Westfield
Hampden County | Massachusetts

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

11/18/2021

Table of Contents

Tables

Figures

About ATSDR

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

Abbreviations

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

PFOS	perfluorooctane sulfonic acid
PFOSA	perfluorooctanesulfonamide
PFPeA	perfluoropentanoic acid
PFPeS	perfluoropentane sulfonic acid
PFTA	perfluorotetradecanoic acid
PFTrA	perfluorotridecanoic acid
PFUnA	perfluoroundecanoic acid
ppt	parts per trillion (same as 1 nanogram per liter)
Sb-PFOA	branched isomers of PFOA
Sm-PFOS	branched isomers of PFOS
UCMR 3	Third Unregulated Contaminant Monitoring Rule

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 blood for long periods. Most people in the United States have been exposed to PFAS. At least one PFAS was detected in more than 99% of NHANES samples collected for the 1999-2000 survey cycle.

The Centers for Disease Control and Prevention (CDC) and the Agency for Toxic Substances and Disease Registry (ATSDR) are conducting exposure assessments (EAs) in communities that were known to have PFAS in their drinking water and are near current or former military bases. This report shares results from the **City of Westfield in Hampden County, Massachusetts,** near Barnes Air National Guard Base (the Base). When all EAs are complete, ATSDR will prepare a report analyzing the results across all sites.

Possibly as early as the 1970s, the Base used aqueous film forming foam (AFFF) containing PFAS for its firefighter training. Over time, the PFAS from the AFFF entered the ground, moved into the groundwater to offsite locations, and affected nearby municipal wells. By January 2016, the Westfield authorities had removed from service the two water wells with the highest levels of PFAS contamination pending a new water treatment system. Based on the information ATSDR has reviewed, the public drinking water supply in Westfield currently meets the U.S. Environmental Protection Agency's (EPA) 2016 health advisory (HA) and state public health guidelines for PFAS in drinking water.[1] At this time, ATSDR does not recommend community members who get drinking water from the City of Westfield's public water system use alternative sources of water.

This EA assessed PFAS levels in the blood and urine of Westfield residents and compared them to PFAS levels in a nationally representative sample. EA participants were recruited from the part of Westfield that lies north of the Westfield River, where the highest PFAS contamination levels in tap water likely occurred. Tap water and indoor dust samples from a subset of households were also analyzed for PFAS. These EA results will help participants and their communities better understand their PFAS exposure, explain what they can do to protect themselves from exposures, and inform public health efforts related to protecting communities from sources of PFAS other than contaminated drinking water supplies.

[1] ATSDR compared PFAS levels in drinking water to public health guidelines in place at the time of data collection. The Massachusetts Department of Environmental Protection (MassDEP) published drinking water standards for PFAS in October 2020.

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

Exposure Assessment Activities

ATSDR invited a randomly selected sample of Westfield households to participate in this EA. To be eligible to participate, household residents must have (1) received their drinking water from the Westfield Water Department, (2) lived north of the Westfield River for at least 1 year before January 20, 2016, (3) been greater than three years old at the time of sample collection (these residents have the greatest likelihood of past exposures to PFAS via the city's drinking water supply), and (4) not be anemic or have a bleeding disorder that would prevent giving a blood sample. Results from randomly selected households allow ATSDR to estimate exposure for all community members, even those who were not tested.

In September 2019, 459 eligible people from 247 households participated in the EA sample collection event. ATSDR performed the following tasks:

- administered exposure history questionnaires to all participants
- collected blood and urine samples from most participants
- collected tap water and dust samples from the homes of 17 randomly selected participants
- tested 7 PFAS in blood, 14 in urine, 18 in water, and 33 in dust[2]
- measured PFHxS, PFOS, PFOA, PFNA, PFDA, and PFUnA across all media, and
- mailed individual biological and environmental results to participants in May 2020

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

The samples were collected and analyzed in strict accordance with ATSDR's *Exposure Assessment Protocol: Biological and Environmental Sampling of PFAS* (EA protocol) to ensure their quality. This EA was designed to estimate geometric mean concentrations of PFOS in blood for the sampling frame (area north of the Westfield River served by the City of Westfield's municipal water supply) population, with a precision goal of at least 15%. The precision is a measure of how wide the confidence interval is around the estimated geometric mean. ATSDR met this goal as precision for this EA ranged from approximately 8% to 14%, depending on the individual PFAS. ATSDR also calculated geometric means that were

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

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 were used to evaluate one variable at a time, mostly as a tool to examine the data broadly and find patterns that existed within the data. Multivariate statistics and regression modeling were used to account for multiple variables simultaneous to control for potential confounding factors.

Westfield Community-Wide Findings

Finding 1. Blood levels of PFHxS, PFOS, and PFOA in the Westfield community are higher than national levels.

Geometric means (i.e., averages) for PFHxS, PFOS, and PFOA blood levels were statistically higher ($p<0.05$) in Westfield participants when compared to CDC's NHANES (2015–2016) data, which was limited to people over 12 years old. The statistically higher blood PFAS levels were observed for both unadjusted geometric means for all EA participants and geometric means adjusted to the age distribution of the U.S. population 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 Westfield EA participants was 3.4 times higher than the national average. Blood PFHxS levels were above the national geometric mean for 92% of the Westfield EA participants and above the NHANES 95th percentile for 46%. The age-adjusted geometric mean blood PFOS and PFOA levels among Westfield EA participants were 1.1 times higher than the national level.

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

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

The three PFAS (PFHxS, PFOS, and PFOA) with statistically elevated blood levels compared to national geometric means were detected in Westfield's drinking water as early as 2013. It is likely that contamination began earlier, but no data are available before 2013. The maximum concentrations observed in active drinking water wells in Westfield were 170 parts per trillion (ppt) for PFHxS, 160 ppt for PFOS, and 43 ppt for PFOA in 2013. In 2016, Westfield reduced concentrations of PFAS below U.S. EPA health advisory levels (70 ppt for PFOA and PFOS combined). Before 2016, PFAS-containing AFFF were primarily formulated with PFOS, but also contained various PFAS precursors that could break down into other PFAS, such as PFHxS, which could explain the elevated blood PFHxS levels. PFHxS, PFOS, and PFOA have long biological half-lives (2.1 to 35 years). There were 3 years and 8 months between the reduction of exposure via contaminated drinking water and collection of biological samples during the EA. Because of the long half-lives of PFHxS, PFOS, and PFOA, past drinking water exposures may have contributed to the EA participants' blood levels.

PFHxS, PFOS, and PFOA were highly correlated in Westfield residents' blood (Pearson correlation coefficient, *r*, between 0.83 and 0.87). This means that typically, residents who had elevated blood

PFHxS levels also had elevated blood PFOS and blood PFOA levels. This correlation suggests a common exposure source, such as the Westfield public water supply, though other sources of exposure may also have contributed to the observed blood levels.

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

- First, in univariate models, a consistent and statistically significant predictor of participant blood levels for PFHxS, PFOS, and PFOA was how long the resident had lived in Westfield before January 2016. Those who lived in the area longest likely drank, in total, more contaminated water. This relationship remained significant in a multivariate model for PFHxS.
- Second, in multivariate models, PFHxS and PFOA blood levels in adults statistically increased with the amount of tap water those adults reported drinking.

Multivariate models conducted separately for males and females suggest that these relationships (between blood levels and residency duration/tap water consumption) were primarily observed in male participants.

Finding 3. Age, sex, breastfeeding, use of stain-resistant products, and blood donation were associated with some PFAS blood levels.

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

- Blood levels of PFHxS, PFOS, and PFOA were higher in older participants, and the size of the effect varied by sex. In males, blood levels for these compounds increased by 0.5% to 1.2% for every year of participant age. In females, blood levels for these compounds increased by 1.8% to 3.5% for every year of participant age.
- Males had higher blood levels of PFHxS, PFOS, and PFOA than females. The difference between males and females was larger in younger people. For example, 30-year-old males had higher blood PFHxS, PFOS, and PFOA levels than 30-year-old females by 107%, 109%, and 57%, respectively. For 50-year-old males, this difference was reduced to 31% for PFHxS, 58% for PFOS, and 19% for PFOA compared to 50-year-old females.
- Females who breastfed had lower blood levels of PFHxS, PFOS, and PFOA than females who did not, and this effect was larger in younger women. For example, 30-year-old females who breastfed had lower blood PFHxS, PFOS, and PFOA levels than 30-year-old females who had never breastfed by 59%, 36%, and 43%, respectively. For 50-year-old females who had breastfed, this difference was reduced to 39% for PFHxS, 19% for PFOS, and 21% for PFOA compared to 50-year-old females who had never breastfed.
- Only 49 participants reported ever using stain resistant products, and most of these reported their frequency of use as “rarely.” Participants who reported ever using stain-resistant products had 44% higher blood levels of PFHxS than those who never reported using these products. Because of the small sample size for people who ever used stain resistant products, these results should be interpreted with caution.

- Only 35 participants reported donating blood at least once or more a year. Participants who reported donating blood at least once or more a year had 34% lower blood levels of PFHxS and 24% lower blood levels of PFOS than participants who never reported donating blood. Because of the small sample size for people who reported donating blood once or more a year, these results should be interpreted with caution.

A few associations were observed in children (<18 years), though many variables could not be examined because of the small number of child participants (n=49). Because of the small sample size, results should be interpreted with caution. Specifically, blood levels of PFOA decreased with age, and children who were breastfed had higher blood levels of PFHxS and PFOA 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 aggregate report on all EA sites will include a more robust analysis of children.

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

ATSDR analyzed 47 (10%) of the urine samples collected. Only perfluorobutanoic acid (PFBA) was detected; it was detected in 59.6% of the 47 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 Westfield tap water samples collected during the EA in 2019 met the EPA's HA and Massachusetts Department of Environmental Protection's (MassDEP) public health guidelines for PFAS in drinking water.

This is based on 16 unfiltered and 8 filtered tap water samples collected in 17 households during the EA. These results are consistent with recent data collected by the City of Westfield.

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, PFOA and PFOS were measured at the highest concentrations. No nationally representative comparison values are available, but geometric mean and median concentrations for PFAS measured in dust collected in the small subset of participating households (n=17) were within the range of levels reported in a few published studies of other U.S. communities. None of the PFAS measured in this EA's household dust samples were statistically correlated with the same PFAS measured in participants' blood. The final aggregate report on all EA sites will likely include a more robust comparison of PFAS measured in dust and blood.

Limitations

There are several limitations associated with this assessment.

- The random sampling recruitment method used for this EA was designed to measure blood PFAS concentrations that were generalizable to all Westfield residents who lived north of the Westfield River and were connected to the municipal drinking water supply. However, the EA participant sample may not be fully representative of the community. Only 18% of the invited households from the random sample participated in the EA sample collection event, and participant characteristics were different than those of the area's overall population. Participants were older and less likely to be Hispanic or Latino. ATSDR addressed some of these

concerns by calculating geometric mean estimates that were adjusted to the age distribution of the community.

- Blood, urine, and environmental PFAS concentrations may improve the understanding of exposure in this community but will not provide discrete information about all sources of exposure. Additionally, identifying every source of exposure is not possible.
- Multivariate regression models did not explain a large portion of the variability in participants' blood PFAS levels (R-squared or R^2, a measure of model goodness-of-fit, ranged between 0.14 and 0.23, in the "all adult" models). This means that other factors not identified could influence the relationships reported in this assessment (see "Statistical Analysis" section for details).
- This study did not directly assess tap water consumption prior to the reduction of PFAS from the municipal water system.
- This EA was not designed to investigate health outcomes. Without additional information about exposure response relationships, the results of this EA cannot be used to assess current or past health problems or predict the future occurrence of disease.
- 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 has demonstrated that past exposures to PFAS in drinking water have impacted the levels of PFAS in people's bodies. These PFAS are eliminated from the body over a long period of time. This allowed ATSDR to measure PFAS even though exposures through drinking water were mitigated, or lowered, years ago.

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

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

1. What the City of Westfield can/should do:
    a. Operators of the municipal water system should continue to monitor concentrations of PFAS in drinking water delivered to the Westfield community to ensure concentrations of PFAS remain below the EPA's HA and MassDEP's guidelines for specific PFAS in drinking water. Results of PFAS monitoring should be shared with community members through appropriate communication channels (Consumer Confidence Reports, https://www.cityofwestfield.org/236/Water-Quality-Reports).
    b. All treatment systems to remove PFAS from the municipal drinking water in Westfield should be maintained appropriately to ensure PFAS concentrations remain below the EPA's HA and MassDEP's guidelines for specific PFAS in drinking water.
2. What community members can/should do:
    a. Become familiar with Consumer Confidence Reports (https://www.cityofwestfield.org/236/Water-Quality-Reports) for information on the City of Westfield's water quality.

b. Private well owners living in the area affected by PFAS should consider having their wells tested for PFAS if testing has not been conducted before. To learn more about testing wells for PFAS visit https://www.mass.gov/info-details/per-and-polyfluoroalkyl-substances-pfas-in-private-well-drinking-water-supplies-faq. To learn more about previous testing for PFAS in private wells in Westfield visit http://eeaonline.eea.state.ma.us/EEA/fileviewer/Rtn.aspx?rtn=1-0020093.

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

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

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

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

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

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

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.

For More Information

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

Background and Purpose

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

The PFAS exposure assessment in Westfield focused on a specific geographic area north of the Westfield River where the highest levels of PFAS in tap water likely occurred. For purposes of this report, we use the terms Westfield EA and Hampden County EA interchangeably to describe the exposure assessment conducted in this area. For more information and a map of the area see the "Methods" section of the report.

The EA involved collecting responses to exposure history questionnaires, biological samples (blood and urine), and environmental samples (tap water and household dust). ATSDR collected biological samples and administered questionnaires at the Westwood Building at 94 North Elm Street in Westfield between September 4 and September 17, 2019. During the same time frame, ATSDR also took water and dust samples in a subset of randomly chosen participant homes.

The results of the EA

- tell us the amount of PFAS in the blood of individual participants and the Westfield 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 Westfield community and how these levels compare to the general U.S. population,
- provide a better understanding of environmental factors that may 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. 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 e reason for this discrepancy is blood pressure or pre-eclampsia in pregnant women, and increased risk of kidney and testicular cancer. [ATSDR 2021; Buck et al. 2011; Gluge et al. 2020; Wang et al. 2017]

There are thousands of different PFAS. This assessment discusses some of the most commonly studied PFAS, which include perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), perfluorohexane sulfonic acid (PFHxS), perfluorononanoic acid (PFNA), perfluorodecanoic acid (PFDA), and perfluoroundecanoic acid (PFUnA). The manufacture and import of PFOA, precursor chemicals that can break down to PFOA, and related higher homologue chemicals, have been mostly phased out in the United States. However, existing stocks of PFOA might still be used and there might be PFOA in some imported articles. PFOS manufacture in the United States has not been reported to the EPA since 2002, however, there are some limited ongoing uses of PFOS. These PFAS with long perfluoroalkyl chains are no longer produced in the United States because of concerns over long biological half-lives. Other countries may still manufacture and use them, but U.S. manufacturers have replaced these compounds with shorter chained PFAS which typically have shorter biological half-lives. Some of the PFAS discussed in this report, such as N-methyl perfluorooctanesulfonamidoacetic acid (MeFOSAA), are considered precursors that can degrade in the environment or in people to other PFAS [ATSDR 2021; Gluge et al. 2020; Wang et al. 2017].

PFAS do not occur naturally but are widespread in the environment. PFAS can be released into the environment during their production, use, or disposal. PFAS have been found in air, water, soil, sediment, animal and plant life, and air. Most PFAS (including PFOA, PFOS, PFHxS, and PFNA) are either very resistant to breaking down or degrade into other PFAS that do not degrade further. Certain PFAS will therefore remain in the environment indefinitely. Most people in the United States have been exposed to PFAS. At least one PFAS was detected in more than 99% of NHANES samples collected for the 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 Westfield are not expected to be an important contributor to PFAS exposure relative to the contribution from drinking water. [Sunderland 2019]

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

- eating food packaged in materials containing PFAS (e.g., popcorn bags, fast food containers, pizza boxes)
- eating fish or shellfish caught in PFAS-contaminated waters
- using consumer products such as stain-resistant carpeting and water-repellent clothing
- eating garden vegetables grown with PFAS-contaminated water or in PFAS-contaminated 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 activities 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 has been linked to harmful health effects. While this EA does not examine specific health outcomes associated with PFAS exposure, EA findings might help inform future studies on how PFAS exposure affects human health.

Why Westfield?

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

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

The date when PFAS first entered Westfield's public water system is not known. These substances were first detected in the city's water in 2013, through testing conducted for the U.S. Environmental Protection Agency's (EPA's) Third Unregulated Contaminant Monitoring Rule (UCMR 3) [EPA 2017]. The rule required testing for six PFAS. At that time, drinking water provided by the Westfield Water Department came from eight groundwater wells, two surface water reservoirs, and a connection with the City of Springfield. UCMR 3 testing indicated two of Westfield's four drinking water wells north of the Westfield River (Wells #7 and #8) were contaminated with PFAS. Wells #7 and #8 were constructed in 1978, but the date when they were first contaminated with PFAS is unknown. The highest sampling result from an active well was 203 parts per trillion (ppt) for the sum of PFOA (43 ppt) and PFOS (160 ppt) in Well #7. PFHxS was also detected in this well at a concentration of 170 ppt. PFAS were not detected in the city's other drinking water sources including the wells located south of the river and the surface water reservoirs.

The levels measured during UCMR 3 were not above EPA's provisional health advisory, which at the time was 400 ppt for PFOA and 200 ppt for PFOS. However, when EPA issued a lifetime health advisory for the sum of PFOA and PFOS levels in drinking water (70 ppt) in 2016, the 2013 contamination levels were

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

above this health advisory. To reduce concentrations of PFOA and PFOS in drinking water, the Westfield Water Department removed the two contaminated wells (#7 and #8) from service. One (#7) was taken offline in December 2015, and the second (#8) was taken offline in January 2016. The information ATSDR obtained from City of Westfield indicates that PFOA and PFOS concentrations in drinking water were below 70 ppt by January 20, 2016.

In addition to UCMR 3 testing, the Westfield Water Department conducted additional testing in the summer of 2016, which showed PFAS detections in the two other wells north of the Westfield River (#1 and #2). PFOA+PFOS were detected at 54 ppt in Well #1 and 82 ppt in Well #2. Based on these preliminary results, the Westfield Water Department issued a health advisory to its customers on September 16, 2016. However, confirmatory sampling of these two wells on September 19, 2016, showed considerably lower levels of PFAS contamination. At Well #1, PFOA, PFOS, and PFHxS were measured at concentrations of 8.3 ppt, 25 ppt, and 45 ppt, respectively; at Well #2, PFOA, PFOS, and PFHxS concentrations were 3.2 ppt, 6.8 ppt, and 17 ppt, respectively. Based on these results, the Westfield Water Department issued a health advisory to its customers on March 31, 2017, indicating that the final sampling results for Wells #1 and #2 were below the EPA health advisory and therefore not a health concern. In 2017, the Westfield Water Department found that Well #2 exceeded the Massachusetts Department of Environmental Protection's (MassDEP) proposed action level at that time of 70 ppt for total PFOA, PFOS, PFNA, PFHxS, and PFHpA [MassDEP 2018].[4] Well #2 was taken offline until a temporary treatment system was installed. The Westfield Water Department conducted multiple additional rounds of testing of Wells #1 and #2 between 2017 and 2019 across these sampling events. The highest PFOA+PFOS concentration was 33.3 ppt (i.e., the result of the Well #1 sample from September 19, 2016).

The Westfield Water Department installed a temporary treatment system on the contaminated wells that remains active. This system ensures that PFAS levels in the treated water are below detection limits. The Westfield Water Department is in the process of installing permanent treatment on its four affected wells. The Westfield Water Department continues to test its water sources and pursue system improvements to address PFAS contamination.

The information available to ATSDR indicates that in 2019, the city's drinking water met the EPA's HA and MassDEP public health guidelines for PFAS in drinking water.

Methods

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

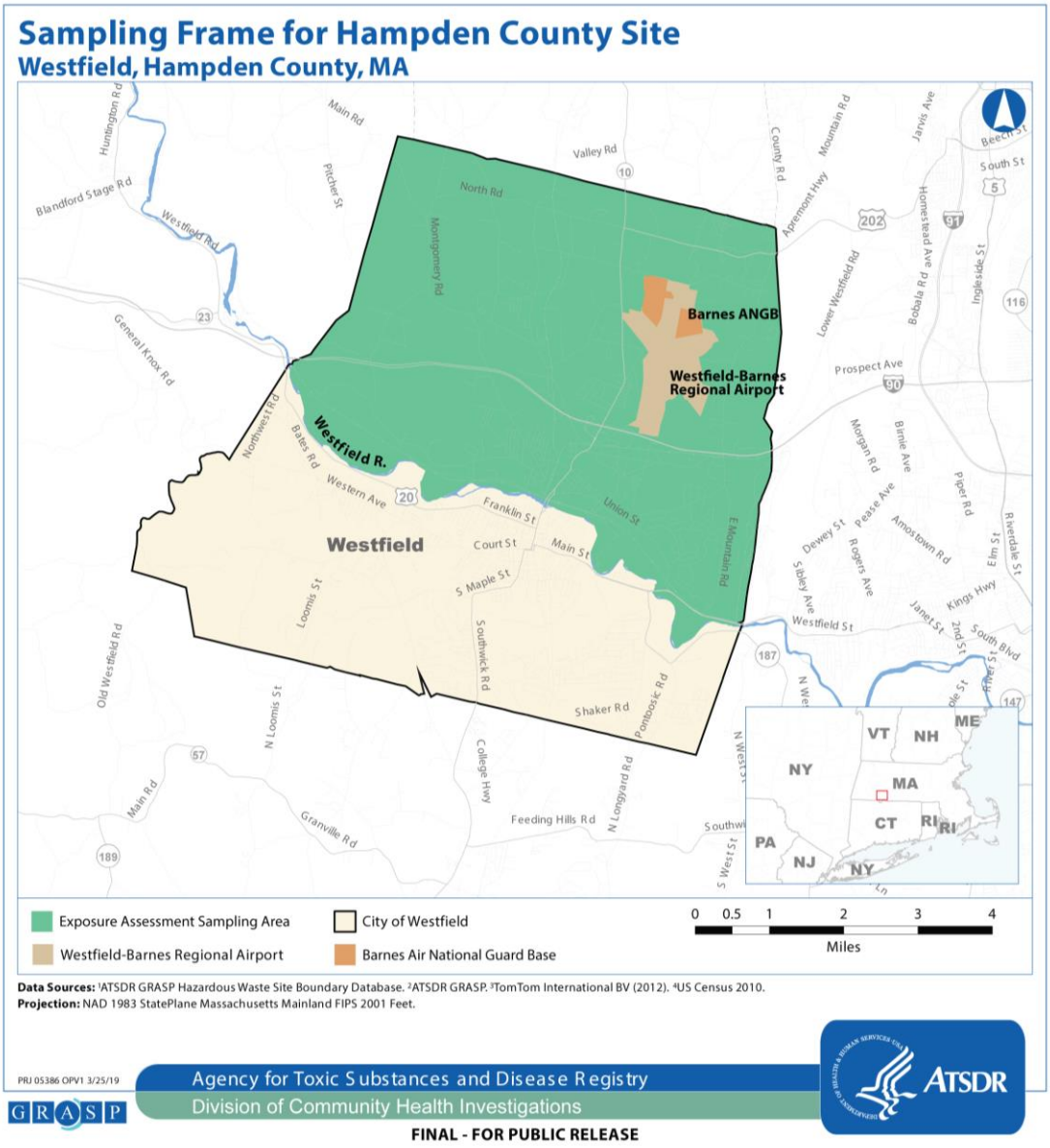
Sampling Frame

This EA focused on a specific geographic area, called the sampling frame or sampling area. The sampling frame for this EA was the part of Westfield that lies north of the Westfield River, where the highest PFAS contamination levels in tap water likely occurred (see Figure 1). Based on a review of Westfield land

[4]ATSDR compared PFAS levels in drinking water to public health guidelines in place at the time of data collection. Subsequent to data collection, in October 2020, the MassDEP published public drinking water standards for PFAS of 20 ppt for total PFOA, PFOS,PFNA, PFHxS, PFHpA, and PFDA ("PFAS6").

parcel data, ATSDR determined that 4,776 households in the sampling frame were connected to the city's water supply. These households formed the sampling frame from which households were randomly selected for recruitment. Households with private wells were not eligible for participation. Private well owners living in the area affected by PFAS should consider having their wells tested for PFAS if testing has not been conducted before. To learn more about testing wells for PFAS visit https://www.mass.gov/info-details/per-and-polyfluoroalkyl-substances-pfas-in-private-well-drinking-water-supplies-faq. To learn more about previous testing for PFAS in private wells in Westfield visit http://eeaonline.eea.state.ma.us/EEA/fileviewer/Rtn.aspx?rtn=1-0020093.

Figure 1. Sampling frame for Hampden County Exposure Assessment



Participant Eligibility

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

- Lived within the sampling frame (served by Westfield Water Department and north of the Westfield River) for at least one year before January 20, 2016, which is when the Westfield Water Department reduced PFAS drinking water concentrations below EPA's health advisory.
- Were at least 3 years old at the time of recruitment. This age criterion was used because national reference values are not available for children under the age of three.
- Did not have bleeding disorders and were not anemic, unless they confirmed with their doctor the ability to safely provide a blood sample.

People potentially exposed to PFAS occupationally, such as firefighters, active-duty military, and veterans, were able to participate if their households were randomly selected. Participants did not receive reimbursements or incentives and paid no costs to participate.

Participant Recruitment

ATSDR randomly selected 1,349 households in the sampling frame for recruitment. This number was chosen to achieve the protocol recruitment target of 395 participants. Every household had an equal chance of being selected, and all members of randomly selected households who met eligibility criteria were invited to participate. This type of recruitment, called a one-stage cluster sampling design, means that a single household may have multiple participants.

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

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

Results from the randomly selected participants can provide information about community-level exposure. Had ATSDR accepted volunteers, results could not be used to estimate exposure across the Westfield sampling frame. After two waves of recruitment (initially reaching out to 349 households and later reaching out to an additional 1,000 households), 514 residents from 260 households scheduled appointments for biological sampling and completing a questionnaire.

ATSDR attempted to recruit approximately 10% of participating households for environmental sampling (i.e., 22 households from which at least one person had scheduled an appointment at the time environmental recruitment calls were made). ATSDR invited 40 households in two waves of recruitment. In total, ATSDR scheduled 19 environmental sampling appointments.

Data Collection and Analysis

The Hampden County exposure assessment 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 Westwood

Building at 94 North Elm Street in Westfield between September 4 and September 17, 2019. During the same time frame, ATSDR also collected environmental samples in a subset of randomly chosen participant homes. All data met the stringent quality control requirements for sample collection and analysis and are therefore of high quality.

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

ATSDR project staff handled all data collected in strict accordance with the *Standard Operating Procedures of PFAS Exposure Assessment Data Management* [ATSDR 2019b]. These procedures have very strict requirements for handling any personally identifiable information. ATSDR project staff protected this information to the extent required by federal and Massachusetts law. All signed consent forms were mailed to ATSDR headquarters and are securely archived there. 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 514 residents who scheduled data collection appointments, 472 (92%) participated in the exposure assessment. ATSDR administered exposure history questionnaires to these 472 individuals: 415 for adults 18 and older, and 57 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.

Phlebotomists collected blood samples from 461 participants. The phlebotomists were not able to collect samples from 11 participants because they lacked viable veins or refused to provide a blood sample. ATSDR processed the blood samples in the field, aliquoting the serum portion of the blood.

After the sampling was complete and upon further review of each participant's residential history, ATSDR determined that two participants had not lived in the sampling frame for at least one full year before January 20, 2016, and therefore were not eligible for the study. Questionnaire and biological data for these participants were excluded from the data evaluation, but ATSDR sent them their individual results. This means a total of 459 blood samples (410 adults and 49 children) were considered in the community exposure summary. These samples were collected from participants residing in 247 unique households. This represents a household participation rate of 18% (i.e., 18% of the 1,349 recruited households had at least one person participate in the EA).

Urine samples were collected from 471 participants (415 adults and 56 children; one child could not provide a urine sample). Per the EA protocol, 10% of the urine samples were randomly selected for

initial analysis. These 47 samples were collected from participants (46 adults and 1 child) who resided in 44 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 17 of the 19 households that had initially scheduled appointments. One household did not keep its environmental sampling appointment, and another household was not located in the sampling frame. Results from participants at this location were not included in the community summary as they did not meet eligibility criteria to participate in the exposure assessment. 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 prior to the scheduled visit. Adapting methods described in Scher et al. [2018], ATSDR collected dust samples using a high-volume air sampler connected to an open-faced 37 millimeter filter cassette with an 0.8 micron filter. A wooden 2 square foot (ft^2) sampling template was used to mark off each sampling area. ATSDR project staff attempted to collect at least 1 gram of dust in the open-faced cassettes from each home by vacuuming the same 2 ft^2 surface at least four times with the cassette (vertically, horizontally, and in circles). Samples were taken preferentially from mats, carpets, and area rugs. Household dust samples were analyzed in accordance with SGS AXYS Method MLA-110 (revision 01, version 06), *Analytical Procedure for the Analysis of Per- and Polyfluoroalkyl Substances (PFAS) in Aqueous Samples, Solids and Solvent Extracts by LC-MS/MS* [SGS AXYS 2019].

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

Table 1. Summary of recruitment and data collection efforts

Recruitment	
Households invited to participate by mail	1,349
Wave 1 of recruitment	*349*
Wave 2 of recruitment	*1,000*
Households reached by mail	1,276
Households reached by phone	631
Household in-person recruitment	991
Biological sampling:	
Individuals enrolled	514
Households enrolled	260
Environmental sampling:	
Wave 1 households invited	*25*
Wave 2 households invited	*15*
Households enrolled	19
Data Collection	
Completed questionnaires	472
Adults	*415*
Children	*57*
Blood samples	
Collected and analyzed (248 households)	461
Adults	*412*
Children	*49*
Included in community statistics (247 households)	459
Adults	*410*
Children	*49*
Urine samples	
Collected	471
Adults	*415*
Children	*56*
Included in community statistics (44 households)	47
Adults	*46*
Children	*1*
Dust samples collected and analyzed (one composite sample per household)	17
Tap water samples collected and analyzed (17 households)	
Filtered	8
Unfiltered	16

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

PFAS Abbreviation	PFAS 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				✓
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 averages, 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 in NHANES.

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

Statistical Terms

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

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

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

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

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

One of the objectives of this EA was to estimate community-level exposures. While random recruitment at the household level helps allow for such an estimation, ATSDR evaluated demographic differences between the Westfield 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. To explore sex-specific associations (e.g., women having biological children [yes/no], having breastfed children [yes/no], duration of breastfeeding), ATSDR also evaluated multivariate models for males and females only.

ATSDR did not conduct detailed statistical analyses for urine data because of low frequencies of detection. ATSDR analyzed a subset of urine samples and found that, for all PFAS, the frequency of detection was < 60%. The protocol specified that all urine samples would be analyzed if the geometric mean calculated for any site exceeded the 95th percentile from NHANES. The protocol specified that geometric means would be calculated if >=60% of samples had detections, and the rest of the samples would be analyzed if the calculated geometric mean exceeded the NHANES 95th percentile. Since no PFAS were detected in 60% or more of the analyzed samples, no geometric means were calculated for any PFAS in urine and ATSDR did not analyze the remainder of the urine samples. ATSDR did calculate the 95th percentile concentration for PFBA, the only 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) and the MassDEP public drinking water standard for PFAS (20 ppt for the sum of PFHpA, PFHxS, PFNA, PFOA, PFOS, and PFDA) [MassDEP 2020]. For dust, ATSDR calculated summary statistics and compared results to those in selected peer-reviewed

literature. ATSDR also evaluated correlations between PFAS levels measured in household dust and blood collected from participants residing in homes where dust samples were collected.

To account for the one-stage cluster design, ATSDR conducted all statistical analyses in SAS (release 9.4, SAS Institute, Cary, NC) using complex survey procedures (e.g., SURVEYMEANS, SURVEYREG). To do this, ATSDR assigned household IDs to all participants and calculated summary statistics while accounting for clustering at the household level. For blood results across all EA participants, intra-cluster correlation coefficients ranged from 0.19 to 0.48, suggesting weak to moderate correlation of PFAS blood levels within a household. Appendix B provides more information on clustering, as well as further details on the statistical methods used for this EA and how results from this EA compared to the assumptions used to estimate the target sample size of 395 participants.

Results

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

Most analyses in this section reflect the entire Westfield 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 Westfield EA Participants

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

Table 3. Characteristics of Westfield EA participants

Characteristics	Count of EA Participants (n)*	Percent of EA Participants (%)**
Adults and children combined		
Age (years)	(mean = 49.7)	
<18	49	11
18 to 50	147	32
50+	262	57
Sex		
Male	213	47
Female	245	54
Race and ethnicity†		
White, non-Hispanic	405	90
Non-white or Hispanic	44	10
Adults only		
Years lived at current address	(mean = 19.9)	
<10	112	27
10 to <20	132	32
20 to <30	70	17
30+	96	23
Current primary drinking water source		
Public water system	302	74
Bottled water	103	25
Average tap water consumption while living at current home (8-ounce cups per day)	(mean = 5.3)	
0	58	14
>0 to <2	23	5.6
2 to <4	81	20
4 to <6	86	21
6 to <8	57	14
8+	105	26
Current use of treatment or filtration device		
One or more filter/treatment device(s)	236	58
None	172	42
Occupational exposures to PFAS in the past 20 years		
One or more occupational exposure(s)	30	7.9
None	348	92

* 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.

** 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.

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

The average age of EA participants was 49.7 years, and 90.2% of the participants identified themselves as White non-Hispanic. Of EA participants, 53.5% identified as female, 46.5% identified as male, and 89.3% 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, 72.7% reported living in their current homes for more than 10 years.
Adults were also asked about their current primary source of drinking water: 73.8% said Westfield's public water system, and 25.2% said bottled water. Adults reported drinking an average of 5.3 8-ounce cups of water a day at home, and 57.8% 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; 7.9% reported holding one or more jobs with potential PFAS exposures (e.g., firefighting, military, aviation).

Comparison of Westfield 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., Westfield households north of the Westfield River). The random sampling recruitment method used for this EA helps ensure the absence of selection bias—that is, everyone in the sampling frame had an equal chance of being chosen to participate. However, ATSDR also explored the potential for participation bias—that is, substantive differences between those who chose to participate and those who did not.

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

- **Age distribution.** The EA participants included a higher proportion of older adults (age 50+ years) and a lower proportion of younger adults (18–50 years) and children (<18 years) than the sampling frame population (Table 4). Specifically, 57% of the EA participants reported being 50 or older, but 34% 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, 11% of the EA participants reported being under 18, but 25% of the sampling frame population falls in that age range.
- **Race/ethnicity.** Among the race/ethnicity characteristics, only the percent of residents who identify as Hispanic or Latino showed a significant difference between the EA participants and the sampling frame population (Table 4). Specifically, the EA population had statistically fewer Hispanic or Latino participants (3.9%) than the sampling frame population (7.0%). 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 More than one race were compared because of the small number of respondents in other categories.

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

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

Demographics	Number of Participants (n)*	Percent of Participants (%)	Sampling Frame Distribution (%)†	p-Value‡
Age group (years)				
<18	49	11	25	<0.001
18 to 50	147	32	41	<0.001
50+	262	57	34	<0.001
Race				
White	424	92	93	0.55
Black or African American	<10	—	1.5	—
Am. Indian and AK Native	<10	—	0.1	—
Asian	<10	—	0.8	—
Nat. Hawaiian/Pacific Islander	<10	—	0.04	—
More than one race	11	2.4	1.8	0.42
Ethnicity				
Hispanic or Latino (of any race)	18	3.9	7.0	0.002

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

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

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

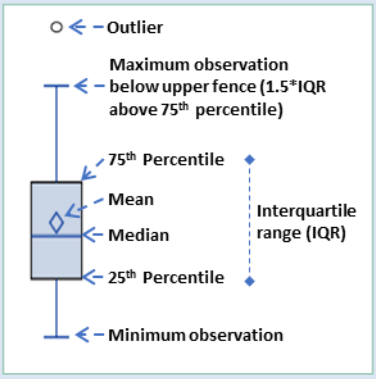
PFAS in Blood

This section summarizes PFAS levels that ATSDR measured from the 459 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 Westfield EA participants' blood for all ages. Five of the seven PFAS—PFHxS, PFOS, PFOA, PFNA, and PFDA—were detected in more than 85% of the blood samples. ATSDR's statistical analyses throughout this section focus on these five chemicals, and Figure 2 shows the distributions of the individual measurements on a $\log_{10}$ scale. The $\log_{10}$ scale allows for more easily visualizing the wide range of serum concentrations as it uses equal spacing for each factor of 10 increase. The PFAS found at highest levels were PFOS (geometric mean = 5.87 micrograms per liter (µg/L)), PFHxS (4.67 µg/L), and PFOA (1.91 µg/L).

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



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

The precision of geometric mean estimates for this EA ranged from approximately 8% to 14%, depending on the PFAS (Appendix B, Table B2). These values are all below the desired precision of 15% used to determine the target sample size for this EA, indicating that the collected data met the precision target specified in the EA protocol.

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

PFAS	FOD (%)	Max	Geometric Mean	95% CI for Geometric Mean	Percentiles				
					25th	50th (Median)	75th	90th	95th
PFHxS	99.6	48.5	4.67	4.13–5.28	2.20	4.53	9.76	19.4	24.9
PFOS	NA*	35.0	5.87	5.40–6.38	3.60	5.88	9.90	15.5	18.6
PFOA	NA*	15.9	1.91	1.79–2.04	1.27	1.86	2.72	4.01	4.88
PFNA	98.0	4.7	0.430	0.403–0.459	0.246	0.389	0.610	0.823	1.08
PFDA	85.8	2.0	0.152	0.143–0.161	NA†	0.105	0.179	0.269	0.347
PFUnA	58.2	0.7	NA‡	NA‡	NA†	NA†	0.159	0.265	0.348
MeFOSAA	54.5	1.6	NA‡	NA‡	NA†	NA†	0.143	0.363	0.556

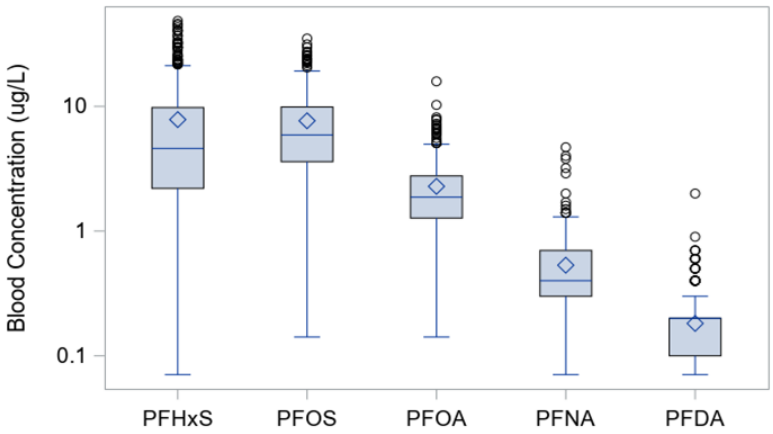
FOD = frequency of detection, CI = confidence interval, NA = not applicable

* PFOA and PFOS are calculated sums of branched and linear subsets and are not measured directly. Linear PFOA was detected in 99.8% of samples with a geometric mean of 1.82 micrograms per liter (µg/L); branched PFOA was detected in 0.7% of samples. Linear PFOS was detected in 99.8% of samples with a geometric mean of 3.93 µg/L; branched PFOS was also detected in 99.8% of samples, but with a geometric mean of 1.86 µg/L.

† Percentile is below the LOD.

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

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



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

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

Since the demographic profile comparison reported above showed that EA participants were significantly older than the sampling frame as a whole, ATSDR also calculated geometric means that were age-adjusted to the sampling frame population based on 2010 Census data for comparison.[5] Age-adjusted geometric means correct for the participation bias discussed earlier and may be more generalizable to the sampling frame community. Table 6 shows that in general, age-adjusted blood PFAS geometric means are lower than unadjusted values. The greatest difference is observed for PFHxS and PFOS, where age-adjusted geometric means are 20% and 18% lower than unadjusted values, respectively. The lower values for age-adjusted geometric means reported here are consistent with older adults having higher blood PFAS levels than younger adults. The effect of age and the implications of these age-adjusted statistics are further discussed throughout this report.

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

	Unadjusted		Age-Adjusted to Sampling Frame	
PFAS	Geometric Mean	95% CI for Geometric Mean	Geometric Mean	95% CI for Geometric Mean
PFHxS	4.67	4.13–5.28	3.84	3.45–4.28
PFOS	5.87	5.40–6.38	4.84	4.48–5.23
PFOA	1.91	1.79–2.04	1.77	1.66–1.88
PFNA	0.430	0.403–0.459	0.411	0.380–0.445
PFDA	0.152	0.143–0.161	0.145	0.136–0.154
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 Westfield EA participants to levels found in the U.S. general population. To explore effects related to differences in the age distribution of EA participants vs. the NHANES populations, ATSDR compares both unadjusted geometric means of all EA participants and geometric means adjusted to the age distribution of the U.S. population in NHANES 2015–2016.

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

Of the PFAS analyzed in blood, PFHxS levels had the largest elevations when compared to national levels. The unadjusted geometric mean blood PFHxS level among Westfield EA participants was 4.0

[5] One participant did not report their age and was therefore excluded from this analysis.

times higher than the national level. Blood PFHxS levels were above the national geometric mean for 92% of the Westfield EA participants and above the NHANES 95th percentile for 46% (Table 7). The unadjusted geometric mean blood PFOS and PFOA levels among Westfield EA participants was 1.2 times higher than the national level. Blood PFOS levels were above the national geometric mean for 61% of the EA participants and above the NHANES 95th percentile for 5%. Blood PFOA levels were above the national geometric mean for 67% of Westfield EA participants and above the NHANES 95th percentile for 9%.

On average, total PFOS measurements were composed of 67% linear PFOS (n-PFOS) and 32% branched PFOS (Sm-PFOS). The proportion of n-PFOS found in EA participants' blood is lower than that found in standard PFOS products (76%–79%) [Kärrman et al. 2007] but comparable to levels found in the blood of the general U.S. population [CDC 2019]. Measurements of total PFOA were composed of 95% linear PFOA (n-PFOA) and 5% branched PFOA (Sb-PFOA), which is also comparable to the proportions found in the U.S. population [CDC 2019]. All remaining statistical analyses in this report focus on total PFOA and PFOS rather than treating 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 over 12 years of age, these geometric mean calculations are based on 436 EA participants. Table 7 and Figure 3 show that blood PFAS geometric means adjusted to the NHANES population profile are lower than unadjusted values. The adjusted geometric mean blood PFHxS levels among Westfield EA participants was 3.4 times the national level. The age-adjusted geometric mean blood PFOS and PFOA levels among Westfield EA participants was 1.1 times higher than the national levels. Even when controlling for the age-distribution in the population, EA participants had statistically higher blood levels of PFHxS, PFOS, and PFOA than the U.S. population.

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

PFAS	NHANES GM (CI)*	Westfield GM (CI)†: Unadjusted	Westfield GM (CI)†: Age-Adjusted to NHANES 2015-2016	Percent of Westfield Results over NHANES GM (%)	NHANES 95th Percentile*	Westfield 95th Percentile	Percent of Westfield Results over NHANES 95th Percentile (%)
PFHxS	1.18 (1.08–1.30)	4.67 (4.13–5.28) *p<0.001*	4.02 (3.58–4.52) *p<0.001*	91.7	4.90	24.9	46.0
PFOS	4.72 (4.40–5.07)	5.87 (5.40–6.38) *p<0.001*	5.29 (4.89–5.73) *p=0.028*	61.2	18.3	18.6	5.45
PFOA	1.56 (1.47–1.66)	1.91 (1.79–2.04) *p<0.001*	1.77 (1.66–1.89) *p=0.005*	66.9	4.17	4.88	9.37
PFNA	0.577 (0.535–0.623)	0.430 (0.403–0.459) *p<0.001*	0.418 (0.390–0.447) *p<0.001*	36.3	1.90	1.08	1.31
PFDA	0.154 (0.140–0.169)	0.152 (0.143–0.161) *p=0.777*	0.148 (0.139–0.158) *p=0.501*	51.9	0.700	0.347	0.44
PFUnA	NA‡	NA‡	NA‡	NA	0.400	0.348	2.61
MeFOSAA	NA‡	NA‡	NA‡	NA	0.600	0.556	4.14

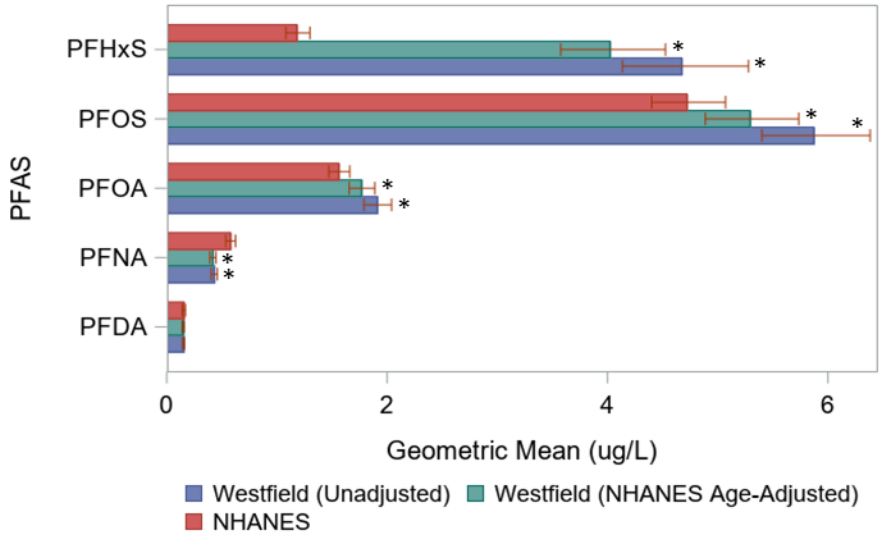
CI = 95% confidence interval, NA = not applicable

* Source: CDC 2019

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

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

Figure 3. EA PFAS blood levels compared to national averages



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

Correlations Among PFAS in Blood

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

PFHxS, PFOS, and PFOA blood levels showed the strongest correlations (Table 8). All pairings of these chemicals had Pearson correlation coefficients close to 1 (*r* = 0.83–0.87). On the other hand, PFNA and PFDA had weaker correlations with each other and the other PFAS (*r* = 0.24–0.57).

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

	PFHxS	PFOS	PFOA	PFNA	PFDA
PFHxS	1.00	0.87	0.83	0.39	0.24
PFOS	0.87	1.00	0.83	0.53	0.33
PFOA	0.83	0.83	1.00	0.54	0.33
PFNA	0.39	0.53	0.54	1.00	0.57
PFDA	0.24	0.33	0.33	0.57	1.00

* p<0.001 for all correlations.

PFAS Blood Levels by Demographics and Other Exposure Characteristics

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

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

- age,
- sex,
- race/ethnicity,
- tap water consumption,
- length of residence in the sampling frame,
- blood donation,
- use of stain-resistant products, and
- breastfeeding (adult females and children only).

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

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

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

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

Parameter	PFHxS			PFOS			PFOA		
	All Adult	Adult Female	Adult Male	All Adult	Adult Female	Adult Male	All Adult	Adult Female	Adult Male
Age (continuous)	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sex (categorical)	✓	NA	NA	✓	NA	NA	✓	NA	NA
Age × sex (continuous)*	✓	NA	NA	✓	NA	NA	✓	NA	NA
Years in sampling frame in the past 20 years [Residency duration] (continuous)	✓	—	✓	—	—	—	—	—	—
Blood donation frequency (categorical)	✓	✓	—	✓	✓	—	—	—	—
Stain-resistant product use (categorical)	✓	✓	—	—	—	—	—	—	—
Tap water consumption at home in cups per day (continuous)	✓	—	✓	—	—	—	✓	—	✓
Breastfeeding (categorical)	NA	✓	NA	NA	✓	NA	NA	✓	NA
Age × breastfeeding (continuous)	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. While blood levels of PFNA and PFDA were not found to be statistically higher than the national geometric means, both PFAS were detected at a high enough frequency to present meaningful results. Summary statistics are therefore provided in Appendix C for completeness, but not discussed below.
- Tables C3 and C4 present univariate modeling results for all questions in the adult and child questionnaire for the

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.

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 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 0.07 to 0.34. 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=49).
- Figures C1–C39 present boxplots for unadjusted blood levels by each demographic and exposure characteristic included in the statistical analyses.

Goodness of Fit Measure

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

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

Blood PFAS Levels and Age

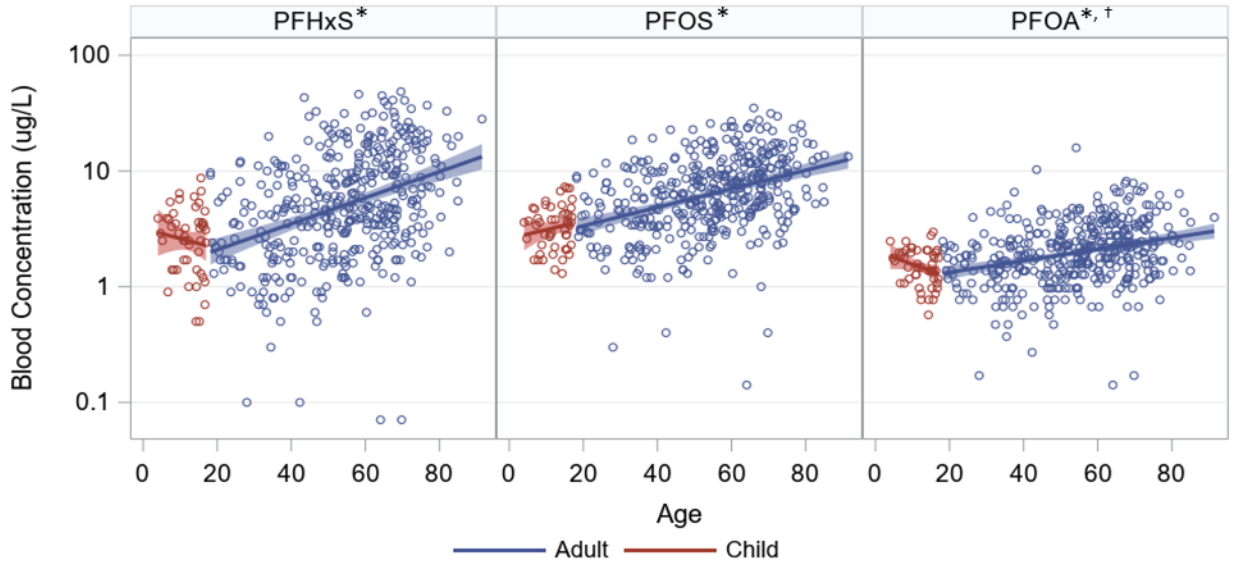
Because many studies have found that older people have higher blood PFAS levels, ATSDR investigated how Westfield EA participants' ages related to their blood levels. As Figure 4 illustrates, the blood levels for PFHxS, PFOS, and PFOA increased with age in adults, but trends were inconsistent in children. For adults, ATSDR's univariate analysis showed that blood PFHxS, PFOS, and PFOA were higher in older individuals than in younger individuals, and this finding was statistically significant. As Figure 4 shows, PFHxS had the strongest age dependence. The univariate analysis indicates that on average, blood PFHxS levels in Westfield EA participants increased 2.6% for every year of participant age in adults. This suggests a 30% increase in blood PFHxS levels for every 10 years of participant age in adults. The calculated increases for PFOS (1.9% per year of participant age) and PFOA (1.2% per year of participant age) were lower.

ATSDR's multivariate analysis provided further perspective on this trend, showing that the age dependence was generally stronger for women than men among adults. For example, the all-adult model (Appendix C, Table C5) suggests a 3.5% increase in blood PFHxS levels in adult females for every year of participant age and a 1.1% increase in blood PFHxS levels in adult males for every year of participant age when controlling for other characteristics; this finding was statistically significant. Similar results were observed in the stratified male-only and female-only models. Age remained a significant predictor of blood levels for all three PFAS in all multivariate models.

As Figure 4 shows, blood PFHxS and PFOA levels were higher in younger children for participants under 18. In univariate analyses, this trend was statistically significant only for PFOA, for which every one-year increase in age under 18 was associated with a 2.6% decrease in blood PFOA levels. Age was not

statistically associated with PFHxS or blood PFOS levels in children. Note that multivariate models were not explored for children because of the relatively small sample size.

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



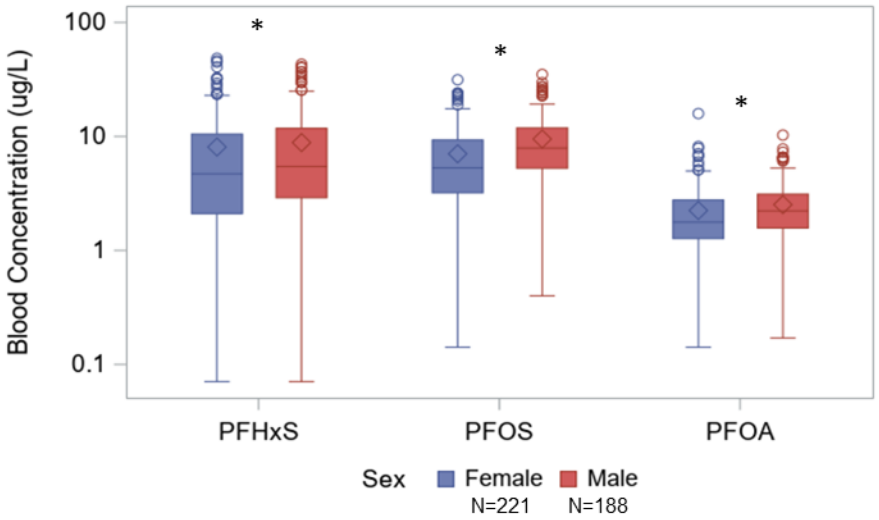
A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically Significant Trend (p<0.05) in Adults*
†Statistically Significant Trend (p<0.05) in Children

Blood PFAS Levels by Sex

ATSDR investigated how blood PFAS levels vary between males and females because previous research has shown that, all other factors considered equal, adult males tend to have higher blood PFAS levels than adult females. ATSDR's univariate and multivariate analyses both showed that PFAS levels were higher in adult males than in adult females for PFHxS, PFOS, and PFOA. Modeled blood levels in adult males were 19% higher for PFHxS, 43% higher for PFOS, and 18% higher for PFOA in univariate models (Figure 5).

The all-adult multivariate models showed that the difference between males and females was larger in younger people. For example, 30-year-old males had higher modeled blood PFHxS, PFOS, and PFOA levels than 30-year-old females by 107%, 109%, and 57%, respectively. For 50-year-old males, this difference was reduced to 31% for PFHxS, 58% for PFOS, and 19% for PFOA compared to 50-year-old females. Blood levels of these three PFAS were not statistically associated with sex in children.

Figure 5. PFAS blood levels in adults by sex (log scale)



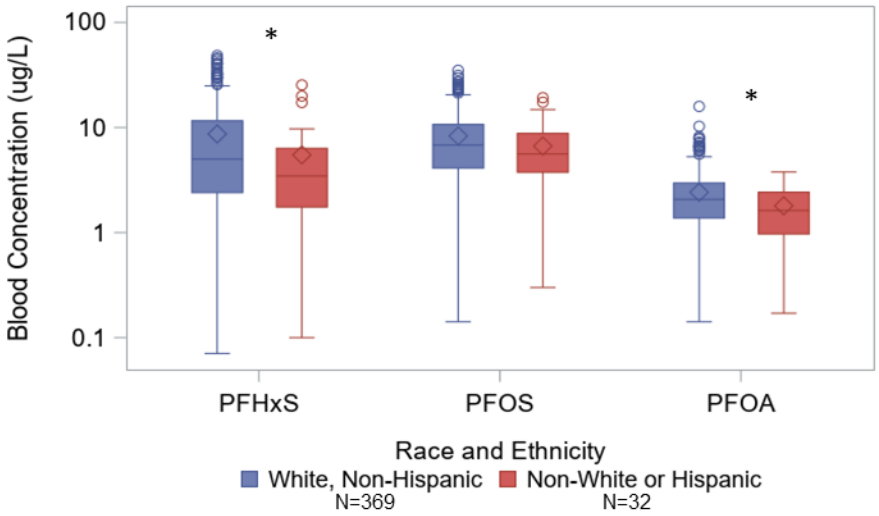
See 'How to read a box and whisker plot' earlier in the PFAS in Blood section.
A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically Significant Difference (p<0.05)*

Blood PFAS Levels by Race/Ethnicity

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

Figure 6 shows that on average, when compared to those who identified as White, non-Hispanic, blood levels in Non-white, or Hispanic participants were 34.8% lower for PFHxS, 20.3% lower for PFOS, and 23.2% lower for PFOA in univariate models. Race and ethnicity did not remain as significant predictors of these PFAS in multivariate analyses. This may result from age being correlated with race and ethnicity in the U.S. population (White, non-Hispanic populations tend to be older than Non-white, or Hispanic populations). Also, in the wider U.S. population, levels of PFAS in Hispanics tended to be lower than in other race and ethnicity groups.

Figure 6. PFAS blood levels in adults by race and ethnicity (log scale)



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

Blood PFAS Levels and Tap Water Consumption

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

For adults, ATSDR first considered participants' primary drinking water source. Adult participants were asked, "What is your current main source of drinking water in your home?" Nearly all of the responses were tap water (74%) or bottled water (25%). There were no statistically significant differences in blood levels between these two groups in univariate or multivariate analyses. The lack of significant differences was an unexpected result, which ATSDR believes may be a result of how the question was worded—particularly the word "current." ATSDR also asked participants about any changes to their drinking water habits in the past year; 18% reported switching from public water to bottled water in the past year. However, since drinking water exposure in Westfield was mitigated in 2016, changes in drinking water behavior within the past year would not affect drinking water exposure. It is possible that participants who reported currently drinking bottled water or switching water sources in the past year drank tap water during the period of contamination, but the extent to which that occurred is not known. Due to these considerations, ATSDR's data analysis did not rely on answers to these questions when interpreting associations between PFAS levels and exposure characteristics.

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

consumed.[6] However, significant relationships were observed 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, PFHxS levels increased by 2.8% and PFOA levels increased by 1.6% in all-adult models; both of these increases were statistically significant. In male-only models, these associations were significant and larger (4.4%). They were not significant in female-only models, suggesting that the relationship was primarily observed in male participants. Associations between tap water consumption and blood PFOS were not statistically significant.

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 Westfield 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 residence within the sampling frame, the greater the likelihood of past PFAS exposure from the Westfield drinking water supply. Any resident reporting prior residences in Westfield was assumed to fall within the sampling frame.

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 shows the relationship between reported residence duration in Westfield for the past 20 years and blood PFAS levels. A consistent relationship was observed for PFHxS, PFOS, and PFOA: blood levels increased with the number of years participants lived in the sampling frame, and this effect was most pronounced for PFHxS. The multivariate analysis showed that only PFHxS had a statistically significant relationship with residency duration: for every additional year that an adult participant lived in Westfield, blood PFHxS increased by 3.6%. In male-only models, this association was significant and larger (4.6%). The association was not significant in female-only models, suggesting that the relationship was primarily observed in male participants. For PFOA and PFOS, the multivariate analysis did not show statistically significant relationships with residency duration.

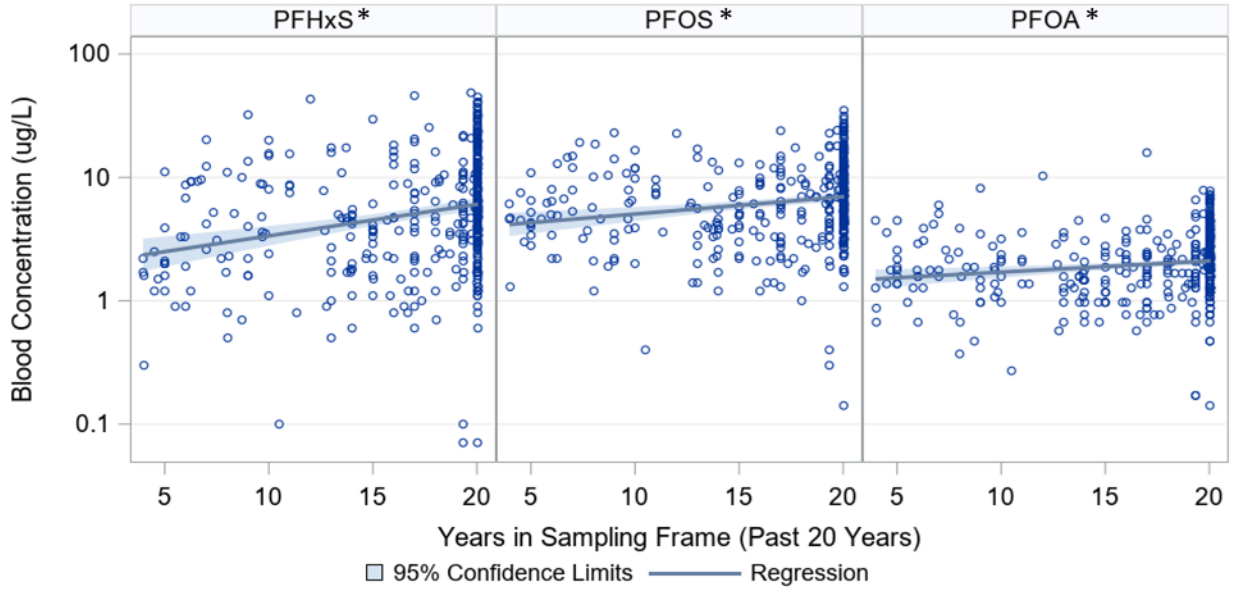
ATSDR also considered relationships between blood PFAS levels and current use of drinking water filtering devices and water treatment devices but found no significant associations. While one would expect properly maintained filtering and treatment devices to decrease PFAS drinking water exposures, the questionnaire did not ask participants when they installed these devices. If they were installed after PFAS mitigation was complete in January 2016, no significant relationships would be expected.

[6] Initially, a significant linear relationship was observed between the reported amount of water consumed per day among all adult participants (ranging from 0 to 64 cups) and blood levels of multiple PFAS. However, two participants reported drinking water rates that were determined to be outliers (i.e., 48 and 64 cups per day). With these outliers excluded, there were no significant associations between tap water consumption at home and blood levels of any PFAS.

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

PFHxS, PFOS, and PFOA were detected in Westfield's drinking water sources (PFHxS at 170 ppt, PFOS at 160 ppt, and PFOA at 43 ppt). Therefore, one explanation for the high correlation among these compounds in the blood is that the Westfield EA participants had a common exposure profile for PFHxS, PFOS, and PFOA, such as drinking water. However, the correlations alone cannot be used to identify the underlying source or combination of sources that contributed most to exposure.

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



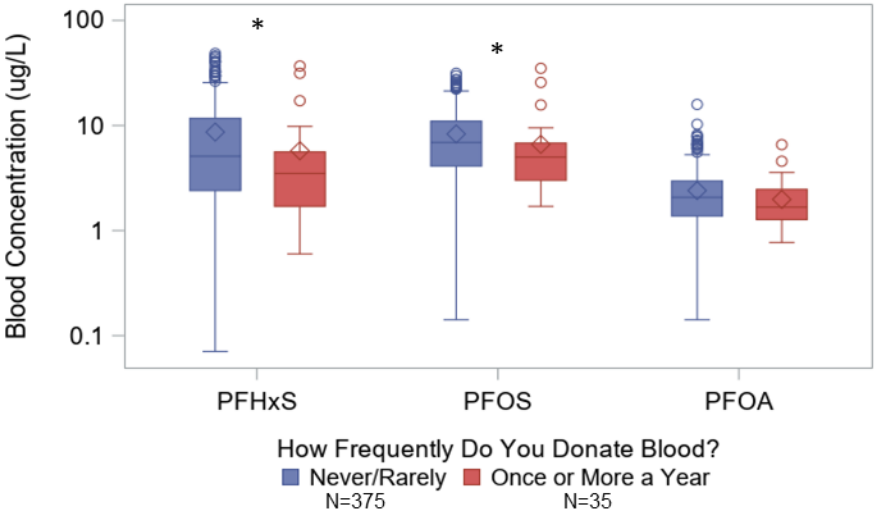
A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically Significant Trend (p<0.05)*

Blood PFAS Levels and Frequency of Blood Donation

Adult participants were asked how often they donate blood or plasma, because frequent blood and plasma donations are expected to result in decreasing blood PFAS levels. Consistent with expectations, blood levels of PFHxS, PFOS, and PFOA were higher among EA participants who reported never or rarely donating blood when compared to blood levels for EA participants who donated blood at least once per year (Figure 8). These differences were statistically significant for PFHxS and PFOS.

ATSDR's multivariate analysis, which accounted for various confounding factors, found blood PFHxS concentrations among adults who donated blood once or more per year to be 34% lower than for EA participants who donated blood never or rarely. The same EA participants had 24% lower PFOS blood levels. The relationship for PFOA was not statistically significant in multivariate models. In female-only models, these associations were significant and larger. They were not significant in male-only models, suggesting that the relationship was primarily observed in female participants. These results are based on a small number of participants (9%, n=19 females and n=16 males) 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 8. PFAS blood levels in adults by blood-donation frequency (log scale)



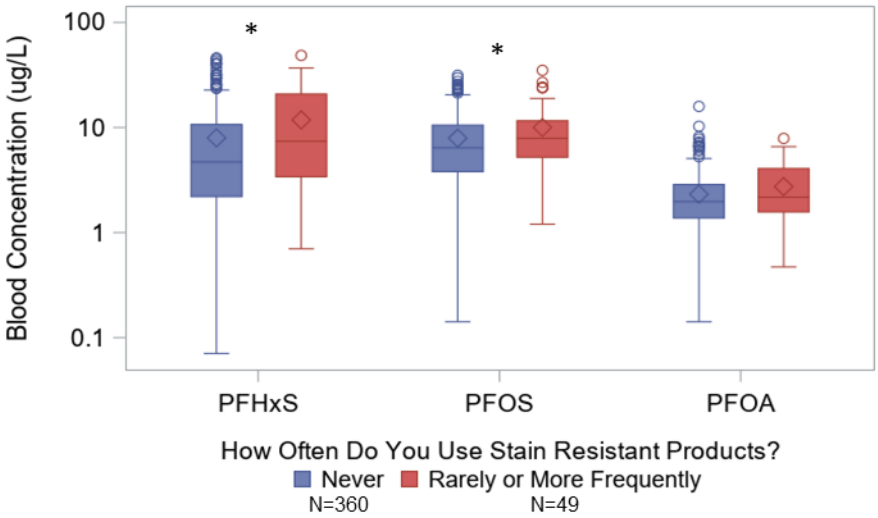
See 'How to read a box and whisker plot' earlier in the PFAS in Blood section.
A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically Significant Difference (p<0.05)*

Blood PFAS Levels and Use of Stain-Resistant Products

Many stain-resistant products used to treat fabrics and carpet have been formulated with PFAS. The exposure history questionnaire asked adult EA participants how frequently they used these products, because such uses may be associated with PFAS exposures. The questionnaire had several response options, including "never," "rarely," "a few times per year," "a few times per month," and "3 times per week or more." Because of the small sample size for some response options, ATSDR collapsed responses into just two categories: never used stain-resistant products (360 adult EA participants) and any reported use (49 adult EA participants). Figure 9 shows how blood PFAS levels varied between these two categories of EA participants.

As Figure 9 shows, Westfield EA adult participants with any self-reported stain-resistant product use had statistically elevated blood levels of PFHxS and PFOS when compared to participants who reported never using these products. However, based on the multivariate statistical analysis, only the trend for PFHxS remained statistically significant. In the all-adult model, with other variables controlled for, blood levels of PFHxS were 44% higher in participants who reported using these products than in participants who never used them. In female-only models, this association was significant and larger (76%). It was not significant in male-only models, suggesting that the relationship was primarily observed in female participants. These results are based on a small number of participants (12%, n=25 females and n=24 males) who reported ever using stain-resistant products and will be explored further in the final report for all EA sites. The results for stain resistant product use for this EA are based on limited data and should be interpreted with caution.

Figure 9. PFAS blood levels in adults by frequency of stain-resistant product use (log scale)



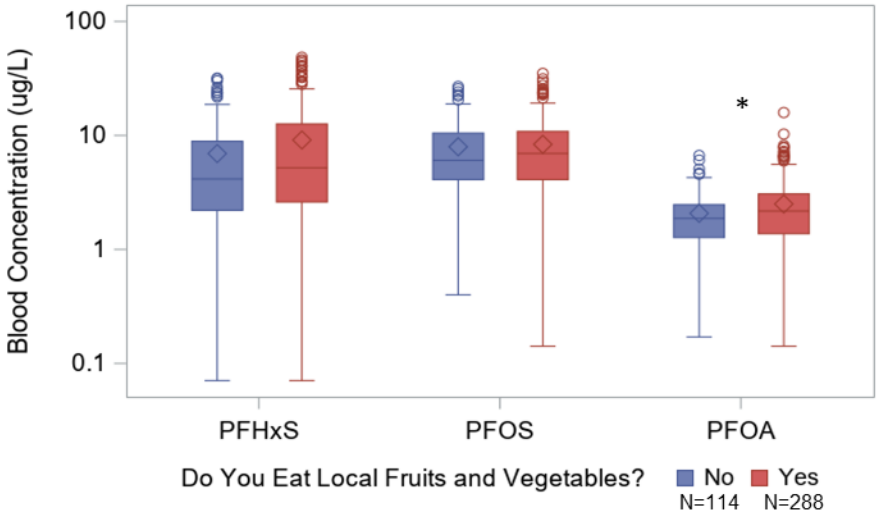
See 'How to read a box and whisker plot' earlier in the PFAS in Blood section.
A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically Significant Difference (p<0.05)*

Blood PFAS Levels and Consumption of Selected Local Food Items

Some PFAS accumulate in plants, fish, and animals. The questionnaire asked adult and child EA participants how often they consume locally grown fruits and vegetables, locally caught fish, and milk from animals in the sampling frame. Too few EA participants reported consuming locally caught fish (n=12) or locally produced milk (n=7) to allow for meaningful statistical analyses. These exposure pathways are not evaluated further.

Consumption of locally grown fruits and vegetables, home-grown produce, or produce raised elsewhere locally and purchased at market was evaluated. EA participants provided information on whether and how often they consume produce. As Figure 10 shows, blood PFHxS, PFOS, and PFOA levels were higher among adult EA participants who reported any locally grown produce consumption than among participants who reported no such consumption. However, a statistically significant relationship was observed only for PFOA, for which blood levels were 17% higher among adult participants who reported consuming local fruit and vegetables. Statistically significant observations were not observed in adults for PFHxS or PFOS, and they were not observed in children for any PFAS. Note that these relationships did not remain significant in multivariate models for all adults.

Figure 10. PFAS blood levels in adults by frequency of consumption of local fruits and vegetables (log scale)



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

Blood PFAS Levels and 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) if it was made using tap water.

Figure 11 summarizes blood levels for females by whether they ever breastfed. Among adult female EA participants, 50% reported that they had breastfed a child, with an average breastfeeding duration across all pregnancies of 16 months. Among adult females, univariate models showed that blood PFHxS, PFOS, and PFOA levels were 30%, 23%, and 19% lower, respectively, when compared to adult females who had never breastfed a child. These findings were all statistically significant. In general, there was a negative association between breastfeeding duration and blood PFAS levels, but this relationship was statistically significant only for PFOA in univariate models.

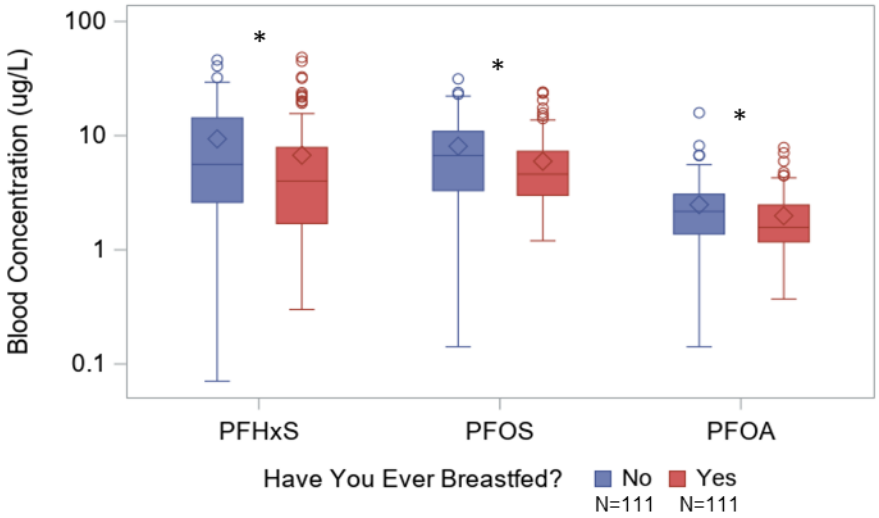
After ATSDR controlled for other covariates, multivariate analyses revealed a significant interaction between age and breastfeeding. Females who breastfed had lower blood levels of PFHxS, PFOS, and PFOA than females who did not, and this effect was larger in younger women. For example, 30-year-old females who breastfed had lower modeled blood PFHxS, PFOS, and PFOA levels than 30-year-old females who had never breastfed by 59%, 36%, and 43%, respectively. For 50-year-old females who had breastfed, this difference was reduced to 39% for PFHxS, 19% for PFOS, and 21% for PFOA, compared to 50-year-old females who had never breastfed. The duration of breastfeeding was not a significant predictor of blood PFAS levels in multivariate models.

Consistent with expectations, the opposite trend in blood PFAS levels was observed among child EA participants who were breastfed. The questionnaire results demonstrate that, overall, 82% of children in the Westfield EA were breastfed. The longer a child breastfed, the greater their blood levels of PFHxS

and PFOA. Among child participants who were breastfed, each month of reported breastfeeding was associated with an increase of 1.7% in blood PFHxS and 1.5% in blood PFOA. For example, 6 months of breastfeeding changed an infant's modeled PFHxS blood level from 2 µg/L to 2.2 µg/L.

Approximately half of the children in the Westfield EA (47%) consumed infant formula reconstituted with tap water (some of these children were also breastfed), but no significant associations were identified between infant formula consumption and any PFAS in blood.

Figure 11. Blood PFAS levels in females by breastfeeding (yes/no) (log scale)



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

Blood PFAS Levels and Other Variables

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

- **Soil exposure.** Adult and child participants were asked how often they play in or touch soil or dirt in the sampling frame. No statistically significant relationship was observed for self-reported soil contact frequency and blood PFAS levels in adults or children.
- **Flooring.** Adult participants were asked about the type of flooring in their living rooms, kitchens, and bedrooms. While carpet has been linked to increased PFAS exposure because PFAS containing stain- and grease-repelling coatings are often applied to carpet [Beesoon et al. 2012], the presence of carpet in EA participants' rooms was not statistically associated with blood PFAS levels among adults.
- **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 Westfield 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.

- **Kidney disease.** The exposure history questionnaire asked about kidney disease because it can affect blood PFAS levels [Vaughn 2013; Watkins 2013]. The questionnaire results indicated that only 8% of adults (n=32) reported a diagnosis of kidney disease, and these adults did not have statistically different blood PFAS levels than those without such a diagnosis.
- **Occupation.** Adult participants were asked about their occupational history over the past 20 years. Participants were specifically asked about experience working at manufacturers of PFAS or PFAS-containing products (e.g., nonstick cookware, water-resistant clothing) and past work in firefighting, the military, or aviation. The 8% of adults (n=30) who identified working in at least one job with potential exposures to PFAS in the past 20 years did not have statistically different PFAS levels than those without occupational exposures.
- **Childbirth (adult females) and birth order (children only).** Adult female participants were asked whether they had any biological children, and if so, how many. Children were asked their birth order. Pregnancy may lead to lower blood PFAS levels for mothers, and birth order may be related to PFAS levels in children (with first-born children having higher PFAS levels than last-born children). Approximately half of adult female EA participants (56%) reported having one or two biological children. Neither having children nor the number of children was statistically associated with blood PFAS levels. Half of all children reported being the first born; birth order was not statistically associated with blood PFAS levels.

PFAS in Urine

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

For the Westfield EA, ATSDR randomly selected 47 participants' urine samples for analysis. These samples were provided by 46 adults and 1 child, and these individuals lived in 44 different households. PFBA was the only PFAS detected in any of the 47 urine samples. Of note, unambiguous quantification of trace levels of PFBA faces known challenges, including selectivity of the analytical instrumentation and potential for external contamination [Abraham et al. 2021]. Therefore, we advise caution when interpreting the PFBA results. Table 10 presents PFBA summary statistics for the randomly selected urine samples and national statistics for comparison. 14 of the 47 samples had PFBA urine concentrations higher than the NHANES 95th percentile. The protocol specified that all urine samples would be analyzed if the geometric mean exceeded the 95th percentile from NHANES. Since no PFAS were detected in more than 60% of the analyzed samples, no geometric means were calculated for any PFAS in urine and ATSDR did not analyze the remainder of the urine samples.

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

PFAS	Frequency of Detection (%)	Range of Concentrations (µg/L)	Westfield Geometric Mean (µg/L)	Westfield 95th Percentile (µg/L)	NHANES Geometric Mean (µg/L)	NHANES 95th Percentile (µg/L)
PFBA	59.6	ND–0.8	NA*	0.491	NA*	0.300

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

* Geometric mean was not calculated because chemical was not detected in at least 60% of the samples (detected in 13.3% of samples in Calafat et al. [2019]).

PFAS in Tap Water

As noted previously, ATSDR collected tap water samples from 17 randomly selected participant households and analyzed these samples for PFAS. One household only provided a filtered water sample, seven provided both filtered and unfiltered samples, and nine provided only unfiltered water samples. Detection limits were 2 ppt for all PFAS, except for HFPO-DA (5 ppt). PFAS were not detected in any of the 16 unfiltered water samples. In one of the eight samples collected from a filter, PFOA, PFOS, and PFHxS were detected but at concentrations below EPA's health advisory of 70 ppt for PFOA and PFOS combined and MassDEP's drinking water standard of 20 ppt for PFHpA, PFHxS, PFNA, PFOA, PFOS, and PFDA combined. This sample was from a refrigerator filter. ATSDR does not know the frequency of filter replacement or maintenance at that location. PFAS were not detected in any of the other filtered samples. The detection limit, and measured concentrations were far below EPA's health advisory of 70 ppt for PFOA and PFOS combined. Since PFAS were detected in only one sample, no statistics or range of detections is provided to protect the privacy of participants.

Why the only PFAS detections were in a filtered sample is unclear, as one might assume that filtered water would be less contaminated than unfiltered water. A possible explanation is related to filter maintenance, though this could not be fully explored as part of this assessment.

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

PFAS in Household Dust

ATSDR collected dust samples from the same 17 randomly selected participant households where tap water samples were collected and analyzed these samples for PFAS. These samples were taken from multiple locations in each household, including the primary living space as identified by the homeowner (e.g., living room, family room, television room), the kitchen, and the bedroom in which participants reported spending the most time. When necessary, additional sampling was performed in other rooms to allow ATSDR to collect the proper amount of dust for testing. Table 11 lists the specific PFAS compounds that were measured in dust along with detailed summary statistics (i.e., frequency of detection, geometric means, 95% confidence intervals around the geometric means, and percentiles). Note that several PFAS were not detected in any sample and are therefore not included in Table 11 (i.e., PFNS, PFDoS, FtS 4:2, HFPO-DA, DONA, 9CL-PF3ONS, and 11CL-PF3OUdS).

Table 11. Summary statistics for dust samples collected in Westfield

PFAS	FOD (%)	Maximum Detected Result (ng/g)	Geometric Mean (ng/g)	95% Confidence Interval for Geometric Mean (ng/g)	Percentiles (ng/g)		
					50th (Median)	90th	95th
PFBS	53	12.0	NA*	NA*	2.03	7.72	10.7
PFPeS	18	12.9	NA*	NA*	0.78	2.29	3.89
PFHxS	88	1300	5.3	2.2–12.8	3.66	18.9	212
PFHpS	18	3.9	NA*	NA *	0.81	2.64	3.51
PFOS	94	350	12.9	5.8–28.8	7.19	168	270
PFDS	53	6.1	NA*	NA*	1.88	4.89	5.24
PFBA	53	59.1	NA*	NA*	5.89	27.8	56.6
PFPeA	47	20.6	NA*	NA*	2.71	8.3	15.8
PFHxA	94	70.8	8.2	4.9–13.6	6.44	27.5	46.7
PFHpA	88	105	5.9	3.0–11.7	4.04	34.9	65.5
PFOA	94	424	15.2	6.7–34.1	7.14	133	289
PFNA	76	30.9	3.8	2.2–6.5	2.76	11.9	21.6
PFDA	88	26.6	4.3	2.8–6.6	3.75	14.0	25.6
PFUnA	65	15.4	2.0	1.2–3.3	2.03	5.71	9.33
PFDoA	76	18.4	2.4	1.4–4.0	2.12	11.3	14.9
PFTrA	35	8.9	NA*	NA*	0.99	3.3	6.16
PFTA	35	13.4	NA*	NA*	1.12	5.0	8.21
PFOSA	29	4.5	NA*	NA*	0.85	2.6	3.42
N-MeFOSA	18	4.8	NA*	NA*	0.93	2.8	3.45
MeFOSAA	59	800	NA*	NA*	2.06	30.4	149
N-MeFOSE	47	1050	NA*	NA*	10.77	37.9	191
N-EtFOSA	5.9	7.9	NA*	NA*	1.95	5.72	6.06
EtFOSAA	71	83.2	6.8	3.1–14.8	3.66	68.9	77.9
N-EtFOSE	35	492	NA*	NA*	6.72	18.3	91.6
FtS 6:2	47	104	NA*	NA*	4.92	26.4	59.3
FtS 8:2	29	47.0	NA*	NA*	3.41	18.3	40.7

FOD = frequency of detection, ng/g = nanograms per gram, NA = not applicable
A total of 17 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, PFOA, PFHxS, PFHpA, PFDA, PFNA, and PFDoA were detected in more than 75% of the households evaluated. Of these, PFOA and PFOS were measured at the highest levels on average, with geometric mean values of 15.2 nanograms/gram (ng/g)[7] (95% confidence interval = 6.7–34.1 ng/g) and 12.9 ng/g (95% confidence interval = 5.8–28.8 ng/g), respectively. Every other PFAS had geometric mean concentrations less than 8.2 ng/g.

[7] 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.

To provide some context to the results summarized above, average levels of PFAS measured in the 17 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 as in this EA, PFOA and PFOS were consistently reported at the highest concentrations. Geometric mean concentrations ranged from 24 to 45 ng/g for PFOA and 27 to 35 ng/g for PFOS (Fraser et al. 2013; Wu et al. 2015]. Two of the studies did not report geometric means; for these studies, median concentrations were reported at 9 ng/g and 51 ng/g for PFOA and 14 ng/g and 67 ng/g for PFOS [Karásková et al. 2016 and Scher et al. 2018, respectively]. Geometric mean and median concentrations for PFOA and PFOS measured in the 17 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 PFAS measured in the dust samples collected in Westfield are comparable to those reported elsewhere in the United States, note that the studies referenced here do not necessarily provide representative comparison values 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 17 dust samples summarized above and from the 37 blood samples collected from participants residing in the same homes. Using log-transformed data, ATSDR calculated Pearson correlation coefficients for all of the PFAS measured in at least 60% of the dust and the same PFAS measured blood samples for this assessment. Data were log-transformed because dust and blood concentrations were log-normally distributed.

None of the PFAS measured in dust were statistically correlated ($p<0.05$) with the same PFAS measured in blood. Pearson correlation coefficients for these comparisons ranged from 0.1 to 0.3, indicating weak correlation between concentrations measured in dust and blood. Note that the sample size for dust measurements in Westfield is relatively small. ATSDR will further explore these findings, as well as correlations between different PFAS measured in dust and blood (e.g., the correlation between PFOA in dust and PFOS in blood) in the PFAS EA aggregate report.

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

Discussion

At least one PFAS was detected in the blood of 458 out of 459 Westfield EA participants (99.8%). Because of the widespread use of PFAS, such high detection frequencies are common in the general U.S. population [CDC 2019]. PFHxS, PFOS, PFOA, PFNA, and PFDA were the most frequently detected compounds for Westfield (detection frequencies above 85%).

Results from this EA were compared to NHANES data from 2015–2016.[8] Age-adjusted geometric mean blood levels of PFHxS, PFOS, and PFOA were statistically higher than these national geometric means (1.1–3.4 times higher), and age-adjusted blood concentrations of PFNA and PFDA were similar to or lower than national geometric means. EA participants had statistically higher blood PFHxS, PFOS, 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 Westfield EA blood levels and the current national geometric mean could be greater than reported here.

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

- For PFHxS, blood levels among Westfield EA participants are within the range of those recently observed in two other communities with contaminated drinking water: Little Hocking, Ohio, and Portsmouth, New Hampshire [Frisbee et al. 2009; NH DPHS 2016]. Water in Little Hocking, Ohio was contaminated due to fluoropolymer manufacturing and had a larger fraction of PFOA (and smaller fractions of PFOS and PFHxS) in the water compared to Westfield. Water in Portsmouth, New Hampshire was contaminated due to AFFF and had a similar mixture of PFAS as observed in Westfield.
- Westfield EA participants' blood PFHxS levels are higher than national geometric means from NHANES 1999–2000, the time NHANES first measured PFAS and the time the highest PFAS levels were observed [CDC 2019]. PFHxS has been detected in legacy AFFF formulations and may be present in groundwater because of degradation of other PFAS. The half-life of PFHxS is between 4.7 and 35 years and is longer than the half-lives for PFOS and PFOA, which may explain why blood PFHxS levels were more elevated than levels of other PFAS. [ATSDR 2021]
- PFOA and PFOS, on the other hand, did not exhibit these trends. These substances' blood levels in Westfield EA participants were considerably lower than blood levels observed in Little Hocking and Portsmouth and the NHANES 1999–2000 blood levels [Frisbee et al. 2009; NH DPHS 2016; CDC 2019].

Generalizability of Westfield EA Community Statistics

The random sampling recruitment method used for this EA was designed to produce summary statistics of blood PFAS levels that were generalizable to the sampling frame as a whole (i.e., Westfield households north of the Westfield River). Although the population invited to participate was likely representative of the sampling frame, the population that ultimately enrolled was older and contained fewer Hispanic individuals. Specifically, adults aged 50 or older represented 57% of the EA population compared with 34% of the sampling frame, and Hispanic participants represented 3.9% of the EA population and 7.0% of the sampling frame population. Given the 18% response rate, it is also possible that other factors were present at different rates than the community as a whole.

[8] 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 aggregate report.

Since both age and ethnicity were associated with blood PFAS levels in univariate analyses, the summary statistics for blood PFAS (Table 5) may be biased, or deviate from the true value, when generalizing to the entire sampling frame. ATSDR believes that any bias caused by differences in ethnicity would be minimal because of the overall small proportion of Hispanic participants in the sampling frame (7%), and because race and ethnicity were not statistically significant in multivariate analyses. 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 this bias by calculating geometric means that were adjusted to the age distribution of sampling frame (Table 6). This analysis showed that differences in age distribution between the sampling frame and the EA participants resulted in unadjusted geometric means for blood PFHxS and PFOS that were biased high by 19% to 20%. Therefore, the sampling frame age-adjusted geometric means for PFHxS and PFOS may be more representative of the average levels in the community. The biases caused by the older EA population for the remaining PFAS were below 7%.

Relationships Between Demographics and PFAS Blood Levels

When evaluating differences in demographic factors by PFAS levels, adult males had statistically higher geometric mean blood levels for PFHxS, PFOS, and PFOA. This trend has been observed in other studies in communities with contaminated drinking water and 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 possible in 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 the number of children a female reported having), was not a significant predictor of PFAS blood levels, but breastfeeding was found to be statistically associated with decreasing blood levels of PFHxS, PFOS, and PFOA among adult women. Multivariate analyses showed that the effect of breastfeeding on PFAS blood levels was larger in younger women than older women.

Blood PFAS levels were statistically higher in older adults than younger adults, and the effect of age was stronger in female participants than males. Blood PFAS levels were found to be higher in younger children or remain unchanged with age among children (3–18 years). Differences in the associations between blood PFAS levels and age in adults and children have been observed in other studies [ATSDR 2013; NH DPHS 2016; CDC 2019]. Generally, increasing blood levels in adults are due to the long biological half-lives of PFAS and diminishing excretion rates with increasing age. The half-life of a chemical is the amount of time it takes for 50% of the substance to be eliminated from the body. Some studies estimate that the half-life of PFHxS is between 4.7 and 35 years [ATSDR 2021]. Half-life estimates range from 3.3 to 27 years for PFOS and from 2.1 to 10.1 years for PFOA [ATSDR 2021]. In the presence of continued exposures that exceed clearance rates, PFAS will accumulate in the human body over time. In this EA, children age 3 to 12 had statistically higher blood levels of PFOA than children age 12 to 18. This association is likely due to multiple factors including early life exposures and growth dilution. Early-life exposures may have occurred since PFAS can cross the placenta and are found in breast milk [ATSDR 2021]. Also, hand-to-mouth touching and spending more time closer to the floor with settled dust is less common in older children. In addition, as a child grows, large increases in body size lowers blood levels despite increasing or constant PFAS body burdens. This process is known as growth dilution [Koponen et al. 2018].

Blood PFAS levels were statistically lower in adult participants who self-identified as Non-white or Hispanic compared to those who identified as White, non-Hispanic. These differences are also observed in the wider U.S. population and may reflect differences in exposure patterns such as lifestyle, diet, and use of PFAS containing products [Calafat et al. 2007b].

Significance of Drinking Water Exposures

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

- The three PFAS (PFHxS, PFOS, and PFOA) with statistically elevated blood levels in comparison to the most current national geometric means were detected in Westfield's water supply as early as 2013. It is likely that contamination began earlier, but no data are available before 2013. In 2013, the maximum concentrations observed in active drinking water wells in Westfield were 170 ppt for PFHxS, 160 ppt for PFOS and 43 ppt for PFOA. In 2016, Westfield mitigated the contamination; however, these PFAS have very long biological half-lives (2.1 to 35 years). Therefore, even though drinking water PFAS exposures in Westfield were significantly reduced in January 2016, past drinking water exposures were likely a contributing factor to the EA participants' elevated blood PFAS levels, observed 3 years and 8 months later. Furthermore, in this EA, PFHxS had the largest deviation from the national average and showed the greatest association with reported drinking water consumption, which is what would be expected given that PFHxS has the longest half-life of the three PFAS and was detected at the highest concentration in Westfield's drinking water.
- PFHxS, PFOS, and PFOA were highly correlated in blood (*r* between 0.83 and 0.87), suggesting similar or common background sources or exposure pathways. PFHxS and PFOS, and to a lesser extent PFOA, have many common exposure sources, as these compounds are often found together in consumer products. While correlations between PFAS have been observed in other studies [NH DPHS 2016; ATSDR 2013; CDC 2019], the correlations observed between these three PFAS in this EA are much higher than those observed in the general U.S. population (*r* between 0.46 and 0.66) [Calafat et al. 2007b]. Instead, the high correlation between PFHxS, PFOS, and PFOA is consistent with those found in the blood of people living in communities with contaminated drinking water [ATSDR 2013], providing further evidence that drinking water was likely a contributing source of exposure among Westfield EA participants. In addition, the correlations between PFHxS, PFOS, and PFOA in this study are much higher than the correlations observed for PFNA and PFDA, two compounds that were not found in Westfield's drinking water, providing further evidence of a distinct exposure pathway for these three compounds.
- Univariate statistical analyses of the EA data found that one of the most consistent predictors of adult blood PFAS levels was length of residency in Westfield. ATSDR considered residency duration to be a suitable surrogate for drinking water exposures because only residents who lived in the sampling frame before January 2016 would have had any exposure to the PFAS-contaminated drinking water, and because of the likelihood that exposure would increase with the number of years that EA participants lived in the area. However, since older adults tended to live in the sampling frame longer, this variable was highly correlated with age in adults. Because of this, it was unclear from univariate models alone whether the association between the time

someone lived in the sampling frame and PFAS blood levels was primarily due to age. After controlling for age, sex, and other data characteristics, the multivariate statistical analysis found that residency duration remained statistically associated with blood PFHxS levels and tap water consumption remained statistically associated with blood PFHxS and PFOA levels. However, multivariate models conducted separately for males and females suggest that these relationships were primarily observed in male participants. Furthermore, multivariate regression models did not explain a large portion of the variability in participants' blood PFAS levels (R^2 ranged between 0.14 and 0.23 in the "all adult" models), indicating that many factors are not accounted for.

- One line of evidence that ATSDR considered and dismissed was the lack of associations between EA participants' self-reported drinking water source (public water or bottled water) and blood PFAS levels. As noted previously, the questionnaire asked only about current drinking water sources, which may not reflect the participants' drinking water sources before PFAS contamination in Westfield's water supply was mitigated. Similarly, any reported changes to drinking water behavior in the past year were not relevant for determining behavior during the period of exposure. Anecdotally, many participants informed EA field staff that they switched to bottled water upon learning of PFAS contamination in the Westfield public water supply, but this information was not systematically collected in the questionnaires. As a result, the lack of associations between current drinking water source or recent changes in drinking water behavior and participants' blood PFAS levels was considered a weak finding based on the data available for the analyses.

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

Other Exposure Characteristics

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

- **Stain-resistant product use.** Stain-resistant products are sometimes applied to carpeting or upholstered furniture and have been linked to PFAS exposures [Beesoon et al. 2012]. Few participants reported frequent use of stain-resistant products at home; however, the 12% (n=49) of participants who reported "ever" using these products had elevated blood levels of PFOS and PFHxS in both univariate and multivariate models compared to those who did not. Both PFOS and PFHxS are primary ingredients in historical formulations of stain-repellent consumer products used to treat carpet, furniture, and clothing. These results are based on limited data and should be interpreted with caution.
- **Blood donation frequency.** Previous research clearly demonstrates that PFAS have a strong affinity for binding to blood proteins and accumulate in human blood [Jian et al. 2018]. Blood donation therefore has the potential to remove PFAS from the body. In multivariate models, lower PFHxS blood levels were observed in the few (9%, n=35) Westfield EA participants who reported donating blood at least once per year. These results are based on limited data and should be interpreted with caution.

Westfield Community-Wide Findings

Finding 1. Blood levels of PFHxS, PFOS, and PFOA in the Westfield community are higher than national levels.

Geometric means (i.e., averages) for PFHxS, PFOS, and PFOA blood levels were statistically higher ($p<0.05$) in Westfield participants when compared to CDC's NHANES (2015–2016) data, which was limited to people over 12 years old. The statistically higher blood PFAS levels were observed for both unadjusted geometric means for all EA participants and geometric means adjusted to the age distribution of the U.S. population 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 Westfield EA participants was 3.4 times higher than the national average. Blood PFHxS levels were above the national geometric mean for 92% of the Westfield EA participants and above the NHANES 95th percentile for 46%. The age-adjusted geometric mean blood PFOS and PFOA levels among Westfield EA participants were 1.1 times higher than the national level.

Other PFAS measured in this EA (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 percent of samples below the limit of detection, geometric means were not calculated.

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

The three PFAS (PFHxS, PFOS, and PFOA) with statistically elevated blood levels compared to national geometric means were detected in Westfield's drinking water as early as 2013. It is likely that contamination began earlier, but no data are available before 2013. The maximum concentrations observed in active drinking water wells in Westfield were 170 parts per trillion (ppt) for PFHxS, 160 ppt for PFOS, and 43 ppt for PFOA in 2013. In 2016, Westfield reduced concentrations of PFAS below U.S. EPA health advisory levels (70 ppt for PFOA and PFOS combined). Before 2016, PFAS-containing AFFF were primarily formulated with PFOS, but also contained various PFAS precursors that could break down into other PFAS, such as PFHxS, which could explain the elevated blood PFHxS levels. PFHxS, PFOS, and PFOA have long biological half-lives (2.1 to 35 years). There were 3 years and 8 months between the reduction of exposure via contaminated drinking water and collection of biological samples during the EA. Because of the long half-lives of PFHxS, PFOS, and PFOA, past drinking water exposures may have contributed to the EA participants' blood levels.

PFHxS, PFOS, and PFOA were highly correlated in Westfield residents' blood (Pearson correlation coefficient, *r*, between 0.83 and 0.87). This means that typically, residents who had elevated blood PFHxS levels also had elevated blood PFOS and blood PFOA levels. This correlation suggests a common exposure source, such as the Westfield public water supply, though other sources of exposure may also have contributed to the observed blood levels.

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

- First, in univariate models, a consistent and statistically significant predictor of participant blood levels for PFHxS, PFOS, and PFOA was how long the resident had lived in Westfield before January 2016. Those who lived in the area longest likely drank, in total, more contaminated water. This relationship remained significant in a multivariate model for PFHxS.
- Second, in multivariate models, PFHxS and PFOA blood levels in adults statistically increased with the amount of tap water those adults reported drinking.

Multivariate models conducted separately for males and females suggest that these relationships (between blood levels and residency duration/tap water consumption) were primarily observed in male participants.

Finding 3. Age, sex, breastfeeding, use of stain-resistant products, and blood donation were associated with some PFAS blood levels.

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

- Blood levels of PFHxS, PFOS, and PFOA were higher in older participants, and the size of the effect varied by sex. In males, blood levels for these compounds increased by 0.5% to 1.2% for every year of participant age. In females, blood levels for these compounds increased by 1.8% to 3.5% for every year of participant age.
- Males had higher blood levels of PFHxS, PFOS, and PFOA than females. The difference between males and females was larger in younger people. For example, 30-year-old males had higher blood PFHxS, PFOS, and PFOA levels than 30-year-old females by 107%, 109%, and 57%, respectively. For 50-year-old males, this difference was reduced to 31% for PFHxS, 58% for PFOS, and 19% for PFOA compared to 50-year-old females.
- Females who breastfed had lower blood levels of PFHxS, PFOS, and PFOA than females who did not, and this effect was larger in younger women. For example, 30-year-old females who breastfed had lower blood PFHxS, PFOS, and PFOA levels than 30-year-old females who had never breastfed by 59%, 36%, and 43%, respectively. For 50-year-old females who had breastfed, this difference was reduced to 39% for PFHxS, 19% for PFOS, and 21% for PFOA compared to 50-year-old females who had never breastfed.
- Only 49 participants reported ever using stain resistant products, and most of these reported their frequency of use as “rarely.” Participants who reported ever using stain-resistant products had 44% higher blood levels of PFHxS than those who never reported using these products. Because of the small sample size for people who ever used stain resistant products, these results should be interpreted with caution.
- Only 35 participants reported donating blood at least once or more a year. Participants who reported donating blood at least once or more a year had 34% lower blood levels of PFHxS and 24% lower blood levels of PFOS than participants who never reported donating blood. Because of the small sample size for people who reported donating blood once or more a year, these results should be interpreted with caution.

A few associations were observed in children (<18 years), though many variables could not be examined because of the small number of child participants (n=49). Because of the small sample size, results

should be interpreted with caution. Specifically, blood levels of PFOA decreased with age, and children who were breastfed had higher blood levels of PFHxS and PFOA 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 aggregate report on all EA sites will include a more robust analysis of children.

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

ATSDR analyzed 47 (10%) of the urine samples collected. Only perfluorobutanoic acid (PFBA) was detected; it was detected in 59.6% of the 47 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 Westfield tap water samples collected during the EA in 2019 met the EPA's HA and Massachusetts Department of Environmental Protection's (MassDEP) public health guidelines for PFAS in drinking water.

This is based on 16 unfiltered and 8 filtered tap water samples collected in 17 households during the EA. These results are consistent with recent data collected by the City of Westfield.

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, PFOA and PFOS were measured at the highest concentrations. No nationally representative comparison values are available, but geometric mean and median concentrations for PFAS measured in dust collected in the small subset of participating households (n=17) were within the range of levels reported in a few published studies of other U.S. communities. None of the PFAS measured in this EA's household dust samples were statistically correlated with the same PFAS measured in participants' blood. The final aggregate report on all EA sites will likely include a more robust comparison of PFAS measured in dust and blood.

Limitations

There are several limitations associated with this assessment.

- The random sampling recruitment method used for this EA was designed to measure blood PFAS concentrations that were generalizable to all Westfield residents who lived north of the Westfield River and were connected to the municipal drinking water supply. However, the EA participant sample may not be fully representative of the community. Only 18% of the invited households from the random sample participated in the EA sample collection event, and participant characteristics were different than those of the area's overall population. Participants were older and less likely to be Hispanic or Latino. ATSDR addressed some of these concerns by calculating geometric mean estimates that were adjusted to the age distribution of the community.
- Blood, urine, and environmental PFAS concentrations may improve the understanding of exposure in this community but will not provide discrete information about all sources of exposure. Additionally, identifying every potential confounding exposure is not possible.
- Multivariate regression models did not explain a large portion of the variability in participants' blood PFAS levels (R-squared or R^2, a measure of model goodness-of-fit, ranged between 0.14

and 0.23, in the "all adult" models). This means that other factors not identified could influence the relationships reported in this assessment (see "Statistical Analysis" section for details).

- This study did not directly assess tap water consumption prior to the reduction of PFAS from the municipal water system.
- This EA was not designed to investigate health outcomes. Therefore, the results of this EA cannot be used to assess current or past health problems or predict the future occurrence of disease.
- 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 has demonstrated that past exposures to PFAS in drinking water have impacted the levels of PFAS in people's bodies. PFAS are eliminated from the body over a long period of time. This allowed ATSDR to measure PFAS even though exposures through drinking water were mitigated, or lowered, years ago.

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

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

1. What the City of Westfield can/should do:
    a. Operators of the municipal water system should continue to monitor concentrations of PFAS in drinking water delivered to the Westfield community to ensure that concentrations of PFAS remain below the EPA's HA and MassDEP's guidelines for specific PFAS in drinking water. Results of PFAS monitoring should be shared with community members through appropriate communication channels (Consumer Confidence Reports, https://www.cityofwestfield.org/236/Water-Quality-Reports).
    b. All treatment systems to remove PFAS from the municipal drinking water in Westfield should be maintained appropriately to ensure that PFAS concentrations remain below the EPA's HA and MassDEP's guidelines for specific PFAS in drinking water.
2. What community members can/should do:
    a. Become familiar with Consumer Confidence Reports (https://www.cityofwestfield.org/236/Water-Quality-Reports) for information on the City of Westfield's water quality.
    b. Private well owners living in the area affected by PFAS should consider having their wells tested for PFAS if testing has not been conducted before. To learn more about testing wells for PFAS visit: https://www.mass.gov/info-details/per-and-polyfluoroalkyl-substances-pfas-in-private-well-drinking-water-supplies-faq. To learn more about previous testing for PFAS in private wells in Westfield visit: http://eeaonline.eea.state.ma.us/EEA/fileviewer/Rtn.aspx?rtn=1-0020093.
    c. Nursing mothers should continue breastfeeding. Based on current science, the known benefits of breastfeeding outweigh the risks for infants exposed to PFAS in breast milk.

d. When possible, eliminate or decrease potential exposure to PFAS in consumer products such as stain-resistant products and food packaging materials. To learn more visit: https://www.fda.gov/food/chemical-contaminants-food/questions-and-answers-pfas-food.
e. Pay attention to advisories about food consumption, such as local fish advisories.
f. Discuss any health concerns or symptoms with your health care provider. Share results of PFAS blood testing with your health care provider and make them aware of ATSDR resources for clinicians (https://www.atsdr.cdc.gov/pfas/resources/info-for-health-professionals.html). Follow the advice of your health care provider and the recommendations for checkups, vaccinations, and health screening tests.
g. Follow the advice of your child's health care provider and the recommendations for well child checkups, vaccinations, and recommended health screening tests. Consult https://health.gov/myhealthfinder to help identify those vaccinations and tests.
h. For additional information about environmental exposures and children's health, contact the Pediatric Environmental Health Specialty Units, a nationwide network of experts in reproductive and children's environmental health (https://www.pehsu.net/).

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.

For More Information

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

References

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

Abraham K, El-Khatib AH, Schwerdtle T, Monien BH. 2021. Perfluorobutanoic acid (PFBA): No high-level accumulation in human lung and kidney tissue. Int J Hyg Environ Health. 2021 Aug;237:113830. doi: 10.1016/j.ijheh.2021.113830.

[ATSDR] Agency for Toxic Substances and Disease Registry. 2013. Perfluorochemical serum sampling in the vicinity of Decatur, Alabama. Atlanta, GA. Available from: https://www.atsdr.cdc.gov/HAC/pha/Decatur/Perfluorochemical_Serum%20Sampling.pdf.

[ATSDR] Agency for Toxic Substances and Disease Registry. 2019a. Exposure Assessment Protocol: Biological and Environmental Sampling of Per- and Polyfluoroalkyl Substances (PFAS), v3.0. Atlanta, GA. Available from:

[ATSDR] Agency for Toxic Substances and Disease Registry. 2019b. Standard Operating Procedures of PFAS Exposure Assessment Data Management. Version 1.3. Atlanta, GA.

[ATSDR] Agency for Toxic Substances and Disease Registry. 2021. Toxicological profile for perfluoroalkyls. Atlanta, GA [accessed 2021 July 12]. Available from: https://www.atsdr.cdc.gov/ToxProfiles/tp200.pdf

Beesoon S, Genuis SJ, Benskin JP, Martin JW. 2012. Exceptionally high serum concentrations of perfluorohexanesulfonate in a Canadian family are linked to home carpet treatment applications. Environ Sci Technology 46(23): 12960–7.

Buck RC, Franklin J, Berger U, Conder JM, Cousins IT, de Voogt P, et al. 2011. Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification, and origins. Integr Environ Assess Manag 7(4):513-41.

Calafat AM, Kuklenyik Z, Reidy JA, Caudill SP, Tully JS, Needham LL. 2007a. Serum concentrations of 11 polyfluoroalkyl compounds in the U.S. population: Data from the National Health and Nutrition Examination Survey (NHANES) 1999-2000. Environ Sci Technol 41:2237-42.

Calafat AM, Wong LY, Kuklenyik Z, Reidy JA, Needham LL. 2007b. Polyfluoroalkyl chemicals in the U.S. population: Data from the National Health and Nutrition Examination Survey (NHANES) 2003–2004 and comparisons with NHANES 1999–2000. Environ Health Perspect 115(11): 1596–602.

Calafat AM, Kato K, Hubbard K, Jia T, Botelho JC, Wong LY. 2019. Legacy and alternative per- and polyfluoroalkyl substances in the U.S. general population: Paired serum-urine data from the 2013–2014 National Health and Nutrition Examination Survey. Environ Int 131: 105048.

Cariou R, Veyrand B, Yamada A, Berrebi A, Zalko D, Durand S, Pollono C, Marchand P, Leblanc JC, Antignac JP, Le Bizec B. 2015. Perfluoroalkyl acid (PFAA) levels and profiles in breast milk, maternal and cord serum of French women and their newborns. Environ Int 84: 71-81.

Chen F, Yin S, Kelly BC, Liu W. 2017. Isomer-Specific Transplacental Transfer of Perfluoroalkyl Acids: Results from a Survey of Paired Maternal, Cord Sera and Placentas. Environ Sci Technol 51(10): 5756-5763.

[CDC] Centers for Disease Control and Prevention. 2019. Fourth national report on human exposure to environmental chemicals: Updated tables, January 2019, volume one. Atlanta GA [accessed 2020 June 23]. Available from: https://www.cdc.gov/exposurereport/pdf/FourthReport_UpdatedTables_Volume1_Jan2019-508.pdf

[EPA] U.S. Environmental Protection Agency. 2017. Unregulated Contaminant Monitoring Rule (UCMR 3): Data Summary. January 2017 [accessed 2018 November]. Available from: https://www.epa.gov/sites/production/files/2017-02/documents/ucmr3-data-summary-january-2017.pdf

Fraser AJ, Webster TF, Watkins DJ, Strynar MJ, Kato K, Calafat AM, et al. 2013. Polyfluorinated compounds in dust from homes, offices, and vehicles as predictors of concentrations in office workers' serum. Environ Int. 60:128-136.

Frisbee SJ, Brooks AP, Maher A, Flensborg P, Arnold S, Fletcher T, et al. 2009. The C8 Health Project: Design, methods, and participants. Environ Health Perspect 117(12): 1873–82.

Gluge J, Scheringer M, Cousins IT, DeWitt JC, Goldenman G, Herzke D, et al. 2020. An overview of the uses of per- and polyfluoroalkyl substances (PFAS). Environ Sci: Processes & Impacts 22: 2345-73.

Helsel, D. 2009. Much ado about next to nothing: Incorporating nondetects in science. Ann Occup Hyg 54(3): 257–62.

[ITRC] Interstate Technology Regulatory Council. 2020. Aqueous Film-Forming Foam (AFFF). Fact Sheet. Available from: https://pfas-1.itrcweb.org/fact_sheets_page/PFAS_Fact_Sheet_AFFF_April2020.pdf.

Jian JM, Chen D, Han F-J, Guo Y, Zeng L, Lu X, Wang F. 2018. A short review on human exposure to and tissue distribution of per- and polyfluoroalkyl substances (PFASs). Sci Total Environ 636: 1058–69.

Karásková P, Venier M, Melymuk L, Bečanová J, Vojta Š, Prokeš R, et al. 2016. Perfluorinated alkyl substances (PFASs) in household dust in Central Europe and North America. Environ Int 94: 315–24.

Kärrman A, Langlois I, van Bavel B, Lindström G, Oehme M. 2007. Identification and pattern of perfluorooctane sulfonate (PFOS) isomers in human serum and plasma. Environ Int 33(6): 782–8.

Kim K, Bennett DH, Calafat AM, Hertz-Picciotto I, Shin HM. 2020. Temporal trends and determinants of serum concentrations of per-and polyfluoroalkyl substances among Northern California mothers with a young child, 2009–2016. Environ Res 186:109491.

Kingsley SL, Eliot MN, Kelsey KT, Calafat AM, Ehrlich S, Lanphear BP, et al. 2018. Variability and predictors of serum perfluoroalkyl substance concentrations during pregnancy and early childhood. Environ Res 165: 247–57.

Koponen J, Winkens K, Airaksinen R, Berger U, Vestergren R, Coustins, IT, et al. 2018. Longitudinal trends of per- and polyfluoroalkyl substances in children's serum. Environ Int (1): 591–9.

Mamsen LS, Björvang RD, Mucs D, Vinnars MT, Papadogiannakis N, Lindh CH, Andersen CY, Damdimopoulou P. 2019. Concentrations of perfluoroalkyl substances (PFASs) in human embryonic and fetal organs from first, second, and third trimester pregnancies. Environ Int 124: 482-492.

[MassDEP] Massachusetts Department of Environmental Protection. 2018. Office of Research and Standards final recommendations for interim toxicity and drinking water guidance values for perfluorinated alkyl substances included in the Unregulated Chemical Monitoring Rule 3. Boston, MA, [accessed 2019 November 18]. Available from: https://www.mass.gov/files/documents/2018/06/11/pfas-ors-ucmr3-recs_0.pdf

[MassDEP] Massachusetts Department of Environmental Protection. 2020. 310 CMR 22: The Massachusetts Drinking Water Regulations [accessed 2020 December 3]. Available from: https://www.mass.gov/regulations/310-CMR-22-the-massachusetts-drinking-water-regulations

[NH DPHS] New Hampshire Division of Public Health Services. 2016. Pease PFC Blood Testing Program: April 2015–October 2015. Concord, NH [accessed 2020 June 24]. Available from: https://www.dhhs.nh.gov/dphs/documents/pease-pfc-blood-testing.pdf.

[NYDOH] New York Department of Health. 2019. Westhampton Beach and Quogue Area PFAS blood testing: Group-level results. Albany, NY [accessed 2020 September 4]. Available from: https://www.health.ny.gov/environmental/investigations/drinkingwaterresponse/docs/westhampton_quogue_group_level_blood_testing.

Olsen GW, Logan PW, Hansen KJ, Simpson CA, Burris JM, Burlew MM. 2003. An occupational exposure assessment of a perfluorooctanesulfonyl fluoride production site: Biomonitoring. AIHA J 64(5): 651–9.

[PA DOH] Pennsylvania Department of Health. 2019. PFAS Exposure Assessment Technical Toolkit (PEATT) pilot project. Harrisburg, PA [accessed 2020 June 24]. Available from: https://www.health.pa.gov/topics/Documents/Environmental%20Health/PEATT%20Pilot%20Project%20Final%20Report%20April%2029%202019.pdf.

Scher DP, Kelly JE, Huset CA, Barry KM, Yingling VL. 2018. Does soil track-in contribute to house dust concentrations of perfluoroalkyl acids (PFAAs) in areas affected by soil or water contamination?. J Expo Sci Environ Epidemiol 29(2): 218–26.

[SGS AXYS] SGS AXYS Analytical, Ltd. 2019. Analytical Procedure for the Analysis of Per- and Polyfluoroalkyl Substances (PFAS) in Aqueous Samples, Solids and Solvent Extracts by LC-MS/MS. Method MLA-110 (revision 01, version 06).

Shoemaker J, Tettenhorst D. 2018. Method 537.1: Determination of Selected Per- and Polyfluorinated Alkyl Substances in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS). U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, DC. Available from: https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NERL&dirEntryId=343042

Sunderland EM, Hu XC, Dassuncao C, Tokranov AK, Wagner CC, Allen JG. 2019. A review of the pathways of human exposure to poly-and perfluoroalkyl substances (PFASs) and present understanding of health effects. J Expo Sci Environ Epidemiol 29(2): 131-147. https://www.nature.com/articles/s41370-018-0094-1

[USCB] U.S. Census Bureau. (2010). 2010 Census. Washington, DC [no date; accessed 2020] Available from: http://www.census.gov/2010census/data/.

Vaughn B, Winquist A, Steenland, K. 2013. Perfluorooctanoic acid (PFOA) exposures and incident cancers among adults living near a chemical plant. Environ Health Perspect 121(11-12): 1313–18.

Wang Y, Rogan WJ, Chen PC, Lien GW, Chen HY, Tseng YC, Longnecker MP, Wang SL. 2014. Association between maternal serum perfluoroalkyl substances during pregnancy and maternal and cord thyroid hormones: Taiwan maternal and infant cohort study. Environ Health Perspect 122(5): 529-34.

Wang Z, DeWitt JC, Higgins CP, Cousins IT. 2017. A never-ending story of per- and polyfluoroalkyl substances (PFASs)? Environ Sci Technol 51:2508–18.

Watkins DJ et al. 2013. Exposure to perfluoroalkyl acids and markers of kidney function among children and adolescents living near a chemical plant. Environ Health Perspect 121(5): 625–30.

Wu XM, Bennett DH, Calafat AM, Kato K, Strynar M, Andersen E, et al. 2015. Serum concentrations of perfluorinated compounds (PFC) among selected populations of children and adults in California. Environ Res 136: 264–73.