0.659
Black or African American	<10	—	2.8	—
Am. Indian & AK Native	<10	—	0.6	—
Asian	<10	—	0.2	—
Nat. Hawaiian/Pacific Islander	<10	—	0.05	—
Ethnicity				
Hispanic or Latino (of any race)	72	33.6	37.8	0.266

\* 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

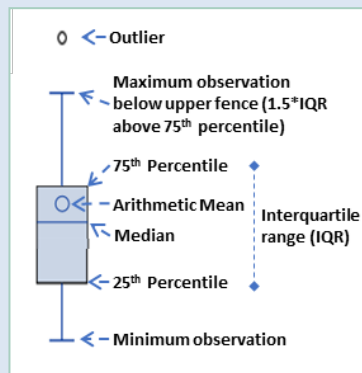
This section summarizes PFAS levels that ATSDR measured from the 214 blood samples provided by eligible participants. Results are summarized in tables and ‘box and whisker’ plots (see text box).

### Unadjusted Community Statistics for PFAS in Blood

ATSDR first calculated the mean levels of PFAS without accounting for the possible effect of age. [Table 5](#) summarizes results for the seven PFAS measured in Lubbock County EA participants’ blood for all ages. Five of the seven PFAS—PFHxS, PFOS, PFOA, PFNA, and PFDA—were detected in more than 77% of the blood samples. ATSDR’s statistical analyses throughout this section focus on these five chemicals, and [Figure 2](#) shows the distributions of the individual measurements on a log<sub>10</sub> scale. The log<sub>10</sub> 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 = 6.04 micrograms per liter (µg/L)), PFOS (4.17 µg/L), and PFOA (2.20 µg/L).

#### How to read a box and whisker plot:

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



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

The precision of geometric mean estimates for this EA for all PFAS ranged from 5% to 24% depending on the PFAS (Appendix B, Table B2). Except for PFHxS and PFOA, these values are all below the desired precision of 15% used to determine the target sample size for this EA. The collected data met the precision target specified in the EA protocol.

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

PFAS	FOD (%)	Max	Geometric Mean	95% CI for Geometric Mean	Percentiles				
					25 <sup>th</sup>	50 <sup>th</sup> (Median)	75 <sup>th</sup>	90 <sup>th</sup>	95 <sup>th</sup>
PFHxS	100	486.5	6.04	4.30-8.49	1.72	4.90	17.0	50.6	80.7
PFOS	NA*	135.4	4.17	3.55-4.88	2.22	3.90	6.60	10.8	20.6
PFOA	NA*	59.3	2.20	1.82-2.66	1.12	1.66	3.62	8.77	13.2
PFNA	77.1	8.2	0.193	0.171-0.217	NA <sup>†</sup>	0.153	0.292	0.474	0.573
PFDA	82.2	3.0	0.134	0.121-0.148	NA <sup>†</sup>	NA <sup>†</sup>	0.154	0.242	0.306
PFUnA	29.9	0.6	NA <sup>‡</sup>	NA <sup>‡</sup>	NA <sup>†</sup>	NA <sup>†</sup>	NA <sup>†</sup>	NA <sup>†</sup>	0.121
MeFOSAA	49.5	1.5	NA <sup>‡</sup>	NA <sup>‡</sup>	NA <sup>†</sup>	NA <sup>†</sup>	0.141	0.433	0.665

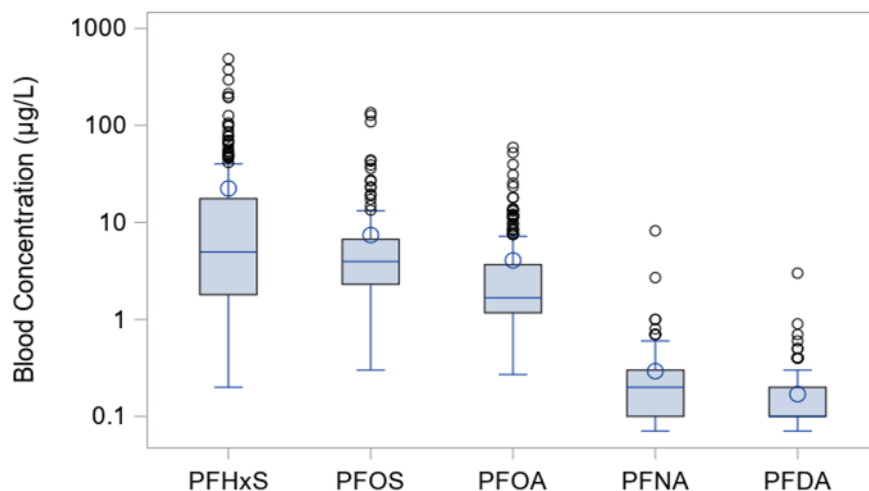
FOD = frequency of detection, CI = confidence interval, NA = not applicable

\* PFOA and PFOS are calculated sums of branched and linear subsets and are not measured directly. Linear PFOA was detected in 100.0% of samples with a geometric mean of 2.08 micrograms per liter (µg/L); branched PFOA was detected in 14.5% of samples. Linear PFOS was detected in 100.0% of samples with a geometric mean of 2.67 µg/L; branched PFOS was detected in 100.0% of samples, with a geometric mean of 1.44 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 log<sub>10</sub> scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.

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

Since the demographic profile comparison reported above showed that EA participants were significantly older than the sampling frame as a whole, ATSDR also calculated geometric means that were age-adjusted to the sampling frame population based on 2010 Census data for comparison. Age-adjusted geometric means correct for the participation bias discussed earlier and are more generalizable to the sampling frame community. [Table 6](#) shows that in general, age-adjusted blood PFAS geometric means are lower than unadjusted values. Of the three PFAS with the highest concentration (PFHxS, PFOS, and PFOA), age-adjusted geometric means are between 4% and 18% 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**

PFAS	Unadjusted		Age-Adjusted to Sampling Frame	
	Geometric Mean	95% CI for Geometric Mean	Geometric Mean	95% CI for Geometric Mean
PFHxS	6.04	4.30-8.49	5.16	3.54-7.51
PFOS	4.17	3.55-4.88	3.43	2.85-4.13
PFOA	2.20	1.82-2.66	2.11	1.75-2.54
PFNA	0.193	0.171-0.217	0.166	0.140-0.198
PFDA	0.134	0.121-0.148	0.124	0.107-0.143
PFUnA	NA*	NA*	NA*	NA*
MeFOSAA	NA*	NA*	NA*	NA*

CI = confidence interval

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

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

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

[Table 7](#) shows the unadjusted comparison for the entire pool of EA participants to the geometric means for the 2015–2016 NHANES survey [CDC 2019]. For PFHxS and PFOA, unadjusted geometric mean blood levels among Lubbock County EA participants were statistically ( $p < 0.05$ ) higher than the national geometric mean. For PFOS, no significant difference was observed between Lubbock County EA participants and the general U.S. population; for PFNA and PFDA, the unadjusted blood levels among Lubbock County EA participants were statistically lower than the national geometric mean.

Of the PFAS analyzed in blood, PFHxS levels had the largest elevations when compared to national levels. The unadjusted geometric mean blood PFHxS level among Lubbock County EA participants was 5.1 times the national level. Blood PFHxS levels were above the national geometric mean for 86% of EA participants and above the NHANES 95<sup>th</sup> percentile for 50% of EA participants ([Table 7](#)). The unadjusted geometric mean blood PFOA level among Lubbock County EA participants was 1.4 times the national level. Blood PFOA levels were above the national geometric mean for 62% of EA participants and above the NHANES 95<sup>th</sup> percentile for 24% of EA participants. The unadjusted geometric mean blood PFOS level among Lubbock County EA participants was lower than the national levels. Blood PFOS levels were above the national geometric mean for 41% of the EA participants and above the NHANES 95<sup>th</sup> percentile for 6%.

On average, total PFOS measurements were composed of 64% 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%) [Kärman 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 95% linear PFOA (n-PFOA) and 4% 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 203 EA participants. [Table 7](#) and [Figure 3](#) show that blood PFAS geometric means adjusted to the NHANES population differ from unadjusted values. The adjusted geometric mean blood PFHxS level among Lubbock County EA participants was 4.2 times the national level. The age-adjusted geometric mean blood PFOA level among Lubbock County 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.



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

PFAS	NHANES GM (CI)*	Lubbock County GM (CI)†: Unadjusted	Lubbock County GM (CI)†: Age-Adjusted to NHANES 2015-2016	Percent of Lubbock County Results over NHANES GM (%)	NHANES 95 <sup>th</sup> Percentile*	Lubbock County 95 <sup>th</sup> Percentile	Percent of Lubbock County Results over NHANES 95 <sup>th</sup> Percentile (%)
PFHxS	1.18 (1.08–1.30)	6.04 (4.30–8.49) <i>p</i> <0.001	4.93 (3.39–7.19) <i>p</i> <0.001	86.0	4.90	80.7	50.0
PFOS	4.72 (4.40–5.07)	4.17 (3.55–4.88) <i>p</i> =0.151	3.58 (3.10–4.14) <i>p</i> <0.001	41.1	18.3	20.6	6.07
PFOA	1.56 (1.47–1.66)	2.20 (1.82–2.66) <i>p</i> <0.001	1.94 (1.60–2.34) <i>p</i> =0.0306	61.7	4.17	13.2	23.8
PFNA	0.577 (0.535–0.623)	0.193 (0.171–0.217) <i>p</i> <0.001	0.169 (0.151–0.188) <i>p</i> <0.001	8.41	1.90	0.573	0.935
PFDA	0.154 (0.140–0.169)	0.134 (0.121–0.148) <i>p</i> =0.0396	0.124 (0.114–0.135) <i>p</i> <0.001	38.3	0.700	0.306	0.935
PFUnA	NA‡	NA‡	NA‡	NA	0.400	0.121	0.467
MeFOSAA	NA‡	NA‡	NA‡	NA	0.600	0.665	5.61

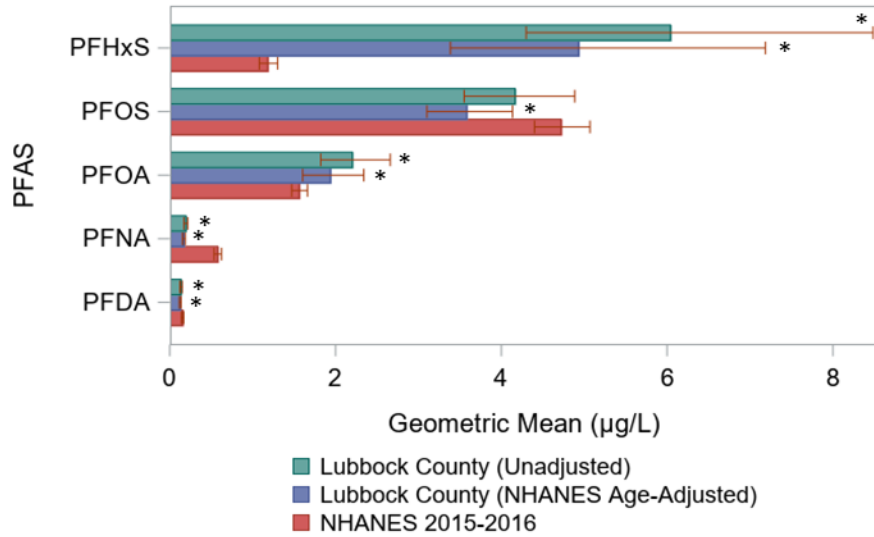
CI = 95% confidence interval, NA = not applicable

\* Source: CDC 2019

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

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

**Figure 3. EA average PFAS blood levels compared to national 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 Lubbock County EA participants. ATSDR used Pearson correlation coefficients ( $r$ ) for this analysis. An  $r$  of 0 means two data sets are uncorrelated, and an  $r$  of 1 means two data sets are exactly correlated (i.e., they rise and fall in proportional amounts). [Table 8](#) shows the Pearson correlation coefficients for the five most frequently detected PFAS.

PFHxS and PFOA blood levels showed the strongest correlations with a Pearson correlation coefficient of 0.85 ([Table 8](#)), and these correlations were statistically significant. On the other hand, PFOS was less strongly correlated with PFHxS, PFOA, and PFNA ( $r = 0.52-0.59$ ). PFDA had weak correlations with other compounds besides PFNA ( $r = 0.71$ ).

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

	PFHxS	PFOS	PFOA	PFNA	PFDA
PFHxS	1.00	0.52	0.85	0.21	-0.01*
PFOS	0.52	1.00	0.54	0.59	0.30
PFOA	0.85	0.54	1.00	0.41	0.13*
PFNA	0.21	0.59	0.41	1.00	0.71
PFDA	-0.01*	0.30	0.13*	0.71	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 for these populations were analyzed separately. Additionally, some questions were applicable only to female adult participants and are therefore also presented separately.

Appendix C (Tables C1 and C2) presents a complete summary of all adult and child questionnaire responses.

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

- age,
- sex,
- tap water consumption,
- drinking water source,
- use of a water filtration or treatment device,
- length of residence in the sampling frame,
- private well testing data,
- blood donation frequency,
- flooring,
- soil exposure,
- breastfeeding (adult females and children), and
- childbirth (adult females).

[Table 9](#) summarizes the demographic and exposure characteristics that were statistically significant in each multivariate model.

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. Summary of 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
Maximum PFAS well concentration (continuous)	✓	✓	✓	✓	✓	✓	✓	✓	✓
Years in sampling frame in the past 20 years (continuous)	✓	✓	✓	—	—	—	✓	✓	✓
Drinking water source (categorical)	✓	✓	✓	—	—	—	—	—	—
Presence of carpet in home (categorical)	✓	✓	—	—	—	—	✓	—	✓
Soil Exposure (categorical)	✓	✓	—	—	—	—	—	—	—
Filter (categorical)	—	—	—	✓	—	✓	—	—	—
Drinking water in cups per day (continuous)	—	—	—	—	—	—	✓	✓	—
Children (categorical)	NA	✓	NA	NA	—	NA	NA	—	NA
Breastfeeding (categorical)	NA	—	NA	NA	✓	NA	NA	—	NA

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

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

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

- Tables C1 and C2 present response frequencies for all questions included in the adult and child questionnaire, respectively. These tables also present geometric means and 95% confidence intervals around geometric means stratified by the response options (e.g., statistics are presented separately for males and females) for PFHxS, PFOS, PFOA, PFNA, and PFDA.
- Tables C3 and C4 present univariate modeling results for all questions in the adult and child questionnaire for the same five PFAS, as data allow. Data are presented only when a category had at least 10 responses. Some categories were collapsed to meet this threshold.
- Tables C5–C13 present multivariate modeling results for PFHxS, PFOS, and PFOA. Multivariate

#### Goodness of Fit Measure

R-squared or R<sup>2</sup> 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<sup>2</sup> 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<sup>2</sup> 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.

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 0.33 to 0.61. ATSDR modeled males and female adults separately to explore sex-specific differences including the potential effect of childbirth and breastfeeding on female blood PFAS levels. The variables considered in male-only and female-only models were limited to those that were significant in final all-adult models. ATSDR did not develop multivariate models for children because of the small sample size for this population (n=24).

**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.

- Figures C1–C34 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***

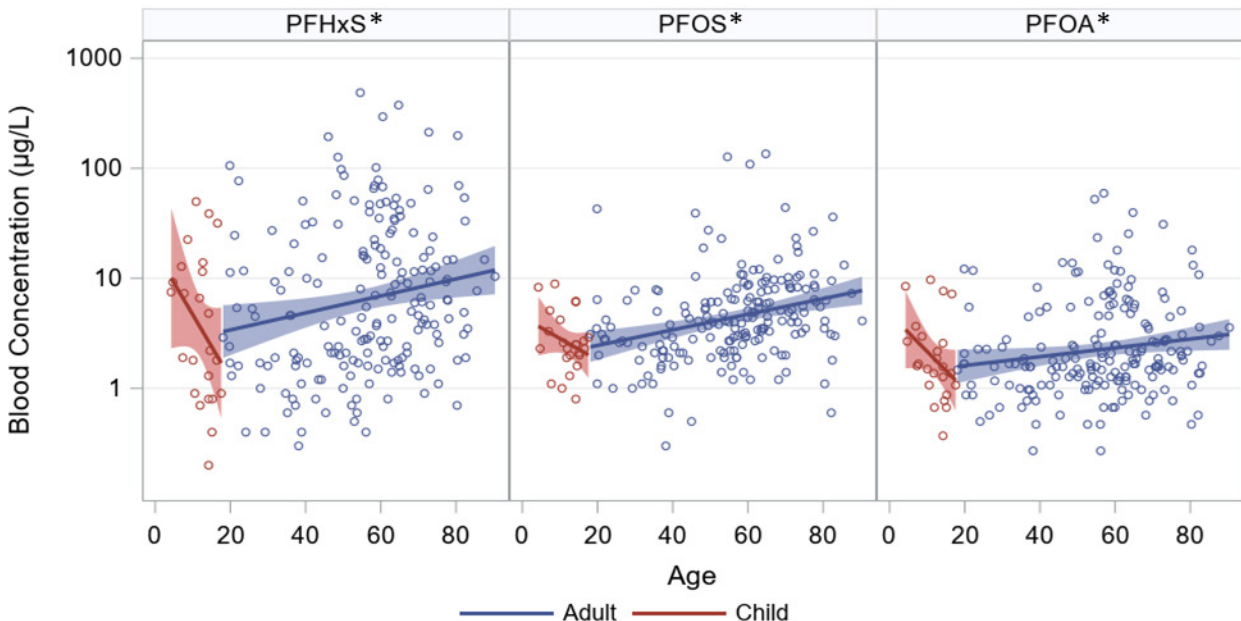
Because many studies have found that older people have higher blood PFAS levels, ATSDR investigated how Lubbock County EA participants' ages related to their blood levels. As [Figure 4](#) illustrates, the blood levels for PFHxS, PFOS, and PFOA statistically increased with age in adults, but trends for children were not statistically significant. Results for children should be interpreted with caution due to the small sample size.

For adults, ATSDR's univariate analysis showed that blood PFHxS, PFOS, and PFOA levels were higher in older individuals than in younger individuals. As [Figure 4](#) shows, PFHxS and PFOS had the strongest age dependence. The univariate analysis indicates that, on average, blood PFHxS levels in Lubbock County EA participants increased 1.8% for every year of participant age for adults, and blood PFOS levels increased by 1.6% for every year of participant age for adults. This suggests a 20% and 17% increase in blood PFHxS and PFOS levels for every 10 years of participant age for adults, respectively. The calculated increase for PFOA (0.9% per year of participant age) was lower.

ATSDR's multivariate analysis provided further perspective on this trend, showing that age remained a significant predictor of blood levels in all-adult multivariate models when controlling for other variables. For each year of participant age, the calculated increases were as follows: 1.0% per year of participant age for PFHxS, 1.7% per year of participant age for PFOS, and 1.2% per year of participant age for PFOA. Multivariate models also showed that age dependence for PFOA was only observed in females. For example, the all-adult model (Appendix C, Table C11) suggests a 1.2% increase in blood PFOA levels in adult females for every year of participant age and no change in blood PFOA levels in adult males was observed when controlling for other characteristics; this finding was statistically significant.

The model results depicted in [Figure 4](#) showed that blood PFHxS, PFOS, and PFOA levels were not statistically associated with age for participants under 18. These results should be interpreted with caution due to the small sample size. 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)**



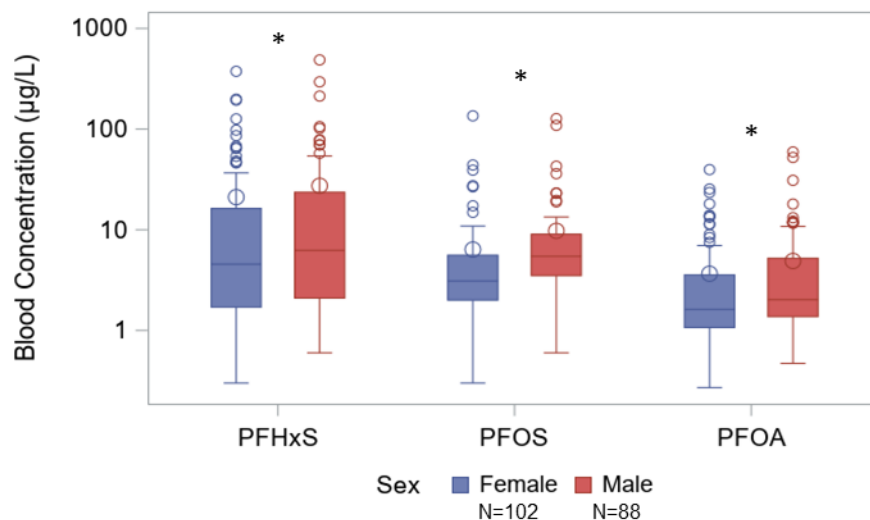
A log<sub>10</sub> scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.  
 \*Statistically Significant Trend ( $p < 0.05$ ) in Adults

**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 significant differences in PFAS levels by sex (Figure 5). On average, blood PFHxS, PFOS, and PFOA were 38%, 68%, and 25% greater in males than in females in univariate models. ATSDR’s multivariate analyses of the all-adult model showed that PFOS and PFOA were higher in adult males than in adult females. For PFOS, males had 70% higher blood levels than females. For PFOA, the all-adult multivariate models showed that the difference between males and females was larger in younger people. For example, 30-year-old males had higher modeled blood PFOA levels than 30-year-old females by 59%. For 50-year-old males, this difference was reduced to 26% for PFOA compared to 50-year-old females.

There were not enough male children (n=8) to statistically evaluate differences by 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 log<sub>10</sub> 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**

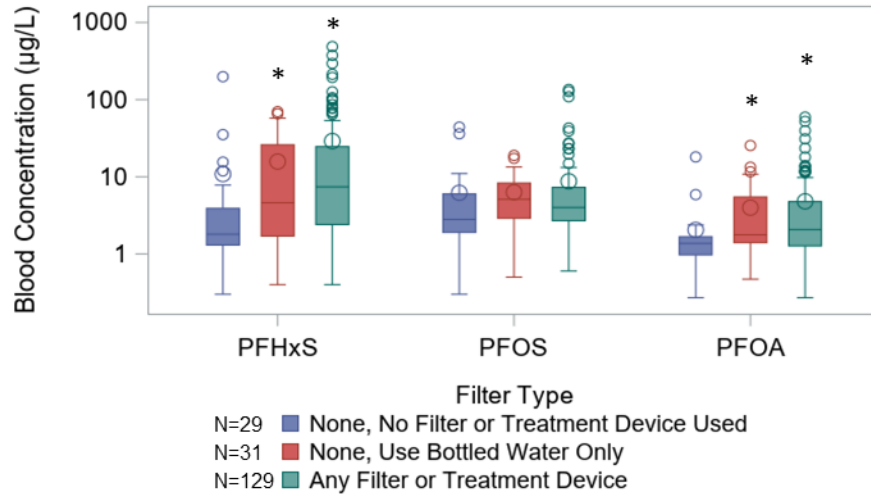
ATSDR investigated several questions from the adult and child questionnaires to characterize relationships between blood PFAS levels and consumption of PFAS-contaminated drinking water. These questions are about the drinking water source, use of filtration devices, amount of tap water consumed at home 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 private drinking well testing results, using sampling data provided by the Air Force.

*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?" Nearly all of the responses were private well (48%) or bottled water (49%). There were no statistically significant differences in blood levels between these two groups in univariate analyses. However, when controlling for other variables in multivariate analyses, participants who identified as primarily drinking bottled water had PFHxS levels 41% lower than those who primarily drank water from a private well. 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 private well was contaminated.

*Use of filtration device.* ATSDR also considered relationships between blood PFAS levels and current use of drinking water filtering and water treatment devices. 68% of participants reported using a filter or treatment device on the tap water that they drink at home, 15% of participants reported no filter or treatment device on the tap water that they drink at home, and 16% reported not drinking tap water at all. In ATSDR's univariate analyses (Figure 6), participants who reported drinking tap water with a filter or treatment device at home had statistically greater blood levels of PFHxS (223%) and PFOA (77%) when compared to participants who drank tap water but did not use a filter. Similarly, in ATSDR's univariate analyses, participants who reported drinking bottled water only had statistically greater levels of blood PFHxS (132%) and PFOA (68%) when compared to participants who drank tap water but did not use a filter.

However, when controlling for other variables in multivariate analyses, reported use of a filter or treatment device only remained significant in models for PFOS, where the direction of the association was reversed. Specifically, participants who reported using a filter or treatment device on the tap water that they drink at home had statistically lower levels of blood PFOS (39%), and participants who reported who reported drinking bottled water only statistically lower levels of blood PFOS (10%) when compared to participants who drank tap water but did not use a filter. While some of these relationships might appear to be the opposite of expectations, the Discussion section provides further context on the complex interplay of variables that relate to PFAS drinking water exposure levels.

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



See 'How to read a box and whisker plot' earlier in the PFAS in Blood section.

A log<sub>10</sub> 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. Adult participants were asked, "During the time you lived in a home served by the water source identified above [i.e., for the question quoted three paragraphs ago], on average how many 8-ounce cups of water or beverages prepared with tap water did you drink while at home per day?" ATSDR's univariate analyses did not reveal a significant linear relationship between blood PFAS levels and the amount of tap water consumed. However, significant relationships were observed for PFOA in the multivariate analysis, which controlled for other potential confounders. For every additional cup of tap water an adult reported drinking at home per day, PFOA levels increased by 2.4% in an all-adult model; this association was statistically significant. In a female-only model, this association was significant and larger (4.0%). It was not significant in a male-only model, suggesting that the relationship was primarily observed in female participants. Associations between tap water consumption and blood PFOS and PFHxS were not statistically significant.

*Length of residency.* For adults, ATSDR also considered the length of residency. The exposure history questionnaire asked adults where they had lived for the past 20 years. ATSDR calculated the total amount of time participants reported living in the sampling frame over this period. These responses can serve as a proxy for potential exposure to PFAS-contaminated drinking water in the community. That is, the longer the residency within the sampling frame, the greater the likelihood of past PFAS exposure from contaminated drinking water. Any resident reporting prior residences with addresses in "Lubbock County, TX" were assumed to fall within the sampling frame. All addresses in the "City of Lubbock, TX" were mapped and categorized as within or outside of the sampling frame accordingly. Note that this is only a proxy for historical drinking water exposure to PFAS as not all of the private wells within the sampling frame had elevated PFAS concentrations. Additionally, there have been recent efforts to extend City water service to some areas inside the sampling frame.

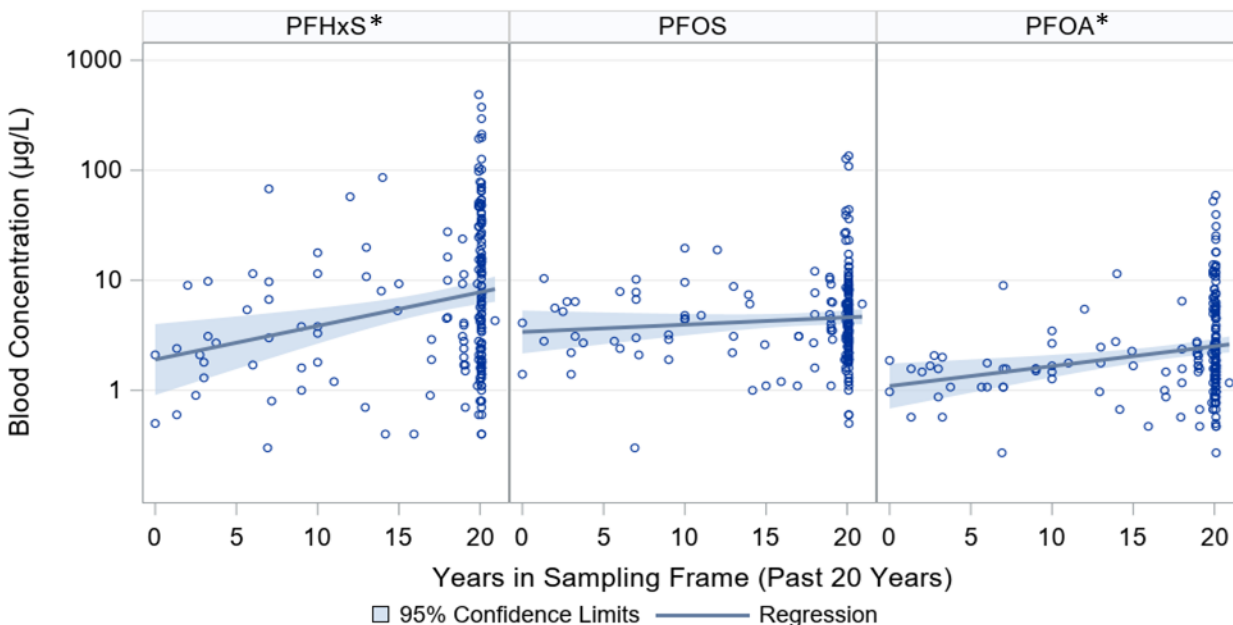
[Figure 7](#) shows the relationship between reported residence duration in Lubbock County for the past 20 years and blood PFAS levels. A consistent relationship was observed for PFHxS and PFOA: blood levels increased with the number of years participants lived in the sampling frame, and this effect was most pronounced for PFHxS. The multivariate analysis confirmed this relationship for PFHxS and PFOA: for every additional year that an adult participant lived in Lubbock County, blood PFHxS increased by 6.2% and blood PFOA increased by 2.4%. In both male-only and female-only models, the association remained statistically significant and was generally stronger in males than females.

### What are confounders?

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

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

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



A log<sub>10</sub> 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)

*Private well testing data.* ATSDR also considered private well testing data obtained from the Air Force. ATSDR linked EA participant households to corresponding households with private wells that were sampled by the Air Force between 2017 and 2019. Since the Air Force conducted multiple rounds of testing in certain households, ATSDR assigned the maximum concentration measured at a household’s private well to each participant in that household for its analyses. ATSDR was able to assign drinking water values to 192 out of 214 participants (90%) in this EA. PFHxS, PFOS, and PFOA were detected in 92%, 57%, and 85% of participants’ wells, respectively. The maximum concentrations measured in drinking water wells of EA participants were 1,410 ppt for PFHxS, 946 ppt for PFOS, and 2,890 ppt for PFOA.<sup>5</sup> Note that 1,450 ppt, 998 ppt, and 2,900 ppt represent the highest PFHxS, PFOA, and PFOS concentrations, respectively, measured by the Air Force across all Lubbock County samples, including non-EA households.

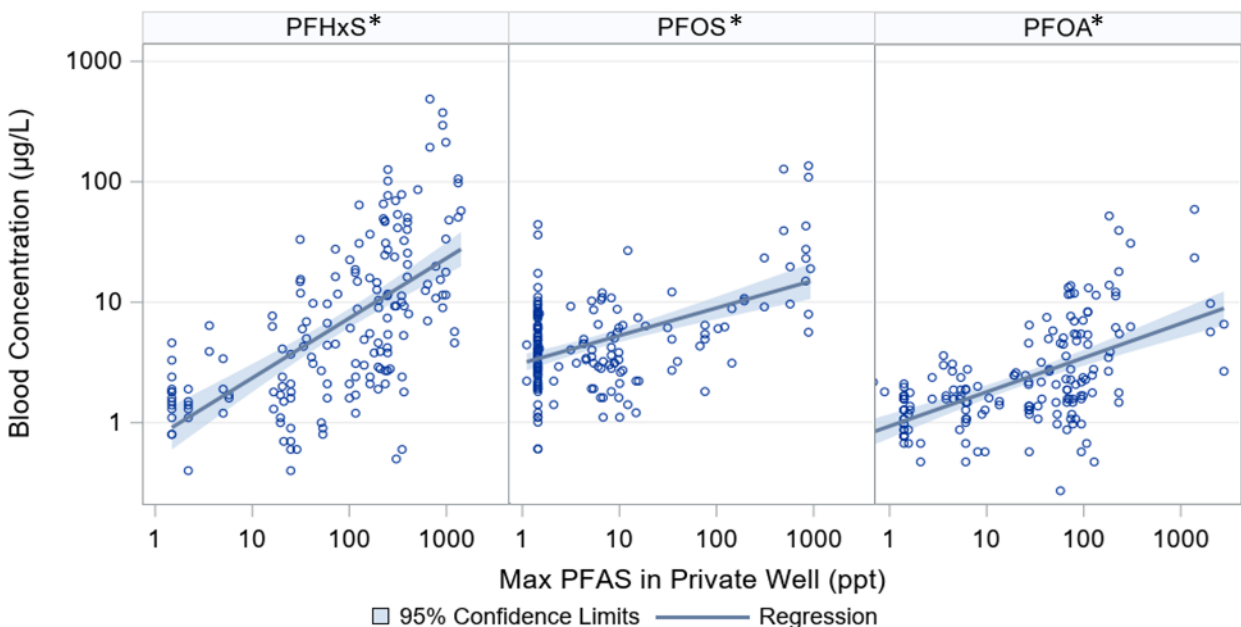
For adults, in univariate models, the log<sub>10</sub> of maximum PFHxS, PFOS, and PFOA well water concentrations were statistically associated with blood PFAS levels (Figure 8). Comparisons were made only between like PFAS and are all based on log<sub>10</sub>-transformed concentrations. For example, the effect of PFHxS well water concentrations were only compared with blood PFHxS levels. For each 1% increase in maximum PFHxS well water concentration, blood PFHxS levels increased on average by 0.50%. For each 1% increase in maximum PFOS well water concentration, blood PFOS levels increased on average by 0.23%, respectively. For each 1% increase in maximum PFOA well water concentration, blood PFOA levels increased on average by 0.29%. In the multivariate analyses, for each 1% increase in maximum

<sup>5</sup> The private well testing data used in this assessment reflect data that ATSDR acquired from the Air Force as of September 2019, prior to the 2020 Lubbock County EA recruitment and data collection.

PFHxS, PFOS, and PFOA well water concentration, there was a corresponding increase in blood PFHxS (0.54%), PFOS (0.27%), and PFOA (0.30%), respectively.

PFHxS and PFOA were detected in Lubbock County private wells at higher concentrations than PFOS (PFHxS at a maximum of 1,410 ppt, PFOA at a maximum of 2,890 ppt, and PFOS at a maximum concentration of 946 ppt in EA participant wells); and PFHxS and PFOA in particular were highly correlated in blood measurements. Therefore, one explanation for the high correlation among these compounds in the blood is that the Lubbock County EA participants had a common exposure profile for PFHxS and PFOA, such as drinking water. PFOS was also correlated, though to a lesser extent. However, the correlations alone cannot be used to identify the underlying source or combination of sources that contributed most to exposure.

**Figure 8. PFAS blood levels in adults by maximum PFAS in private well (log scale)**



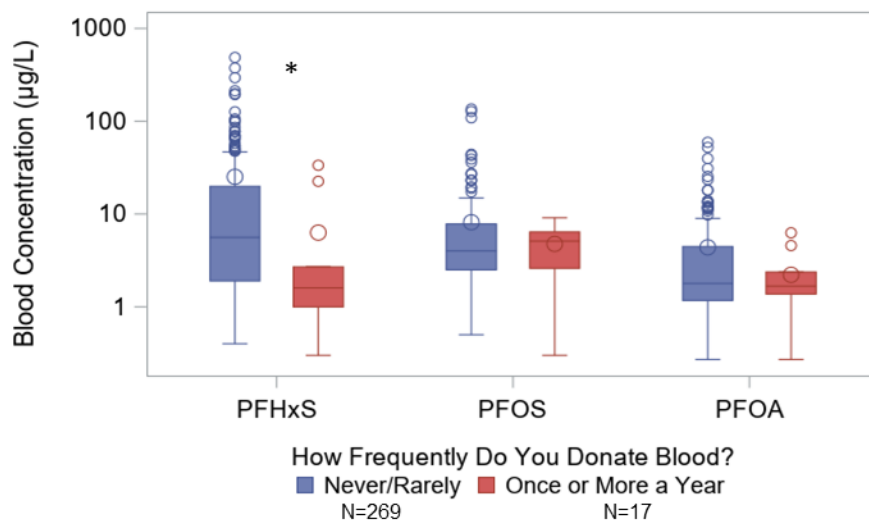
A log<sub>10</sub> scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.

\*Statistically Significant Trend ( $p < 0.05$ )

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

Adult participants were asked how often they donate blood or plasma, because frequent blood and plasma donations might result in decreasing blood PFAS levels. Consistent with expectations, blood levels of PFHxS were higher among EA participants who reported never or rarely donating blood when compared to blood levels for EA participants who donated blood at least once per year (Figure 9). However, frequency of blood donation was not significant in multivariate models. These results are based on a small number of participants (6%,  $n=11$ ) who donated blood and will be explored further in the final report for all EA sites. The results for blood donation for this EA are based on limited data and should be interpreted with caution.

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



See 'How to read a box and whisker plot' earlier in the PFAS in Blood section.

A log<sub>10</sub> 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 Flooring***

Adult participants were asked about the type of flooring in their living rooms, kitchens, and bedrooms because PFAS-containing stain- and grease-repelling coatings are often applied to carpet [Beesoon et al. 2012]. The presence of carpet in Lubbock County EA participants' rooms was not statistically associated with blood PFAS levels among adults in univariate models. However, in multivariate models, participants who reported having carpet in any room ( $n=37$ ) had blood levels of PFHxS and PFOA that were 100% and 36% higher than those who reported not having carpet in their home, respectively.

### ***Blood PFAS Levels and 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 among adults in univariate models. However, in multivariate models, participants who reported coming in contact with soil a few times per month (63%) and three times a week or more (78%) had higher blood PFHxS levels than those who reported coming in contact with soil a few times per year or less.

The soil exposure data were not evaluated for children due to the limited sample size.

### ***Blood PFAS Levels and Childbirth (adult females only)***

The adult questionnaire asked female participants whether they had any biological children, and if so, how many. Most adult female EA participants (78%) reported having biological children. Neither having children nor the number of children was statistically associated with blood PFAS levels in univariate models. However, in multivariate models, female participants reporting having children had statistically lower blood PFHxS (58%) levels than females who did not have children.

### ***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, 40% reported that they had breastfed a child, with an average breastfeeding duration across all pregnancies of 18 months. Having ever breastfed a child (yes/no) and total breastfeeding duration were not associated with PFAS blood levels in univariate models. However, in female-only multivariate models, females who reported having ever breastfed a child (yes/no) had statistically lower PFOS blood levels (26%) when compared to adult females who had never breastfed a child.

The questionnaire results demonstrate that, overall, 67% of children in the Lubbock County EA were breastfed. Among child participants who were breastfed, each month of reported breastfeeding was associated with an increase of 4.2% in blood PFOS. For example, 6 months of breastfeeding changed an infant's modeled PFOS blood level from 2 µg/L to 2.6 µg/L.

Less than half of the children in the Lubbock County EA (38%) consumed infant formula reconstituted with tap water (some of these children were also breastfed), but no associations between infant formula consumption and PFAS in blood were evaluated because of the small number of children who did consume infant formula reconstituted with tap water (n=9).

### ***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.

- **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 Lubbock County EA participants who self-identified as White, non-Hispanic and those who identified as non-White, or Hispanic. No statistical relationship was observed for self-reported race/ethnicity and blood PFAS level in adults.
- **Kidney disease.** The exposure history questionnaire asked about 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=12) reported a diagnosis of kidney disease, and these adults did not have statistically different blood PFAS levels than those without such a diagnosis. Note that kidney disease was self-reported and there may be misclassification with this variable.
- **Cleaning frequency.** Adult participants were asked how often their homes are cleaned. No statistically significant relationship was observed for self-reported cleaning frequency and blood PFAS levels in adults.
- **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. Lubbock County EA adult participants with any self-reported stain-resistant product use did not

have statistically elevated blood levels of any PFAS when compared to participants who reported never using these products.

- **Fast food consumption.** PFAS may be present in fast food take-away containers and food packaging. Consumption of fast food may serve as an additional source of PFAS exposure. However, among Lubbock EA adult participants, reported frequency of fast food consumption was not statistically associated with blood PFAS levels. In recent years, fast food packaging has likely been reformulated to contain shorter chain PFAS compounds. This shift may make it more challenging to link PFAS exposure to fast food consumption.
- **Consumption of selected local food items.** Some PFAS accumulate in plants, fish, and animals. The questionnaire asked adult and child participants how often they consume locally grown fruits and vegetables, locally caught fish, and milk from animals in the sampling frame. Too few adult EA participants reported consuming locally caught fish (n=2) or locally produced milk (n=0) to allow for meaningful statistical analyses, and a statistically significant relationship was not observed between consumption of locally grown fruits and vegetables and blood PFAS levels.
- **Occupation.** Adult participants were asked about their occupational history over the past 20 years. Participants were specifically asked about experience working at manufacturers of PFAS or PFAS-containing products (e.g., nonstick cookware, water-resistant clothing) and past work in firefighting, the military, or aviation. Too few adult EA participants reported relevant occupational exposures (n=3) for meaningful statistical analyses.

## PFAS in Urine

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

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

For the Lubbock County EA, ATSDR randomly selected 22 participants' urine samples for analysis. The samples used for summary statistics were provided by 20 adults and 2 children, and these individuals lived in 20 different households. PFBA and PFHxA were the only PFAS detected in any of the 22 urine samples. Of note, there are challenges in measurement of trace levels of PFBA in urine, including selectivity of the analytical instrumentation and potential for external contamination [Abraham et al. 2021]. Therefore, we advise caution when interpreting the PFBA results. [Table 10](#) presents PFBA and PFHxA summary statistics for the randomly selected urine samples and national statistics for comparison. Geometric mean concentrations were not calculated for either substance, because the frequency of detection did not exceed 60%. 1 of the 22 urine samples had PFBA concentrations greater than the NHANES 95<sup>th</sup> percentile. 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)	Lubbock County Geometric Mean (µg/L)	Lubbock County 95 <sup>th</sup> Percentile (µg/L)	NHANES Geometric Mean (µg/L)	NHANES 95 <sup>th</sup> Percentile (µg/L)
PFHxA	4.55	ND–0.4	NA*	NA <sup>†</sup>	NA*	NA <sup>†</sup>
PFBA	9.09	ND–0.4	NA*	NA <sup>†</sup>	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 (PFHxA and PFBA were detected in 22.6% and 13.3% of samples, respectively, in Calafat et al. [2019]).

<sup>†</sup> 95<sup>th</sup> percentile is below the limit of detection.

## PFAS in Tap Water

As noted previously, ATSDR collected tap water samples from 12 randomly selected EA participant households and analyzed these samples for PFAS. Six households only provided a filtered water sample, six only provided an unfiltered water sample, and four provided both filtered and unfiltered samples. Detection limits were 2 ppt for all PFAS, except for HFPO-DA (5 ppt). PFHxA was detected in 3 of the 10 filtered samples. In two of the filtered samples in which PFHxA was detected, PFBS, PFHpA, PFHxS, and PFOA were also detected. PFHxA, PFBS, PFHpA, PFHxS, and PFOA were also detected in two of the six unfiltered samples. All measured concentrations were below EPA’s health advisory of 70 ppt for PFOA and PFOS combined. There is no EPA HA for PFHxA, PFBS, PFHxS, or PFHpA. [Table 11](#) shows the range and detection frequencies in filtered and unfiltered samples.

**Table 11. Summary statistics for tap water samples collected during the Lubbock County EA**

PFAS	Filtered Samples (n=10)		Unfiltered Samples (n=6)	
	Frequency of Detection (%)	Range of Concentrations (ppt)	Frequency of Detection (%)	Range of Concentrations (ppt)
PFBS	20	ND–11	33	ND–12
PFHpA	20	ND–2.5	33	ND–4.5
PFHxA	30	ND–54	33	ND–48
PFHxS	20	ND–36	33	ND–67
PFOA	20	ND–4.6	33	ND–14

ND = not detected, ppt = parts per trillion

## PFAS in Household Dust

ATSDR collected dust samples from the same 12 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 12](#) 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 12](#) (i.e., PFPeS, PFHpS, PFNS, PFDoS, PFBA, PFTrA, PFOSA, N-EtFOSA, FtS 4:2, FtS 8:2, HFPO-DA, ADONA, 9CL-PF3ONS, and 11CL-PF3OUdS).

**Table 12. Summary statistics for dust samples (n=12) collected in Lubbock County**

PFAS	FOD (%)	Maximum Detected Result (ng/g)	Geometric Mean (ng/g)	95% Confidence Interval for Geometric Mean (ng/g)	Percentiles (ng/g)		
					50 <sup>th</sup> (Median)	90 <sup>th</sup>	95 <sup>th</sup>
PFBS	8	16.3	NA*	NA*	1.41	4.09	8.97
PFHxS	42	226.0	NA*	NA*	1.59	6.63	94.7
PFOS	67	135.0	5.42	2.40–12.2	4.42	18.5	67.0
PFDS	8	4.1	NA*	NA*	1.41	3.94	4.08
PFPeA	8	8.2	NA*	NA*	2.81	7.32	7.76
PFHxA	67	24.3	3.56	2.10–6.05	2.98	6.69	13.8
PFHpA	50	10.6	NA*	NA*	2.09	4.21	6.78
PFOA	67	78.2	4.77	2.35–9.68	4.09	11.1	38.3
PFNA	25	4.1	NA*	NA*	1.59	3.94	4.08
PFDA	25	7.0	NA*	NA*	1.63	4.09	5.26
PFUnA	8	4.1	NA*	NA*	1.51	3.94	4.08
PFDoA	17	4.1	NA*	NA*	1.51	4.03	4.08
PFTA	17	4.1	NA*	NA*	1.51	3.94	4.08
N-MeFOSA	8	4.7	NA*	NA*	1.73	4.20	4.45
MeFOSAA	33	30.9	NA*	NA*	1.76	7.30	17.2
N-MeFOSE	50	311.0	NA*	NA*	25.7	142	216
EtFOSAA	17	10.3	NA*	NA*	1.51	4.09	6.57
N-EtFOSE	8	30.6	NA*	NA*	10.5	30.3	30.5
FtS 6:2	8	14.7	NA*	NA*	5.06	13.1	13.9

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

A total of 12 dust samples are summarized in this table.

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



PFOS, PFHxA, and PFOA were detected in 67% of the households evaluated. PFOS, PFHxA, and PFOA had geometric mean values of 5.42 nanograms/gram (ng/g)<sup>6</sup> (95% confidence interval = 2.40–12.2 ng/g), 3.56 ng/g (95% confidence interval = 2.10–6.05 ng/g), and 4.77 ng/g (95% confidence interval = 2.35–9.68 ng/g), respectively. Geometric means were not calculated for any other PFAS because these PFAS were detected in less than 60% of samples.

To provide some context to the results summarized above, average levels of PFAS measured in the 12 samples collected as part of this EA were compared to average dust levels reported in other U.S.-based studies. This includes evaluations of indoor dust collected at 30 homes in the greater Boston area [Fraser et al. 2013], 124 homes in California [Wu 2015], 15 U.S. homes [Karásková et al. 2016], and 19 homes in Minnesota cities with PFAS-contaminated soil and drinking water [Scher et al. 2018]. Across these studies and in this EA, PFOA and PFOS were consistently reported at the highest concentrations. Geometric mean concentrations ranged from 24 to 45 ng/g for PFOA and 27 to 35 ng/g for PFOS [Fraser et al. 2013; Wu et al. 2015]. Two of the studies did not report geometric means; for these studies, median concentrations were reported at 9 ng/g and 51 ng/g for PFOA and 14 ng/g and 67 ng/g for PFOS [Karásková et al. 2016 and Scher et al. 2018, respectively]. Geometric mean and median concentrations for PFOA and PFOS measured in the 12 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 Lubbock County were found at lower levels than reported elsewhere in the United States, note that the studies referenced here do not necessarily provide representative comparisons and are provided only for additional context. The sample collection methods and analytical methods were also not consistent among these studies.

ATSDR also evaluated the correlation between PFAS measured in dust and blood. This analysis included analytical data from 10 dust samples summarized above and from the 18 blood samples collected from participants residing in the same homes (two households did not participate in biological sample collection). Using log-transformed data, ATSDR calculated Pearson correlation coefficients only 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 ( $r=0.55$ ,  $p=0.019$ ) with PFOA 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 Lubbock County is relatively small. ATSDR will further explore these findings, as well as correlations between different PFAS measured in dust and blood (e.g., the correlation between PFOA in dust and PFOS in blood) in the report for all ATSDR PFAS 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

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<sup>6</sup> 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.

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 Lubbock County EA participants (100%). Because of the widespread use of PFAS, such high detection frequencies are common in the general U.S. population [CDC 2019]. PFHxS, PFOS, PFOA, PFNA, and PFDA were the most frequently detected compounds in Lubbock County EA participants (detection frequencies above 77%).

Results from this EA were compared to NHANES data from 2015–2016.<sup>7</sup> Age-adjusted geometric mean blood levels of PFHxS and PFOA were statistically higher than these national geometric means (4.2 and 1.2 times the national level, respectively), and age-adjusted blood concentrations of PFOS, PFNA, and PFDA were similar to or lower than national geometric means. EA participants had statistically higher blood PFHxS and PFOA levels than national levels.

All PFAS measured in blood for this EA have been phased out of production in the United States. Following this phase-out, national blood PFAS levels have been steadily declining since 2000 [CDC 2019]. Differences between geometric mean Lubbock County 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 Lubbock County EA blood levels and the NHANES 2015-2016 geometric mean presented here.

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

- For PFHxS and PFOA, blood levels among Lubbock County EA participants are within the range of those observed in other communities with contaminated drinking water (Appendix A, Table A2).
- Lubbock County EA participants' blood PFHxS levels are higher than the national geometric mean from 1999–2000, the time NHANES first measured PFAS and the time the highest PFAS levels were observed [CDC 2019].
- PFOS, on the other hand, did not exhibit these trends. PFOS blood levels among Lubbock County EA participants are lower than those observed in some other communities with contaminated drinking water, the NHANES 2015-2016 blood levels, and the NHANES 1999-2000 blood levels [CDC 2019].

These results are consistent with the observation that PFOS was only detected in 57% of EA participants' wells compared to 92% for PFHxS and 85% for PFOA.

### Generalizability of Lubbock County EA Community Statistics

The recruitment method used for this EA was designed to produce summary statistics of blood PFAS levels that were generalizable to the sampling frame as a whole (i.e., Lubbock County households in the area shown in [Figure 1](#)). Although all households in the sampling frame were invited to participate in

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<sup>7</sup> 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.

this EA, the population that ultimately enrolled was older. Specifically, adults aged 50 or older represented 60% of the EA population compared with 25% of the sampling frame. The EA population and the sampling frame as a whole did not statistically differ in the proportion of people who identify as White, non-White, or Hispanic. Given the 14% 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 were biased high by 13% to 23%. 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 PFOS and PFOA, 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, gestation (as measured by reporting ever having had children) was a significant predictor of PFHxS blood levels in multivariate models, and having ever breastfed a child was found to be statistically associated with decreasing blood levels of PFOS among adult women. Similarly, children who were breastfed had higher PFOS levels than those who were not.

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 PFOA. Blood PFAS levels were not statistically associated with age among children (3–18 years). Differences in the associations between blood PFAS levels and age in adults and children have been observed in other studies, and the results of this EA are consistent with the findings for adults [ATSDR 2013; NH DPHS 2016; CDC 2019]. Generally, increasing blood levels in adults are due to the long biological half-lives of PFAS and diminishing excretion rates with increasing age. The half-life of a chemical is the amount of time it takes for 50% of the substance to be eliminated from the body. Some studies estimate that the half-life of PFHxS is between 4.7 and 35 years [ATSDR 2021]. Half-life estimates range from 3.3 to 27 years for PFOS and from 2.1 to 10.1 years for PFOA [ATSDR 2021]. In the presence of continued exposures that exceed clearance rates, PFAS will accumulate in the human body over time. In this EA, blood PFHxS, PFOS, and PFOA levels were higher in younger children for participants under 18. Although this trend was not statistically significant, this association is likely due to multiple factors including early life exposures and growth dilution. Early-life exposures may have occurred during gestation, since PFAS can cross the placenta and is found in breast

milk [ATSDR 2021]. In addition, hand-to-mouth touching and spending more time closer to the floor with settled dust is much greater in toddlers than in older children. As a child grows, these early-life exposure factors diminish. Additionally, large increases in body size lower blood levels despite increasing or constant PFAS body burdens. This process is known as growth dilution [Koponen et al. 2018].

## Significance of Drinking Water Exposures

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

- PFHxS and PFOA blood levels in EA participants were statistically higher than 2015-2016 NHANES national geometric means. PFAS were first detected in Lubbock County private wells in 2017. It is likely that contamination began earlier, but no data are available before 2017. Among the site documents ATSDR reviewed, the highest sampling result from private wells in Lubbock County was 1,450 ppt for PFHxS, 998 ppt for PFOS, and 2,900 ppt for PFOA. The information available to ATSDR indicates that the last time the Air Force measured PFAS drinking water concentrations in a private well above EPA's health advisory or TCEQ's PCL prior to the 2020 Lubbock County EA recruitment and data collection was in September 2019. However, these PFAS have long biological half-lives (on the order of years). Therefore, even though drinking water PFAS exposures in private wells were significantly reduced by September 2019, past drinking water exposures would contribute to the EA participants' elevated blood PFAS levels observed years later. Furthermore, in this EA, PFHxS blood levels exceeded the national average by the greatest margin (4.2 times the national level when adjusted for age) and showed the greatest association with reported drinking water consumption, which is what would be expected given that PFHxS has the longer half-life of the two PFAS. PFOA blood levels when adjusted for age were 1.2 times the national average.
- The strongest evidence linking blood PFAS levels to drinking water data is the consistent and strong association observed with maximum concentrations of PFAS measured in each household's private well. Drinking water measurements provided by the Air Force indicate that maximum concentrations of PFHxS, PFOS, and PFOA for households in this EA were 1,410 ppt, 946 ppt, and 2,890 ppt. (Note that the previously reported maximum concentrations of 1,410 ppt PFHxS, 2,890 ppt PFOA, and 946 ppt PFOS was measured in households that did not participate in the EA). For PFHxS, PFOS, and PFOA the individual drinking water measurements were statistically associated with corresponding PFAS measured in blood ([Figure 8](#)). In other words, residents of households that had the highest private well contamination for PFHxS, PFOS, and PFOA generally had higher blood levels for these substances. These results further suggest that elevated blood PFHxS and PFOA levels were due to PFAS-contaminated drinking water. Average blood PFOS levels were not elevated compared to national levels; however, the association observed between levels in drinking water and blood were still significant. This discrepancy can be explained because PFOS was detected in the wells of fewer participants (only 57%) compared to PFHxS (92%) and PFOA (85%).
- Univariate statistical analyses of the EA data found that one of the most consistent predictors of adult blood PFHxS and PFOA levels was longer length of residency in Lubbock County. ATSDR considered residency duration to be a suitable surrogate for drinking water exposures because only residents who lived in the sampling frame before September 2019 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 have lived in the sampling frame longer, this variable was highly correlated with age in adults. Because of this, it was unclear from univariate models alone whether the association between the time someone lived in the sampling frame and PFAS blood levels was primarily due to age. After controlling for age, sex, and other data characteristics, the multivariate statistical analysis found that residency duration remained statistically associated with blood PFHxS and PFOA levels, and age remained statistically associated with blood PFHxS, PFOS, and PFOA levels. In multivariate models conducted separately for males and females, the association with PFHxS and PFOA levels remained significant, suggesting that this relationship was robust and applied to both males and females. However, multivariate regression models did not explain a portion of the variability in participants' blood PFAS levels ( $R^2$  ranged between 0.33 and 0.61 for PFHxS, PFOS, and PFOA), indicating that there may be many factors not accounted for.

- ATSDR also considered associations with blood PFAS levels and multiple exposure history questions pertaining to drinking water. Notably, these questions pertained to current drinking water practices. It is uncertain whether responses would have applied to past drinking water practices. Drinking water consumption rates were statistically associated with blood PFOA levels in multivariate models, and participants who reported drinking primarily bottled water had lower blood PFHxS levels than those who reported primarily drinking private well water. In ATSDR's univariate analyses, participants who reported using a filter or treatment device on tap water at home had on average higher PFHxS and PFOA blood levels than those who drank tap water without any filter or treatment device. Although the direction of these results is the opposite of what was expected, after controlling for other variables in multivariate analyses, this relationship was no longer significant for PFHxS and PFOA, and was instead significant in the opposite direction for PFOS. That is, participants who reported use of filter or treatment device had lower blood PFOS levels. ATSDR believes the initial unexpected associations for PFHxS and PFOA were because the Air Force installed treatment devices, particularly whole house filters, on private wells that exceeded EPA's health advisory or TCEQ's PCLs. In other words, participants who currently have filters installed by the Air Force previously had elevated PFAS levels in their drinking water. These results provide further evidence for a drinking water exposure route for PFHxS, PFOS, and PFOA.
- PFHxS and PFOA were highly correlated in blood ( $r = 0.85$ ), suggesting similar or common background sources or exposure pathways. PFHxS and PFOS, and to a lesser extent PFOA, have many common exposure sources, as these compounds are often found together in consumer products. In addition, a common historical formulation of AFFF contained PFOS and precursors that can break down to PFHxS and PFOA. While correlations between PFAS have been observed in other studies [NH DPHS 2016; ATSDR 2013; CDC 2019], the correlations observed between these two 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. 2007]. The high correlation between blood PFHxS and PFOA observed in Lubbock County is consistent with that found in the blood of people living in a community with contaminated drinking water [ATSDR 2013], providing further evidence that drinking water was likely a contributing source of exposure among Lubbock County EA participants. In addition, the correlations between PFHxS and PFOA in this study are much higher than the correlations observed for PFOS, PFNA, and PFDA, providing further evidence of a distinct exposure pathway for PFHxS and PFOA.

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

- **Blood donation frequency.** Previous research clearly demonstrates that PFAS have a strong affinity for binding to blood proteins and accumulate in human blood [Jian et al. 2018]. Blood donation therefore has the potential to remove PFAS from the body. In univariate models, lower PFHxS blood levels were observed in the few (6%, n=11) Lubbock County EA participants who reported donating blood at least once per year. This relationship was not significant in multivariate models.
- **Flooring.** 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]. In multivariate models, participants who reported having carpet in any room (n=37) had blood levels that were higher than those who reported not having carpet in their home.
- **Soil Exposure.** PFAS can be present in soil that has been irrigated with contaminated drinking water or through deposition. In multivariate models, participants who reported coming in contact with soil more frequently had higher blood PFHxS levels than those who reported coming in contact with soil infrequently.

These observations are based on limited data, should be interpreted with caution, and will be re-examined in the report analyzing results across all EA sites.

## Lubbock County Community-Wide Findings

**Finding 1. Average blood levels of PFHxS and PFOA in the Lubbock County 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 Lubbock County EA participants when compared to CDC's NHANES (2015–2016) testing, which was limited to people over 12 years old. The statistically higher blood PFAS levels were observed for both unadjusted geometric means for all EA participants and geometric means adjusted to the age distribution of the U.S. population from NHANES 2015–2016.

Of the PFAS analyzed in blood, PFHxS had the largest elevations when compared to national levels. The age-adjusted geometric mean blood PFHxS level among all Lubbock County EA participants was 4.2 times the national level. Blood PFHxS levels were above the national geometric mean for 86% of the Lubbock County EA participants and above the NHANES 95<sup>th</sup> percentile for 81% of the Lubbock County EA participants. The age-adjusted geometric mean blood PFOA level was 1.2 times the national level.

Other PFAS measured in this EA (PFOS, PFNA, and PFDA) were not higher than the national average. PFUnA and MeFOSAA were detected in fewer than 60% of the EA participant samples; due to the large 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.**

The two PFAS (PFHxS and PFOA) with statistically elevated blood levels compared to national geometric means were detected in Lubbock private wells as early as 2017. It is likely that contamination began earlier, but no data are available before 2017. The maximum concentrations measured by the Air Force in private drinking water wells in Lubbock County were 1,450 parts per trillion (ppt) for PFHxS, 2,900 ppt for PFOA, and 998 ppt for PFOS (note the maximum PFHxS, PFOA, and PFOS concentrations measured in EA participant drinking water wells was 1,410 ppt, 2,890 ppt, and 946 ppt, respectively). Between 2017 and 2019, actions taken by the Air Force reduced PFAS levels in drinking water in the affected area below EPA health advisory for PFOS and PFOA and Texas Commission on Environmental Quality's (TCEQ's) protective concentration levels (PCLs) for multiple PFAS. Before 2016, PFAS-containing AFFF were primarily formulated with PFOS, but also contained various PFAS precursors that could break down into other PFAS, such as PFHxS, which could explain the elevated blood PFHxS levels. PFHxS and PFOA have long biological half-lives (2.1 to 35 years). There was 1 year and 4 months between when concentrations of PFAS in private wells were reduced 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 two 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 Lubbock County residents' blood (Pearson correlation coefficient,  $r = 0.85$ ). 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 contaminated groundwater that supplies drinking water to private wells in the area, though other sources of exposure may also have contributed to the observed blood levels.

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

- First, a consistent and statistically significant predictor of participant blood levels for PFHxS and PFOA was how long the resident had lived in Lubbock County during the past 20 years. Those who lived in the area longest likely drank, in total, a larger volume of contaminated water. For every year a participant reported having lived in the affected area of Lubbock County, there was an increase in blood PFHxS (6.2%) and PFOA (2.4%) levels.
- Second, exposure history questions pertaining to drinking water were statistically associated with either PFHxS or PFOA:
  - Adults who reported mainly drinking bottled water at home on average had statistically lower PFHxS blood levels when compared to those who reported mainly drinking private well water.
  - PFOA blood levels in adults statistically increased with the amount of tap water those adults reported drinking.
- Third, blood PFHxS and PFOA levels were statistically associated with corresponding private well water PFAS concentration data measured by the Air Force. Among adults, for every 1% increase in maximum well PFHxS and PFOA concentrations, there was an increase in blood PFHxS (0.54%) and PFOA levels (0.30%). Average blood PFOS levels were not elevated compared to national levels; however, the association observed between levels in drinking water and blood was still

significant. This discrepancy can be explained because PFOS was detected in the wells of fewer participants (only 57%) compared to PFHxS (92%) and PFOA (85%).

**Finding 3. Age, sex, flooring, soil exposure, childbirth, and breastfeeding 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 Lubbock County EA data set in adult participants (and are consistent with those reported in other non-ATSDR PFAS studies):

- Blood levels of PFHxS, PFOS, and PFOA were higher in older participants. Adult blood PFHxS increased by 1.0% and PFOS by 1.7% for every year of age. For PFOA, a difference was observed between males and females. In females, blood levels for PFOA increased by 1.2% for every year of participant age. In male, blood levels for PFOA did not show a change with age.
- Males had statistically higher blood levels of PFOS and PFOA than females. Blood levels in adult males were 70% higher for PFOS. For PFOA, the difference between males and females was larger in younger people. For example, 30-year-old males had higher blood PFOA levels than 30-year-old females by 59%. For 50-year-old males, this difference was reduced to 26% compared to 50-year-old females.
- Participants who reported having carpet in any room (n=37) had blood levels of PFHxS and PFOA that were 100% and 36% higher than those who reported not having carpet in their home, respectively.
- Participants who reported coming in contact with soil a few times per month (63% higher) and three times a week or more (78% higher) had higher blood PFHxS levels than those who reported coming in contact with soil a few times per year or less.
- Female participants reporting having children had lower blood PFHxS (58%) levels than females who did not have children.
- Females who breastfed had lower blood levels of PFOS by 27% than females who did not.

One additional association was observed in children (<18 years), though many variables could not be examined because of the small number of child participants (n=24). Because of the small sample size, results should be interpreted with caution. Specifically, children who were breastfed had higher blood levels of PFOS compared to non-breastfed children. Infants born to mothers exposed to PFAS can be exposed in utero and while breastfeeding. However, based on current science, the benefits of breastfeeding outweigh the risks for infants exposed to PFAS in breast milk. The final report on all EA sites will include a more robust analysis of children.

**Finding 4. Only two PFAS were detected in urine.**

ATSDR analyzed 22 (10%) of the urine samples collected. Only perfluorobutanoic acid (PFBA) and perfluorohexanoic acid (PFHxA) were detected; they were detected in 4.6% and 9.1%, respectively, of the 22 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 tap water samples from Lubbock County private wells collected during the EA in 2020 met the EPA's HA and the Texas Commission on Environmental Quality's (TCEQ's) protective concentration levels (PCLs) for specific PFAS in drinking water.**

This is based on 6 unfiltered and 10 filtered tap water samples collected in 12 households during the EA.



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

Among the PFAS detected most frequently in household dust samples, PFOS, PFOA, and PFHxA were measured at the highest concentrations. No nationally representative comparison values are available, but geometric mean and median concentrations for PFAS measured in dust collected in the small subset of participating households (n=12) 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, only PFOA was statistically correlated with the same PFAS measured in participants' blood. The final report on all EA sites will include a more robust comparison of PFAS measured in dust and blood.

## **Limitations**

There are several limitations associated with this assessment.

- The EA participant sample may not be representative of the community. All households in the study area were invited to participate, and 14% of the households participated in the EA. Participant characteristics were different than those of the area's overall population; specifically, participants were older. ATSDR addressed some of these differences by calculating geometric mean estimates that were adjusted to the age distribution of the community.
- Measurement of blood, urine, and environmental PFAS concentrations for EA participants may improve the understanding of exposure in this community but will not provide information about all sources of exposure. Additionally, identifying every potential confounding exposure is not possible.
- There are challenges in measurement of trace levels of PFBA in urine, including selectivity of the analytical instrumentation and potential for external contamination. Therefore, we advise caution when interpreting the PFBA results in urine.
- While multivariate regression models explained a moderate to large portion of the variability in participants' blood PFAS levels (R-squared or  $R^2$ , a measure of model goodness-of-fit, ranged between 0.43 and 0.56 in the "all adult" models), other factors not identified could still influence the relationships reported in this assessment (see "Statistical Analysis" section for details).
- The correlation between PFOS and PFHxS in blood of EA participants in Lubbock County was lower than observed at other sites with known AFFF contamination. Additionally, concentrations of PFOS in the blood of Lubbock County EA participants were statistically significantly lower than the national reference population from NHANES 2015-2016. These observations differ from other sites where concentrations of PFHxS and PFOS in participants' blood were more highly correlated and both PFHxS and PFOS were elevated relative to NHANES 2015-2016. The measured concentrations in blood do align with the maximum reported concentrations in pre-mitigation drinking water with PFHxS and PFOA present at higher concentrations than PFOS in private wells.
- A small number of households in the sampling frame refused testing for PFAS in private wells offered by the Air Force. Additionally, private well testing for PFAS has continued in phases with small numbers of additional wells identified with PFAS concentrations exceeding either EPA's HA or state guidelines for PFAS. Because of these factors, ATSDR is unable to definitively conclude that all drinking water exposures in the area have been mitigated; however, all known drinking

water exposures have been mitigated and the Air Force has continued to take action to mitigate exposures when new data become available.

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

## Recommendations

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

Although the exposure contribution from PFAS in private well water in Lubbock County has been mitigated in most private wells, there are actions community members and other stakeholders can take to further reduce exposures to PFAS and protect public health.

Households that receive bottled water and/or have water filtration systems installed by the Air Force should continue to use them.

1. What the Air Force can/should do:
  - a. With permission from homeowners, test private wells in the affected area that have not been previously tested.
  - b. Continue to provide whole-house water treatment system installation, monitoring, and maintenance. When the Air Force installs a system, continue to monitor it on a routine basis to ensure proper operation.
  - c. Continue to work on developing a cooperative agreement with the City of Lubbock to build water lines to affected homes within the city limits.
2. What community members can/should do:
  - a. The alternative drinking water provided by the Air Force (whether through whole-house filters or bottled water) currently meets all federal and state guidelines for PFAS. Households that receive bottled water and/or have water filtration systems installed by the Air Force should continue to use them. Residents should coordinate monitoring and maintenance of the water filtration systems with the Air Force. All treatment systems to remove PFAS from private well water in Lubbock County should be maintained appropriately to ensure that PFAS concentrations remain below EPA's HA and the TCEQ's PCLs for specific PFAS in drinking water.
  - 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. For more information contact: Air

Force Installation and Mission Support Center (AFIMSC) at [AFIMSC.PA.workflow@us.af.mil](mailto:AFIMSC.PA.workflow@us.af.mil) or call Paul Carrol, AFCEC Program Manager at (806) 885-5010.

- c. All private well owners should follow best public health practices for the testing, operation, and maintenance of their wells:  
<https://www.cdc.gov/healthywater/drinking/private/wells/index.html>
- d. Nursing mothers should continue breastfeeding. Based on current science, the known benefits of breastfeeding outweigh the potential risks for infants exposed to PFAS in breast milk.
- e. 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>
- f. Pay attention to advisories about food consumption, such as local fish advisories.
- g. 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.
- h. ATSDR does not recommend EA participants get retested for PFAS. At this time, ATSDR does not have plans to conduct additional blood testing for PFAS or recommend PFAS EA participants get individually retested for PFAS in blood. The biological half-lives of many of the PFAS measured in people's blood are long. PFHxS, in particular, has one of the longest half-lives—some estimates range in the decades. This means that PFAS blood levels are not expected to change significantly in the near term, even if exposure stops. Additionally, it is unclear what an individual's PFAS test results mean in terms of possible health effects.  
For the general population, blood tests for PFAS are most useful when they are part of a scientific investigation like the EA. Test results tell you how much of each PFAS is in your blood, but it is unclear what the results mean in terms of possible health effects. In addition, blood testing for PFAS is not a routine test offered by most doctors or health departments. 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>).
- 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 Lubbock County EA site, call 800-CDC-INFO or email [pfas@cdc.gov](mailto: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](mailto: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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