Orange County

New York | near Stewart Air National Guard Base

INFORMATION TO PROTECT OUR COMMUNITIES

Per- and Polyfluoroalkyl Substances (PFAS) Exposure Assessment

REPORT

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

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About ATSDR

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

Abbreviations

9Cl-PF3ONS	9-chlorohexadecafluoro-3-oxanone-1-sulfonic acid
11Cl-PF3OUdS	11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid
AFFF	aqueous film forming foam, also known as “A triple F”
ATSDR	Agency for Toxic Substances and Disease Registry
CDC	Centers for Disease Control and Prevention
DONA	4,8-dioxa-3H-perfluorononanoic acid
EA	exposure assessment
EPA	U.S. Environmental Protection Agency
EtFOSAA	N-ethyl perfluorooctanesulfonamidoacetic acid
FOD	frequency of detection
FtS 4:2	fluorotelomer sulfonic acid 4:2
FtS 6:2	fluorotelomer sulfonic acid 6:2
FtS 8:2	fluorotelomer sulfonic acid 8:2
HA	health advisory
HFPO-DA (GenX)	hexafluoropropylene oxide dimer acid
LOD	limit of detection
MeFOSAA	N-methyl perfluorooctanesulfonamidoacetic acid
µg/L, or ug/L	micrograms per liter (same as parts per billion or 1,000 parts per trillion)
ng/g	nanograms per gram (same as parts per billion or micrograms per kilogram)
NHANES	National Health and Nutrition Examination Survey
N-EtFOSA	N-ethyl perfluorooctanesulfonamide
N-EtFOSE	N-ethyl perfluorooctanesulfonamidoethanol
N-MeFOSA	N-methyl perfluorooctanesulfonamide
N-MeFOSE	N-methyl perfluorooctanesulfonamidoethanol
n-PFOA	linear isomer of PFOA
n-PFOS	linear isomer of PFOS
NYS MCL	New York State Maximum Contaminant Level
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
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 break down further in the environment. Certain PFAS will therefore remain in the environment indefinitely. Major exposure routes for PFAS include drinking contaminated water and eating contaminated food, but exposure can also occur through other routes (i.e., ingestion of contaminated dust). Once PFAS enter people's bodies, some of them (including PFOA, PFOS, PFHxS, and PFNA) can remain in the body for long periods and can be measured in the blood years after exposure. Most people in the United States have been exposed to PFAS. At least one PFAS was detected in more than 99% of National Health and Nutrition Examination Survey (NHANES) samples collected 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 Newburgh in Orange County, New York, near Stewart Air National Guard Base (the Base). When all EAs are complete, ATSDR will prepare a report describing the results across all sites.

The Base previously used aqueous film forming foam (AFFF) containing PFAS for its firefighter training. It is not known when the Base first used the foam, but it is believed to have started as early as the 1980s. Over time, the PFAS from the AFFF moved to offsite locations, and affected the City of Newburgh's surface water source, Washington Lake. To reduce levels of PFAS in drinking water, City of Newburgh authorities stopped using Washington Lake as its water source in May 2016, and New York City's Catskill Aqueduct has served as the primary water supply since that time. Based on the information ATSDR has reviewed, the City of Newburgh drinking water supply currently meets or is below the U.S. Environmental Protection Agency's (EPA) 2016 health advisory (HA) and state public health standards for PFAS in drinking water. At this time, ATSDR does not recommend that community members who get drinking water from the City of Newburgh's public water system use alternative sources of water.

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

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

Exposure Assessment Activities

ATSDR invited a randomly selected sample of Orange County households to participate in the EA. To be eligible to participate, household residents must have (1) lived within the sampling frame and received their drinking water from the City of Newburgh's public drinking water system for at least 1 year before May 2, 2016 (these residents have the greatest likelihood of past exposures to PFAS via the city's drinking water supply), (2) been greater than three years old at the time of sample collection, and (3) not been anemic or had a bleeding disorder that would prevent giving a blood sample. Results from randomly selected households allow ATSDR to estimate exposure for all community members, even those who were not tested. Residents with private wells were not recruited.

In October 2020, 59 eligible people (58 adults and 1 child) from 48 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 6 randomly selected participants[1]
- tested for 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
- mailed individual biological and environmental results to participants in May and September 2021, respectively.

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

The samples were collected and analyzed in 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 (i.e., average) concentrations of PFOS in blood for the sampling frame (Orange County households served by the City of Newburgh's public drinking water supply) population, with a precision goal of at least 15%. The precision is a measure of how wide the confidence interval is around the estimated geometric mean. ATSDR met this goal for PFOS, and precision for all PFAS measured in this EA ranged from approximately 9% to 37%. ATSDR also calculated geometric means that were adjusted to the age distribution of the sampling frame population to correct for

[1] Tied to precautions associated with the COVID-19 pandemic, ATSDR delayed in-home tap water and dust sampling until June 2021.

[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.

participation bias and to provide an estimate that is more generalizable to the sampling frame community. ATSDR also calculated geometric means that were adjusted to the national age distribution for comparison with the 2015–2016 NHANES survey. To assess possible relationships between blood levels and various demographic and exposure variables, ATSDR used statistical models. Univariate statistics, which evaluate one variable at a time, were used to examine the data broadly and find patterns that existed within the data. Multivariate statistics and regression modeling were used to simultaneously account for multiple variables and to control for potential confounding factors.[3] In this report we use the term 'average' to refer to the national age-adjusted geometric mean.

Orange County Community-Wide Findings

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

Geometric means (i.e., averages) for PFHxS blood levels were statistically higher ($p<0.05$) in Orange County EA participants when compared to CDC's NHANES (2015–2016) data, which was limited to people over 12 years old. The statistically higher blood PFHxS 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, only PFHxS was elevated when compared to national levels. The age-adjusted geometric mean blood PFHxS level among all Orange County EA participants was 3.0 times the national level. Blood PFHxS levels were above the national geometric mean for 95% of the Orange County EA participants and above the NHANES 95th percentile for 70%.

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

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

PFHxS, PFOS, and PFOA were detected in the City of Newburgh drinking water as early as 2013. Because no data are available prior to 2013, we do not know if contamination began earlier. Only one of these PFAS (PFHxS) had statistically elevated blood levels compared to national geometric means. The maximum concentrations observed in finished City of Newburgh drinking water were 70 parts per trillion (ppt) for PFHxS, 170 ppt for PFOS, and 27 ppt for PFOA in 2013 and 2014.

In 2016, the City of Newburgh reduced concentrations of PFAS below U.S. EPA HA levels (70 ppt for PFOA and PFOS combined) by switching its water source. 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 (on the order of years). There were 4 years and 5 months between when the City of Newburgh changed water sources to reduce exposure to contaminated drinking water and collection of biological samples during the EA. Because of the long half-lives of PFHxS, PFOS, and PFOA,

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

past drinking water exposures may have contributed to the EA participants' blood levels. PFHxS has the longest estimated half-life of the three compounds (up to 35 years), which may contribute to why it exceeded the NHANES 2015-2016 geometric mean by the largest margin.

An additional observation supports the finding that past exposure to contaminated drinking water may have contributed to the elevated blood levels. In univariate and multivariate models, a consistent and statistically significant predictor of participant blood levels for PFHxS was how long the resident had lived in the sampling frame (City of Newburgh and a small portion of the Town of Newburgh) before January 2016. Those who lived in the area longest likely drank, in total, a larger volume of contaminated water. Each year of residence in the sampling frame over the past 20 years was associated with a 19% increase in PFHxS levels. Multivariate models conducted separately for males and females suggest that the relationship between blood levels and residency duration was primarily observed in female participants.

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

Finding 3. Age, sex, and local fruit and vegetable consumption 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 Orange County EA data set were observed in adult participants (and are consistent with those reported in other non-ATSDR PFAS studies):

- Blood levels of PFHxS, PFOS, and PFOA changed with age, but the size and direction of the effect varied by sex. In females, blood levels for these compounds increased by 2.4% to 5.4% for every year of participant age. In males, blood levels for these compounds decreased by 0.58% to 1.3% for every year of participant age. The decreasing association with age in males was unexpected, possibly due to the small number of young adults in this EA (no adults under 30 years of age participated).
- Males had higher blood levels of PFHxS, PFOS, and PFOA than females. The difference between males and females was larger in younger people.
- PFUnA blood levels were 44% higher among adult EA participants who reported any locally grown produce consumption when compared to participants who reported no such consumption. While PFUnA levels were higher in participants who consumed local produce, PFUnA blood levels were not elevated in the community.

Demographic and exposure variables could not be evaluated in children because of the small number of child participants. The final report on all EA sites will include an analysis of children.

Finding 4. PFAS concentrations in blood are declining over time in Orange County EA participants.

Twenty-three EA participants shared previous (2016 or 2017) blood PFAS blood results. A comparison of these results with those collected as part of this EA showed that levels decreased in all participants, between 17%-80% for PFHxS, 34%-86% for PFOS, and 17%-80% for PFOA.

Finding 5. No PFAS were detected in urine.
ATSDR analyzed 7 (10%) of the urine samples collected. No PFAS were detected in any of the samples. ATSDR did not analyze all participants' urine samples because none of the species were detected in more than 60% of the samples analyzed.

Finding 6. All Orange County tap water samples collected during the EA in 2021 met the EPA's HA and New York State public health standards for PFAS in drinking water.
This is based on 6 unfiltered and 5 filtered tap water samples collected in 6 households during the EA. No PFAS were detected in any of these samples. These results are consistent with recent data collected by the City of Newburgh.

Finding 7. 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=6) were generally in the concentration ranges reported in a few published studies of other U.S. communities (with or without known PFAS contamination). None of the PFAS measured in this EA's household dust samples were statistically correlated with the same PFAS measured in participants' blood. The final report on all EA sites will include a more robust comparison of PFAS measured in dust and blood.

Limitations
There are several limitations associated with this assessment.

- The random sampling recruitment method used for this EA was designed to measure blood PFAS concentrations that were generalizable to all Orange County residents who lived in the area served by the City of Newburgh's public drinking water supply. However, the EA participant sample may not be fully representative of the community. Only 1.6% 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, more likely to identify as White, and less likely to identify as Black or Hispanic. ATSDR addressed some of these differences by calculating geometric mean estimates that were adjusted to the age distribution of the community.
- Very few young adults and children participated in this EA (e.g., one child participant and no adults under 30 years). Therefore, age-adjusted estimations may still not be fully adjusted to the NHANES or sampling frame populations.
- The significant associations reported here between blood PFAS levels and certain demographic and exposure characteristics should be interpreted with caution as they are sometimes based on a limited number of participants.
- Measurement of blood, urine, and environmental PFAS concentrations for EA participants may improve the understanding of exposure in this community but will not provide information about all sources of exposure. Identifying every source of exposure is not possible.
- While multivariate regression models explained a moderate portion of the variability in participants' blood PFAS levels (R-squared or R^2, a measure of model goodness-of-fit, ranged between 0.21 and 0.65, in the "all adult" models), other factors not identified could still

influence the relationships reported in this assessment (see "Statistical Analysis" section for details).

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

Recommendations

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

Although the exposure contribution from PFAS in City of Newburgh drinking water in Orange County 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 Newburgh's public drinking water system, ATSDR does not recommend an alternate source of drinking water at this time.

1. What the City of Newburgh can/should do:
    a. Operators of the public drinking water system should continue to monitor concentrations of PFAS in drinking water delivered to the Newburgh community to ensure that concentrations of PFAS remain below the EPA's HA or other applicable guidelines and New York State standards 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.cityofnewburgh-ny.gov/196/Water-Quality-Reports).
    b. Any treatment systems to remove PFAS from the City of Newburgh drinking water should be maintained appropriately to ensure that PFAS concentrations remain below the EPA's HA or other applicable guidelines and New York State standards for specific PFAS in drinking water.
2. What community members can/should do:
    a. Become familiar with Consumer Confidence Reports (https://www.cityofnewburgh-ny.gov/196/Water-Quality-Reports) for information on the City of Newburgh'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.health.ny.gov/environmental/water/drinking/private_wells.htm. To learn more about previous testing for PFAS in private wells in the Newburgh area visit:

https://www.health.ny.gov/environmental/investigations/newburgh/index.htm. Global public health organization NSF International has developed a test method to verify a water filter's ability to reduce PFOA and PFOS to below the HA levels set by the EPA. NSF International-approved devices can be found at: https://info.nsf.org/Certified/DWTU/. Click on "reduction devices" at the bottom of the page for PFOA and PFOS.

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

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

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

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

g. At this time, ATSDR does not have plans to conduct additional blood testing for PFAS or recommend PFAS EA participants get individually retested for PFAS in blood. The biological half-lives of many of the PFAS measured in people's blood are long. PFHxS, in particular, has one of the longest half-lives—some estimates range in the decades. This means that PFAS blood levels are not expected to change significantly in the near-term, even if exposure stops. Additionally, it is unclear what an individual's PFAS test results mean in terms of possible health effects.

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

h. ATSDR is funding a multi-Site PFAS health study in the Orange County area (Hoosick Falls and Newburgh) that is being conducted by the New York State Department of Health and the University of Albany's School of Public Health. The study will evaluate PFAS levels in serum as well as health markers and neurobehavioral outcomes in children. If you are interested in being included in the study or want further information, please contact Multi-Site PFAS Health Study | University at Albany.

i. 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.

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

For More Information

If you have questions or comments or want more information on the Orange County 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 Newburgh in Orange County, New York. This report summarizes the findings of the Orange County EA. When all EAs are complete, ATSDR will prepare a report describing the results across all sites.

Exposure assessment (EA) participants were recruited among Orange County residents living near Stewart Air National Guard Base who received drinking water from the City of Newburgh that had PFAS levels above state or federal guidelines. For more information and a map of the area see the "Methods" section of the report.

The EA involved collecting responses to exposure history questionnaires, biological samples (blood and urine), and environmental samples (tap water and household dust). ATSDR collected biological samples at 10 New Britain Road in Newburgh between October 23 and October 29, 2020. During this same time frame, ATSDR administered questionnaires over the phone. ATSDR took water and dust samples in a subset of randomly chosen participant homes on June 8 and 9, 2021.[4]

The results of the EA

- tell us the amount of PFAS in the blood of individual participants and the Orange County community and how these levels compare to the general U.S. population,
- tell us the amount of PFAS in the urine of a subset of individual participants and the EA community and how these levels compare to the general U.S. population,
- provide a better understanding of environmental factors that 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

[4] Tied to precautions associated with the COVID-19 pandemic, ATSDR delayed in-home tap water and dust sampling until June 2021.

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

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

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

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

- eating food packaged in materials containing PFAS (e.g., popcorn bags, fast food containers, pizza boxes)
- eating fish or shellfish caught in PFAS-contaminated waters
- using 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 EA 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. Most studies estimate a half-life of PFHxS between 4.7 and 8.5 years, although some have estimated half-lives as long as 35 years [ATSDR 2021]. Most half-life estimates for PFOS are between 3.3 and 7.4 years, with a maximum of 27 years [ATSDR 2021]. For PFOA, most studies estimate the half-life between 2.1 and 3.9 years with a maximum of 10.1 years [ATSDR 2021].

The body of science about PFAS exposure and health effects is growing rapidly. Some, but not all, scientific studies have shown that exposure to certain PFAS 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 Orange County?

Orange County was one of several sites located near military installations with identified PFAS drinking water contamination from use of products such as aqueous film forming foam (AFFF). When selecting EA sites, ATSDR considered the extent of PFOA and PFOS contamination in drinking water supplies, the duration over which exposure may have occurred, and the number of potentially affected residents.[5]

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 1980s, the Stewart Air National Guard Base used AFFF containing PFAS for its firefighter training. Over time, the PFAS from the AFFF moved off site into surface water bodies used as municipal water sources.

When PFAS first entered the City of Newburgh'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 City of Newburgh came from the surface water from Washington Lake. Another surface water source, Brown's Pond, was occasionally used as a backup. Samples taken during UCMR 3 from an entry point to the distribution system at the one water treatment plant indicated that the drinking water in the City of Newburgh was contaminated with PFAS. The highest sampling result was 197 parts per trillion (ppt) for the sum of PFOA and PFOS. The highest individual measurements for PFAS were 70 ppt for PFHxS, 170 ppt for PFOS, and 27 ppt for PFOA.

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

[5]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.

of PFOA and PFOS levels in drinking water (70 ppt) in 2016, the 2013 and 2014 contamination levels were above this HA.

After the UCMR3 detections and before the City of Newburgh water supply stopped using Washington Lake water (March 2016), the New York State Department of Health (NYSDOH) collected two finished water samples from an entry point to the distribution system. PFOA+PFOS concentrations in these samples were 174 ppt and 176 ppt.

The City of Newburgh stopped using Washington Lake as its primary water source in May 2016. After this occurred, New York State Department of Environmental Conservation (NYSDEC) collected 22 additional water samples from the Washington Lake between September 2016 and July 2017. The detailed sampling results are not presented here because they characterize contamination after residents were no longer potentially exposed. However, the highest PFOA+PFOS concentration that NYSDEC measured in the lake during the time frame was 831 ppt.

In May 2016, NYSDOH collected water samples from Brown's Pond—the backup supply for the City of Newburgh. The highest PFOA+PFOS concentration reported for an entry point from Brown's Pond was 13 ppt, indicating that the backup source for the City of Newburgh also contained PFAS, albeit at considerably lower levels than Washington Lake. On June 7, 2016, the City of Newburgh switched it primary water source to New York City's Catskill Aqueduct.

The information available to ATSDR indicates that in 2021, the City of Newburgh's public drinking water met or were below the EPA's HA and New York State standards for PFAS in drinking water.

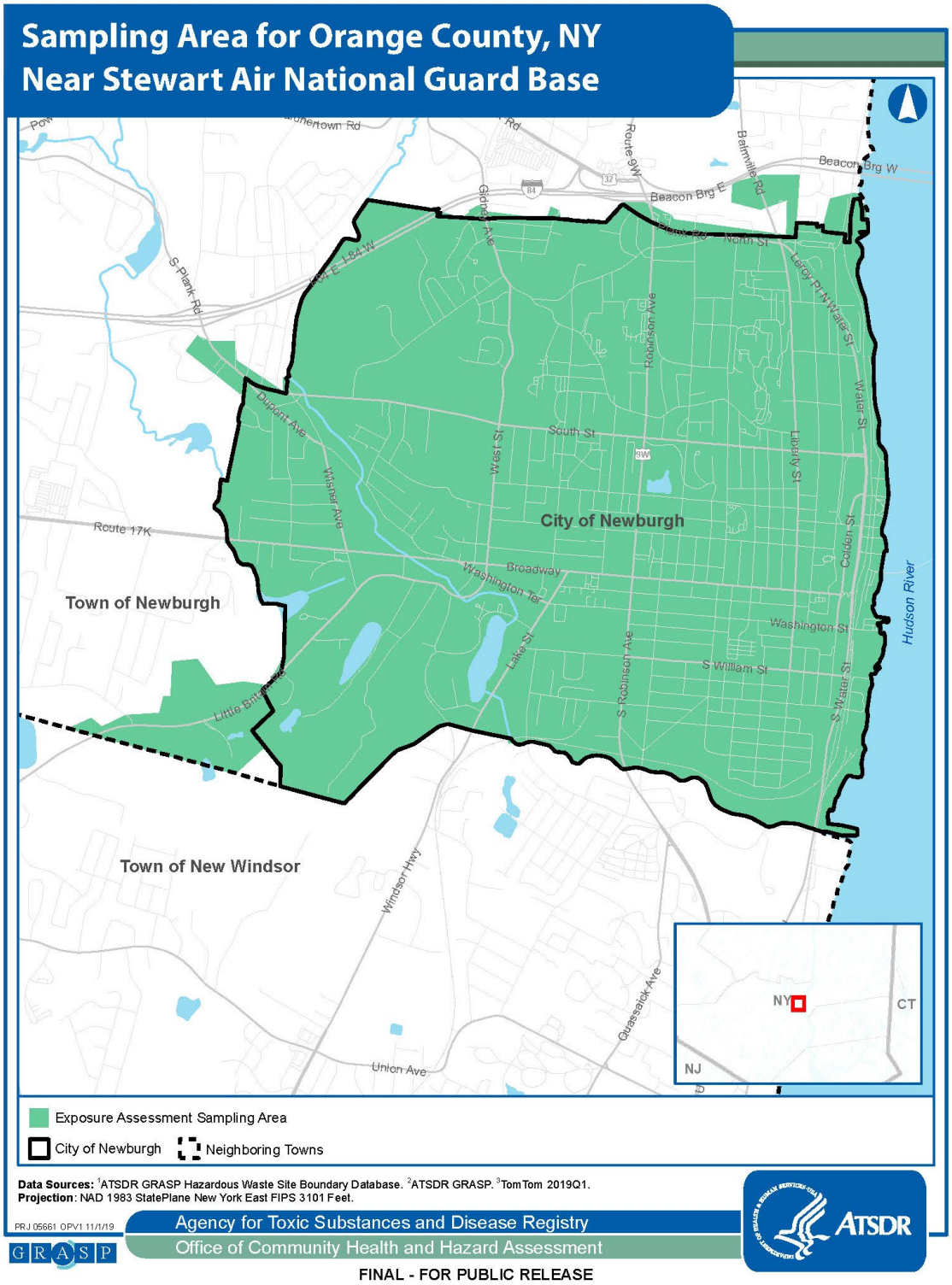
Methods

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 Orange County EA.

Sampling Frame

This EA targeted a specific geographic area, called the sampling frame or sampling area. The sampling frame for this EA included the City of Newburgh and some homes in the Town of Newburgh that were served by the City of Newburgh's public drinking water system (see Figure 1). Based on a review of Newburgh land parcel data, ATSDR determined that 9,568 households in the sampling frame were connected to the City of Newburgh's public 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.health.ny.gov/environmental/water/drinking/private_wells.htm. To learn more about previous testing for PFAS in private wells in the City of Newburgh area visit: https://www.health.ny.gov/environmental/investigations/newburgh/index.htm.

Figure 1. Sampling frame for Orange County Exposure Assessment



Participant Eligibility

Orange County residents within the sampling frame who were randomly selected to participate and met the following criteria were eligible to participate in the EA:

- Lived within the sampling frame (i.e., households served by the City of Newburgh's public drinking water supply) for at least one year before May 2, 2016, which is when the City of Newburgh Water Department reduced PFAS drinking water concentrations below EPA's HA.
- Were at least three 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 incentives and paid no costs to participate.

Participant Recruitment

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

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

Recruitment was done through mailings, phone calls, and in-person visits to households that could not be reached by phone. All recruitment materials distributed were in English and Spanish. Recruitment was paused and data collection delayed due to the initial surges of COVID-19 in March 2020. Recruitment was resumed in September 2020, just prior to biological data collection. Each household for which ATSDR had a phone number received a minimum of three recruitment call attempts. In each attempt, ATSDR called all working phone numbers (cell phone and landline) associated with a household. For calls that went to voicemail, ATSDR staff left messages encouraging residents to call back to schedule appointments. Door-to-door recruitment occurred after each household had received an initial outreach letter and at least one recruitment call attempt.

Results from the randomly selected participants can provide information about community-level exposure. Had ATSDR accepted volunteers, results could not be used to estimate exposure across the Orange County EA sampling frame. After two waves of recruitment (initially reaching out to 2,324 households and later reaching out to an additional 676 households), 74 residents from 55 households scheduled appointments for biological sampling and questionnaire completion. The low community participation rate may be due to the pause in recruitment and data collection in March 2020 due to the COVID-19 pandemic. Even when recruitment resumed and data collection was rescheduled for October 2020, the second COVID-19 wave was ramping up and may have contributed to lower community participation. Language barriers also may have played a role in the low enrollment numbers, despite ATSDR's efforts to actively engage the diverse population of Newburgh. Lastly, some community

members questioned whether the EA would answer their health questions and expressed some reluctance to participating in the EA.

ATSDR attempted to recruit approximately 10% of participating households for environmental sampling. ATSDR invited 10 households to participate, and 7 households scheduled environmental sampling appointments.

Data Collection and Analysis

The Orange County EA involved collection of three types of data: questionnaires, biological samples (blood and urine), and environmental samples (tap water and household dust). The ATSDR project team collected biological samples at 10 New Britain Road between October 23 and October 29, 2020. During this same time frame, ATSDR administered questionnaires over the phone. Due to the COVID-19 pandemic, ATSDR collected environmental samples in a subset of randomly chosen participant homes from June 8-9, 2021. All data met the stringent quality control requirements for sample collection and analysis.

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

ATSDR project staff handled all data collected in accordance with the *Standard Operating Procedures of PFAS Exposure Assessment Data Management* [ATSDR 2019b]. These procedures have very strict requirements for handling any personally identifiable information (PII). ATSDR project staff protected this information to the extent required by federal and New York law. All signed consent forms were mailed to and are securely archived at ATSDR headquarters. Questionnaire data were collected using dedicated encrypted laptops with no internet access, and these data were transferred at program completion to ATSDR's secure data network. All information provided by participants was kept confidential, and no PII 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 total 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 74 residents who scheduled data collection appointments, 61 (82%) participated in the EA. ATSDR administered exposure history questionnaires to these 61 individuals: 59 adults 18 and older, and 2 children between the ages of 3 and 17. ATSDR used one questionnaire for adults and another for children. Both addressed topics relevant to PFAS exposure, such as residential and work histories, drinking water habits, and use of PFAS-containing consumer products.

A phlebotomist collected blood samples from all 61 participants. ATSDR processed the blood samples in the field, aliquoting the serum portion of the blood.

After the sampling was complete and upon further review of each participant's residential history, ATSDR determined that two participants had not lived in the sampling frame for at least one full year before May 2, 2016, and therefore were not eligible for the study. Questionnaire and biological data for these participants were excluded from the data evaluation, but ATSDR sent them their individual results. This means that a total of 59 blood samples (58 adults and 1 child) were considered in the community exposure summary. These samples were collected from participants residing in 48 unique households.

This represents a household participation rate of 1.6% (i.e., 1.6% of the 3,000 recruited households had at least one person participate in the EA).

Urine samples were collected from 61 participants (59 adults and 2 children). Per the EA protocol, 10% of the urine samples were randomly selected for initial analysis. These 7 samples were collected from participants (7 adults) who resided in 7 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 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 six of the seven households that had initially scheduled appointments. One household was unavailable to complete their environmental sampling appointment. At each participating household, ATSDR collected a drinking water sample from the kitchen tap. If point-of-use filtration was in place, ATSDR project staff attempted to collect a sample before and after filtration. Tap water samples were collected and analyzed in accordance with EPA's *Method 537.1: Determination of Selected Per- and Polyfluorinated Alkyl Substances in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry* [Shoemaker and Tettenhorst 2018].

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

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

Table 1. Summary of recruitment and data collection efforts

Recruitment	
Households invited to participate by mail	3,000
Wave 1 of recruitment	*2,324*
Wave 2 of recruitment	*676*
Households reached by mail	2,172
Households reached by phone	541
Household door-to-door visits	2,643
Biological sampling:	
Individuals enrolled	74
Households enrolled	55
Environmental sampling:	
Households invited	*10*
Households enrolled	7
Data Collection	
Completed questionnaires	61
Adults	*59*
Children	*2*
Blood samples	
Included in community statistics (48 households)	59
Adults	*58*
Children	*1*
Urine samples	
Collected	61
Adults	*59*
Children	*2*
Included in community statistics (7 households)	*7*
Adults	*7*
Children	*0*
Dust samples collected and analyzed (one composite sample per household)	6
Tap water samples collected and analyzed (6 households)	
Filtered	5
Unfiltered	6

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 levels, and (3) explore relationships between questionnaire data and measured biological and environmental data.

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

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

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

Statistical Terms

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

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

Confidence intervals: A confidence interval provides information about the reliability of a statistic. In this EA, ATSDR estimated geometric means for the PFAS blood levels measured among study participants. The 95% confidence interval around the geometric mean represents the range within which the true population mean is expected to lie. More specifically, if we hypothetically repeated the study 100 times, 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 Orange County EA participants and all residents in the sampling frame. This was done for age, race, and ethnicity using a two-sample test for equality of proportions. To correct for participation bias, ATSDR also calculated geometric means adjusted to the age distribution of the sampling frame population using 2010 Census block data.

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

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

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

ATSDR did not conduct detailed statistical analyses for urine data because of low frequencies of detection. ATSDR analyzed a subset of urine samples and found no PFAS in any of the samples. The protocol specified that all urine samples would be analyzed if the geometric mean calculated for any site exceeded the 95th percentile from NHANES. Since no PFAS were detected, no geometric means were calculated for any PFAS in urine, and ATSDR did not analyze the remainder of the urine samples.

For tap water data, ATSDR compared PFAS levels measured with and without filtration to EPA's HA value (70 ppt for PFOA and PFOS combined) and the New York State Maximum Contaminant Level (NYS MCL; 10 ppt for PFOA and PFOS individually) [NYSDOH 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 0.14 to 0.65, 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 Orange County 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 Orange County EA participant population, but some pertain to subsets of that population. This is because some questions on the adult questionnaire only applied to females. For this EA, ATSDR does not present or analyze results for children separately due to the small number of child participants. The final report on all EA sites will include an analysis of children.

Profile of Orange County EA Participants

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

Table 3. Characteristics of Orange County EA participants

Characteristics	Count of EA Participants (n)*	Percent of EA Participants (%)†
Adults and children combined		
Age (years)	(mean = 62.3)	
<18	1	1.7
18 to 50	12	20
50+	46	78
Sex		
Male	26	44
Female	33	56
Race and ethnicity‡		
White, non-Hispanic	41	75
non-White or Hispanic	14	24
Adults only		
Years lived at current address	(mean = 21.8)	
<10	14	24
10 to <20	15	26
20 to <30	12	21
30+	17	29
Current primary drinking water source		
Public water system	43	74
Bottled water	15	26
Average tap water consumption while living at current home (8-ounce cups per day)	(mean = 6.5)	
0	4	7
>0 to <2	0	0
2 to <4	7	12
4 to <6	16	28
6 to <8	7	12
8+	23	40
Current use of treatment or filtration device		
One or more filter/treatment device(s)	33	57
None	25	43
Occupational exposures to PFAS in the past 20 years		
One or more occupational exposure(s)	6	11
None	51	89

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

† 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 62.3 years, and 75% of the participants identified themselves as White non-Hispanic. Of EA participants, 56% identified as female, 44% identified as male, and 98% 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, 76% reported living in their current homes for more than 10 years.

Adults were also asked about their current primary source of drinking water: 74% said public water system, and 26% said bottled water. Adults reported drinking an average of 6.5 8-ounce cups of water a day at home, and 57% said they currently use some type of filtering or treatment device for their drinking water. Examples include filters on refrigerators, pitchers, and faucets; whole-house carbon filtration systems; and reverse osmosis treatment systems. The questionnaire asked adults for their occupational histories over the past 20 years; 11% reported holding one or more jobs with potential PFAS exposures (e.g., firefighting, military, aviation).

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

This EA was designed to estimate PFAS levels in blood that were generalizable to the sampling frame as a whole (i.e., households that receive drinking water from the City of Newburgh's public water system). 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) than the sampling frame population (Table 4). Specifically, 78% of the EA participants reported being 50 or older, but 21% 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, 20% of the EA participants reported being 18–50 years, but 49% of the sampling frame population falls in that age range. A statistical comparison could not be conducted with children under age 18 years because only one child participated in this EA, though the proportion of children in the sampling frame is 31%.
- **Race/ethnicity.** Among the race/ethnicity characteristics, the percent of residents who identify as White, Black, and Hispanic showed a significant difference between the EA participants and the sampling frame population (Table 4). Specifically, the EA population had statistically more White participants (78%) than the sampling frame population (39%), and statistically fewer Black (7%) and Hispanic (15%) participants than the sampling frame population (30% and 48%, respectively). For this comparison, combined race and ethnicity were not available at the block level from the Census.

The effect of age and race/ethnicity 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	1	1.7	31	<0.001
18 to 50	12	20	49	<0.001
50+	46	78	21	<0.001
Race				
White	46	78	39	<0.001
Black or African American	4	7	30	<0.001
Am. Indian and AK Native	0	0	1.7	0.624
Asian	0	0	1.0	0.927
Nat. Hawaiian/Pacific Islander	0	0	0.11	1
More than one race	2	3.4	5.2	0.739
Ethnicity				
Hispanic or Latino (of any race)	9	15	48	<0.001

* Counts may not sum to total because participants may have refused to answer questions.

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

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

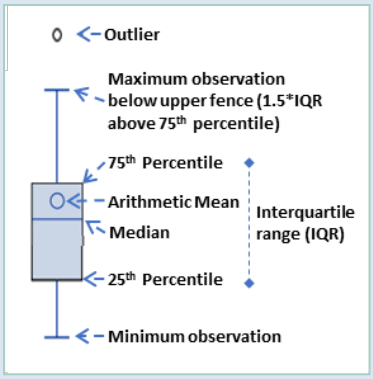
PFAS in Blood

This section summarizes PFAS levels that ATSDR measured from the 59 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 geometric mean levels of PFAS without accounting for the possible effect of age. Table 5 summarizes results for the seven PFAS measured in Orange County EA participants' blood for all ages. Six of the seven PFAS—PFHxS, PFOS, PFOA, PFNA, PFDA, and PFUnA—were detected in more than 84% of the blood samples. ATSDR's statistical analyses throughout this section focus on these six chemicals, and Figure 2 shows the distributions of the individual measurements on a $\log_{10}$ scale. The $\log_{10}$ scale allows for more easily visualizing the wide range of serum concentrations as it uses equal spacing for each factor of 10 increase. The PFAS found at highest levels were PFOS (geometric mean = 10.6 micrograms per liter (µg/L)), PFHxS (8.30 µg/L), and PFOA (2.00 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.



One PFAS—MeFOSAA—was detected in fewer than 60% of the samples. This low frequency of detection is consistent with NHANES data. Detailed statistics are not included for this chemical, and concentration percentiles (25^{th}, 50^{th}, 75^{th}, 90^{th}, 95^{th}) are shown only for measurements above the LOD.

The precision of geometric mean estimates for this EA ranged from approximately 8.8% to 37%, depending on the PFAS (Appendix B, Table B2). Except for PFOA and PFNA, these values are all below the desired precision of 15% used to determine the target sample size for this EA. The collected data met the precision target specified in the EA protocol.

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

PFAS	FOD (%)	Max	Geometric Mean	95% CI for Geometric Mean	Percentiles				
					25th	50th (Median)	75th	90th	95th
PFHxS	100	50.7	8.30	6.09–11.3	4.08	10.4	17.0	25.6	30.8
PFOS	NA*	38.0	10.6	8.01–13.9	5.78	13.2	20.3	27.9	32.1
PFOA	NA*	5.3	2.00	1.65–2.42	1.35	2.22	3.11	4.68	4.90
PFNA	98.3	6.2	0.513	0.399–0.658	0.296	0.506	0.678	0.905	1.15
PFDA	96.6	0.8	0.216	0.187–0.250	0.119	0.178	0.249	0.295	0.368
PFUnA	84.7	0.7	0.157	0.133–0.184	NA†	0.121	0.178	0.252	0.305
MeFOSAA	45.8	1.0	NA‡	NA‡	NA†	NA†	0.158	0.405	0.605

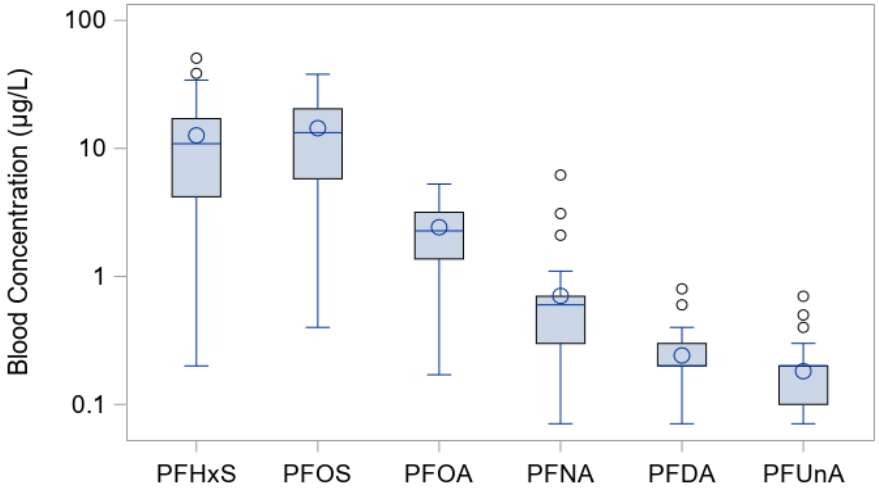
FOD = frequency of detection, CI = confidence interval, NA = not applicable

* PFOA and PFOS are calculated sums of branched and linear subsets and are not measured directly. Linear PFOA was detected in 100% of samples with a geometric mean of 1.90 micrograms per liter (µg/L); branched PFOA was detected in 1.7% of samples. Linear PFOS was detected in 100% of samples with a geometric mean of 7.18 µg/L; branched PFOS was also detected in 100% of samples, but with a geometric mean of 3.27 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.[6] 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 74% and 73% 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. Because there were very few young adults or children who participated in the EA, these age-adjusted calculations may still not be fully adjusted to the sampling frame population. 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	8.30	6.09–11.3	2.12	1.89–2.38
PFOS	10.6	8.01–13.9	2.82	2.62–3.03
PFOA	2.00	1.65–2.42	1.01	0.932–1.10
PFNA	0.513	0.399–0.658	0.196	0.182–0.212
PFDA	0.216	0.187–0.250	0.143	0.134–0.151
PFUnA	0.157	0.133–0.184	0.104	0.0963–0.112
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 Orange County EA participants to levels found in the U.S. general population. To explore effects related to differences in the age distribution of EA participants vs. the NHANES populations, ATSDR compared both unadjusted geometric means of all EA participants and geometric means adjusted to the age distribution of the U.S. population in NHANES 2015–2016.

Table 7 shows the unadjusted comparison for the entire pool of EA participants to the data available from NHANES, which are the geometric means for the 2015–2016 survey [CDC 2019]. For PFHxS, PFOS, PFOA, and PFDA, unadjusted geometric mean blood levels among Orange County EA participants were statistically ($p<0.05$) higher than the national geometric mean. For PFNA, no significant difference was observed between Orange County EA participants and the general U.S. population. Geometric means were not calculated during NHANES for PFAS detected in less than 60% of samples, which included PFUnA and MeFOSAA. In this EA, PFUnA was detected in over 60% of samples and geometric means were calculated.

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

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 Orange County EA participants was 7.0 times the national level. Blood PFHxS levels were above the national geometric mean for 95% of the Orange County EA participants and above the NHANES 95th percentile for 70% (Table 7). The unadjusted geometric mean blood PFOS and PFOA levels among Orange County EA participants were 2.2 and 1.2 times the national level, respectively. Blood PFOS levels were above the national geometric mean for 80% of the EA participants and above the NHANES 95th percentile for 34%. Blood PFOA levels were above the national geometric mean for 73% of Orange County EA participants and above the NHANES 95th percentile for 14%.

On average, total PFOS measurements were composed of 69% linear PFOS (n-PFOS) and 31% branched PFOS (Sm-PFOS). The proportion of n-PFOS found in EA participants' blood is lower than that found in standard PFOS products (76%–79%) [Kärrman et al. 2007] but comparable to levels found in the blood of the general U.S. population [CDC 2019]. Measurements of total PFOA were composed of 96% linear PFOA (n-PFOA) and 4% branched PFOA (Sb-PFOA), which is also comparable to the proportions found in the U.S. population [CDC 2019]. All remaining statistical analyses in this report focus on total PFOA and 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 there were very few young adults or children over 12 (e.g., 1 child participant and no adults under 30 years), these age-adjusted calculations may still not be fully adjusted to the NHANES population. 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 Orange County EA participants was 3.0 times the national level. The age-adjusted geometric mean blood PFOS and PFOA levels among Orange County EA participants were not higher than the national levels. Even when controlling for the age-distribution in the population, EA participants had statistically higher blood levels of PFHxS than the U.S. population.

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

PFAS	NHANES GM (CI)*	Orange County GM (CI)†: Unadjusted	Orange County GM (CI)†: Age-Adjusted to NHANES 2015-2016	Percent of Orange County Results over NHANES GM (%)	NHANES 95th Percentile*	Orange County 95th Percentile	Percent of Orange County Results over NHANES 95th Percentile (%)
PFHxS	1.18 (1.08–1.30)	8.30 (6.09–11.3) *p<0.001*	3.56 (3.00–4.22) *p<0.001*	94.9	4.90	30.8	69.5
PFOS	4.72 (4.40–5.07)	10.6 (8.01–13.9) *p<0.001*	4.76 (4.23–5.35) *p=0.907*	79.7	18.3	32.1	33.9
PFOA	1.56 (1.47–1.66)	2.00 (1.65–2.42) *p=0.015*	1.32 (1.17–1.49) *p=0.013*	72.9	4.17	4.90	13.6
PFNA	0.577 (0.535–0.623)	0.513 (0.399–0.658) *p=0.363*	0.293 (0.259–0.331) *p<0.001*	50.9	1.90	1.15	5.08
PFDA	0.154 (0.140–0.169)	0.216 (0.187–0.250) *p<0.001*	0.171 (0.158–0.186) *P=0.075*	83.1	0.700	0.368	1.69
PFUnA	NA‡	0.157 (0.133–0.184) §	0.126 (0.113–0.141) §	NA	0.400	0.305	3.39
MeFOSAA	NA‡	NA‡	NA‡	NA	0.600	0.605	5.08

CI = 95% confidence interval, NA = not applicable

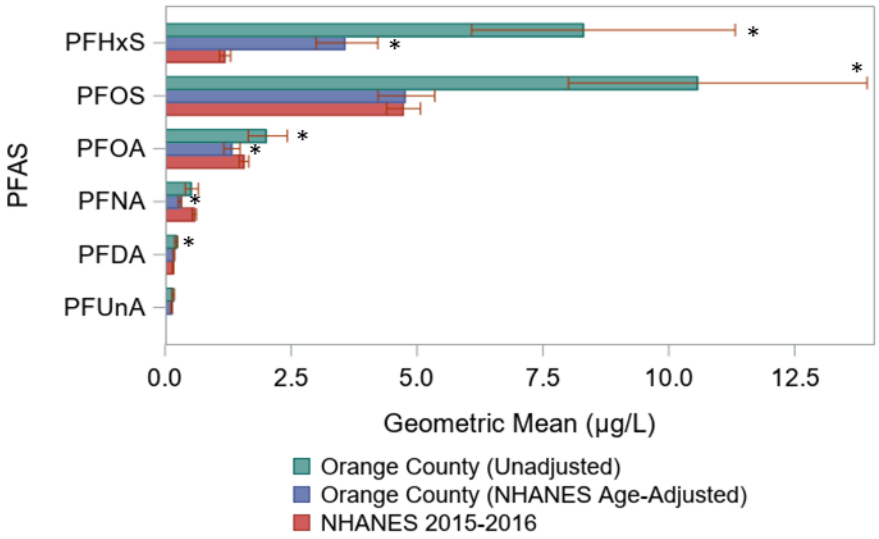
* Source: CDC 2019

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

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

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

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



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

Correlations Among PFAS in Blood

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

PFHxS and PFOS blood levels showed the strongest correlation with Pearson correlation coefficients close to 1 (*r* = 0.93, Table 8). PFOA blood levels were also strongly correlated with PFHxS and PFOS blood levels (*r* = 0.78–0.79). On the other hand, PFNA, PFDA, and PFUnA were more correlated with one another (*r* = 0.56–0.77).

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

	PFHxS	PFOS	PFOA	PFNA	PFDA	PFUnA
PFHxS	1.00	0.93	0.79	0.52	0.33	0.10*
PFOS	0.93	1.00	0.78	0.62	0.51	0.23*
PFOA	0.79	0.78	1.00	0.64	0.49	0.21*
PFNA	0.52	0.62	0.64	1.00	0.71	0.56
PFDA	0.33	0.51	0.49	0.71	1.00	0.77
PFUnA	0.10*	0.23*	0.21*	0.56	0.77	1.00

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

PFAS Blood Levels by Demographics and Other Exposure Characteristics

This section examines how the demographic and exposure history information collected during the questionnaire relates to blood PFAS levels. Different questionnaires were administered to adult and child participants. Here we focus on adults only. Additionally, some questions were applicable only to

female adult participants and are therefore also presented separately. Appendix C (Table C1) presents a complete summary of all adult questionnaire responses.

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

- age,
- sex,
- race/ethnicity,
- length of residence in the sampling frame,
- fruit and vegetable consumption, and
- number of biological children (adult females only).

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

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

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

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

Parameter	PFHxS			PFOS			PFOA			PFUnA		
	All Adult	Adult Female	Adult Male	All Adult	Adult Female	Adult Male	All Adult	Adult Female	Adult Male	All Adult	Adult Female	Adult Male
Age (continuous)	✓	✓	—	✓	✓	—	✓	✓	—	—	—	—
Sex (categorical)	✓	NA	NA	✓	NA	NA	✓	NA	NA	—	NA	NA
Age × sex (continuous)*	✓	NA	NA	✓	NA	NA	✓	NA	NA	—	NA	NA
Years in sampling frame in the past 20 years [Residency duration] (continuous)	✓	✓	—	✓	✓	—	✓	✓	—	✓	—	✓
Water source [public water system or bottled water] (categorical)	✓	—	—	—	—	—	—	—	—	—	—	—
Fruit and Vegetable Consumption (categorical)	—	—	—	—	—	—	—	—	—	✓	—	✓

✓ = 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.

- Table C1 presents response frequencies for all questions included in the adult questionnaire. This table also presents geometric means and 95% confidence intervals around geometric means stratified by the response options (e.g., statistics are presented separately for males and females) for PFHxS, PFOS, PFOA, PFNA, PFDA, and PFUnA. 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.
- Table C2 presents univariate modeling results for all questions in the adult questionnaire for the same six 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 C3–C10 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 0.21 to 0.77. 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<10).
- Figures C1–C21 present box and whisker plots for unadjusted blood levels by each demographic and exposure characteristic included in the statistical analyses.

Goodness of Fit Measure

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

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

Blood PFAS Levels and Age

Because many studies have found that older people have higher blood PFAS levels, ATSDR investigated how Orange County EA participants' ages related to their blood levels. As the trendlines in Figure 4 indicate, ATSDR's univariate analysis showed that blood PFHxS, PFOS, and PFOA were higher in older adults than in younger adults, and this finding was statistically significant. PFHxS and PFOS had the strongest age dependence. The univariate analysis indicates that on average, blood PFHxS levels in Orange County EA participants increased 3.9% for every year of participant age in adults and blood PFOS levels

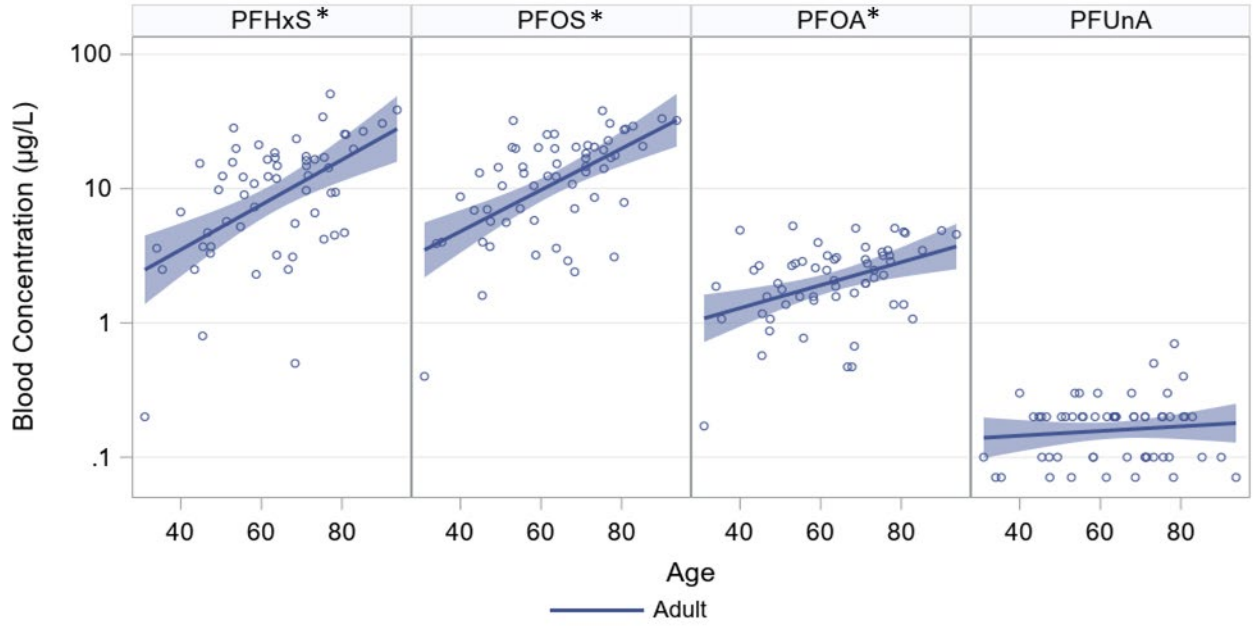
Variability describes the spread or dispersion of data values. If the values are similar to each other there is little variability, if the values are spread out there is more variability.

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.

increased by 3.6% per year. This suggests a 47% and 42% increase in blood PFHxS and PFOS levels for every 10 years of participant age in adults, respectively. The calculated increase for PFOA (2.0% per year of participant age) was lower.

ATSDR's multivariate analysis provided further perspective on this trend, showing that blood PFAS levels increased with participant age only for women, and that blood levels decreased with participant age in men. For example, the all-adult model (Appendix C, Table C5) suggests a 5.4%, 3.3%, and 2.4% increase in blood PFHxS, PFOS, and PFOA levels in adult females for every year of participant age, respectively, and a 1.3%, 0.77%, and 0.58% decrease in blood levels in adult males for every year of participant age when controlling for other characteristics. The decreasing association with age in males was unexpected, possibly due to the small number of young adults in the EA. Similar results were observed in the stratified female-only models, where age remained a significant predictor of blood levels for all three PFAS, but age was not significant in male-only models.

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



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

Blood PFAS Levels by Sex

ATSDR investigated how blood PFAS levels vary between males and females because previous research has shown that, all other factors considered equal, adult males tend to have higher blood PFAS levels than adult females. ATSDR's univariate analysis did not reveal a significant relationship between blood PFAS levels and sex. However, multivariate analyses showed that PFAS levels were higher in adult males than in adult females for PFHxS, PFOS, and PFOA, and that the difference between males and females was larger in younger adults.

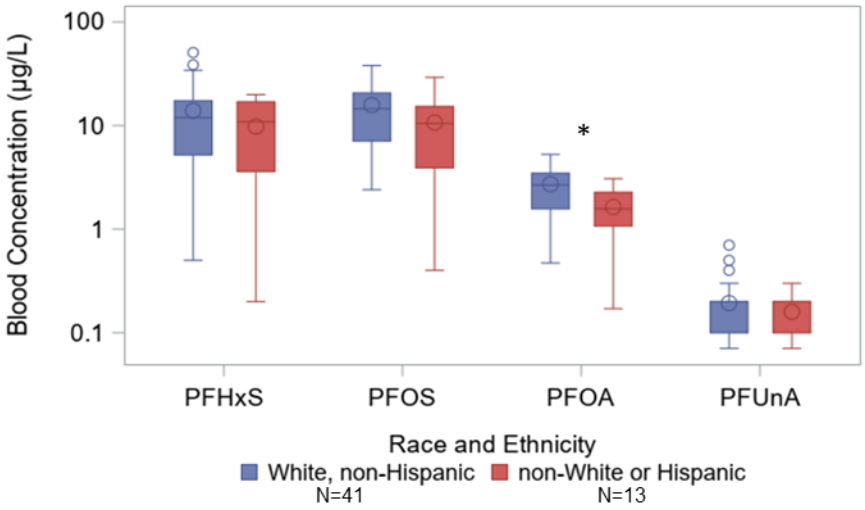
Blood PFAS Levels by Race/Ethnicity

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 Orange County EA participants who self-identified as White, non-Hispanic and those who identified as non-White, or Hispanic.

Figure 5 shows that on average, when compared to those who identified as White, non-Hispanic, blood PFOA levels in non-White or Hispanic participants were 44.5% lower 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 5. 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 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, 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?" All responses were either tap water (74%) or bottled water (26%). There were no statistically significant differences in blood levels between these two groups in univariate analyses. However, in multivariate analyses, which controlled for other potential confounders, participants who reported primarily drinking bottled water had blood PFHxS levels that were 50% higher than those who reported primarily drinking tap water. This association with PFHxS is in the opposite direction as expected and 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; 3% reported switching from public water to bottled water in the past year. However, since drinking water exposure in Orange County 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 and multivariate analyses did not reveal a significant linear relationship between blood PFAS levels and the amount of tap water consumed.

For adults, ATSDR also considered the length of residency. The exposure history questionnaire asked adults where they had lived for the past 20 years. ATSDR calculated the total amount of time participants reported living in the City of Newburgh 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 City of Newburgh drinking water supply. Any resident reporting prior residences in the sampling frame area (City of Newburgh and a small portion of the Town of Newburgh) 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.

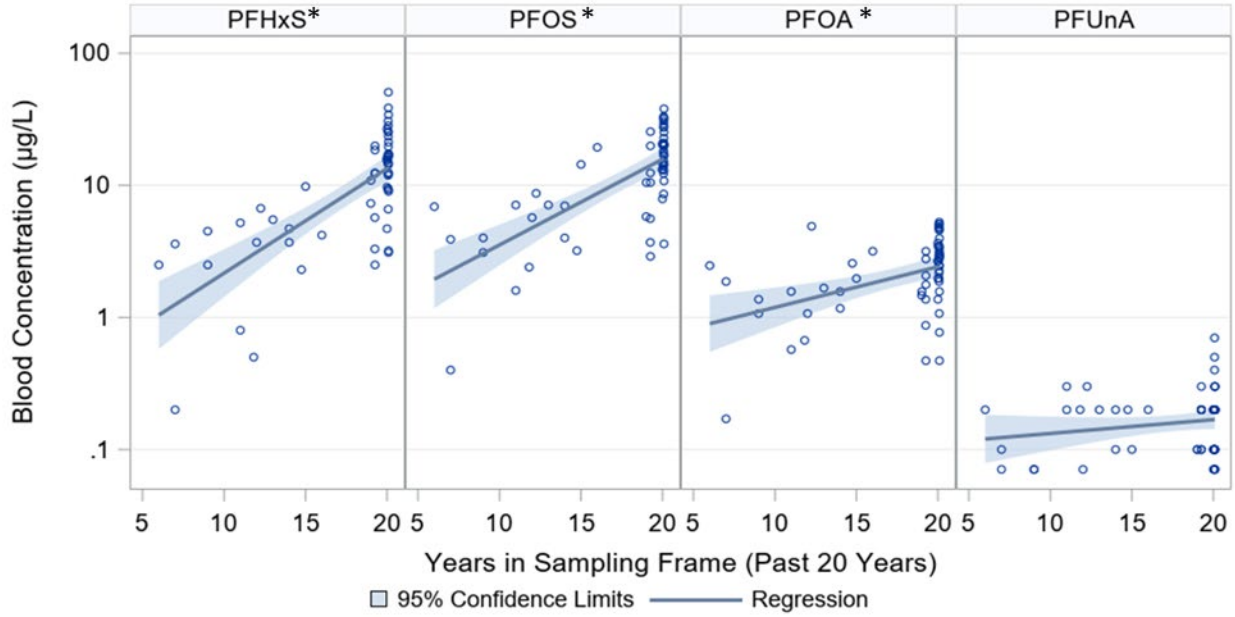
Figure 6 shows the relationship between reported residence duration in the City of Newburgh for the past 20 years and blood PFAS levels. A consistent relationship was observed for PFHxS, PFOS, and PFOA: blood levels increased with the number of years participants lived in the sampling frame, and this effect was most pronounced for PFHxS. The multivariate analyses showed that the association with residency duration remained significant for PFHxS, PFOS, and PFOA and was also significant for PFUnA: for every additional year that an adult participant lived in City of Newburgh, blood PFHxS increased by 19%, PFOS by 15%, PFOA by 7%, and PFUnA by 4%. In female-only models, these associations were significant and larger for PFHxS, PFOS, and PFOA. The association was not significant in male-only models for these compounds, suggesting that the relationship was primarily observed in female participants. In contrast, for PFUnA, the relationship only remained significant in male-only models.

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.

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 City of Newburgh's drinking water sources (PFHxS at 70 ppt, PFOS at 170 ppt, and PFOA at 27 ppt). Therefore, one explanation for the high correlation among these compounds in the blood is that the Orange County EA participants had a common exposure profile for PFHxS, PFOS, and PFOA, such as drinking water. However, the correlations alone cannot be used to identify the underlying source or combination of sources that contributed most to exposure.

Figure 6. PFAS blood levels in adults by length of residence in sampling frame (log scale)



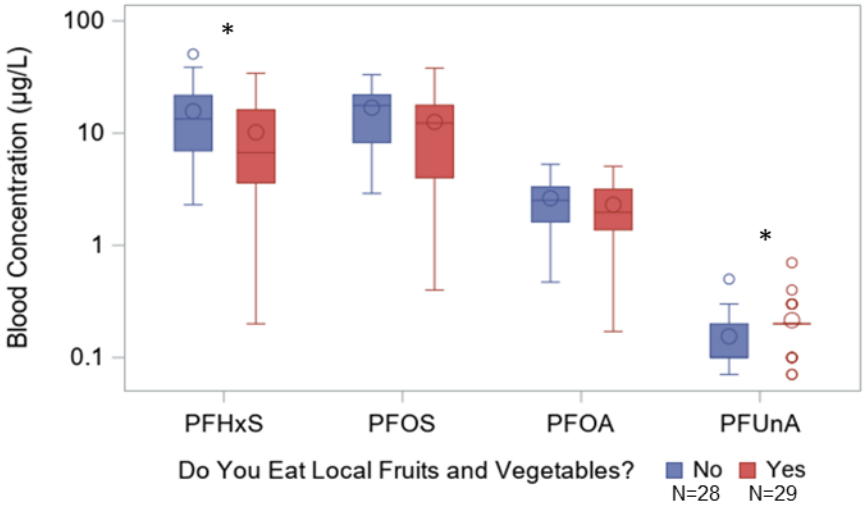
A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically Significant Trend (p<0.05)*

Blood PFAS Levels and Consumption of Selected Local Food Items

Some PFAS accumulate in plants, fish, and animals. The questionnaire asked 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=5) or locally produced milk (n=4) 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 7 shows, blood PFHxS and PFUnA levels were statistically different among the 49% of adult EA participants who reported any locally grown produce consumption than among participants who reported no such consumption. PFHxS blood levels were 46% lower and PFUnA levels were 44% higher among adult participants who reported consuming local fruit and vegetables. However, when controlling for other factors, these relationships only remained statistically significant in multivariate analyses for PFUnA, and local fruit and vegetable consumption was associated with a 61% decrease in PFUnA levels.

Figure 7. 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 Past PFAS Blood Levels

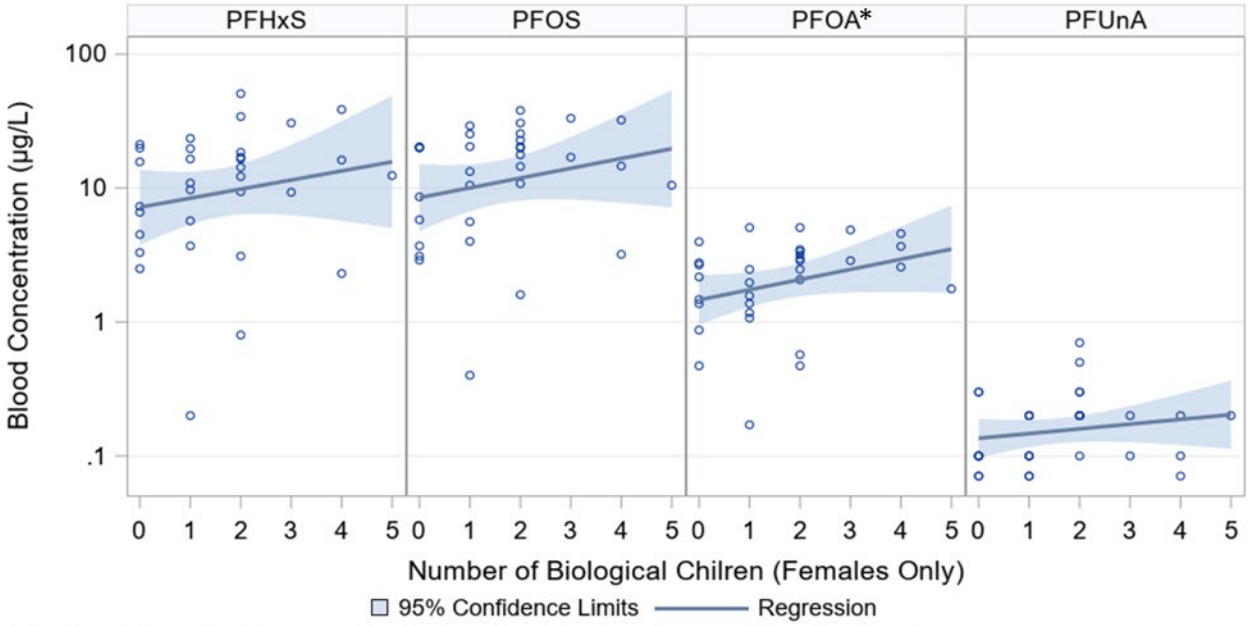
Adult participants were asked if they previously had their blood tested for PFAS. 23 EA participants from 18 households submitted blood PFAS test results from the New York State Department of Health (NYSDOH) blood testing program, which tested PFAS levels in approximately 3,763 people in the Newburgh area from November 2016 through December 2017 (information can be found online at: https://www.health.ny.gov/environmental/investigations/newburgh/docs/infosheetgroupresults.pdf).

Blood PFAS levels decreased in all participants between 17% to 80% for PFHxS, 34% to 86% for PFOS, and 17% to 80% for PFOA. This corresponds to an average annual decrease of 5% and 22% per year for PFHxS, between 8% and 23% per year for PFOS, and between 5% and 22% per year for PFOA. ATSDR also calculated half-life estimates for each participant. The average half-life was 6.2 years (range: 1.6–13.2 years) for PFHxS, 3.8 years (1.3–6.5 years) for PFOS, and 5.0 years for PFOA (1.5–11.6 years).

Blood PFAS Levels and Childbirth (adult females only).

The adult questionnaire asked female participants whether they had any biological children, and if so, how many. Most adult female EA participants (81%) reported having biological children. In univariate models, blood PFAS levels in females who reported ever having a biological child was not significantly different than levels of those who reported not having a child. However, Figure 8 shows that the number of children was associated with blood PFOA levels. The more children a female participant had the higher their blood PFOA levels (19% per child). Though this association is the opposite of what is expected, it was not statistically significant in multivariate models indicating potential confounding by other factors such as age.

Figure 8. PFAS blood levels in female adults by number of biological 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)*

Blood PFAS Levels and Other Variables

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

- **Blood donation frequency.** Adult participants were asked how often they donate blood or plasma, because frequent blood and plasma donations might result in decreasing blood PFAS levels. Relatively few participants (n=11) reported donating blood once or more a year, and no statistically significant relationship was observed with blood PFAS levels in adults.
- **Soil exposure.** Adult and child participants were asked how often they play in or touch soil or dirt in the sampling frame. No statistically significant relationship was observed for self-reported soil contact frequency and blood PFAS levels in adults. As noted, children were not evaluated due to the low number of child participants.
- **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.
- **Stain-resistant product use.** Many stain-resistant products used to treat fabrics and carpet have been formulated with PFAS. The exposure history questionnaire asked adult participants how frequently they used these products, such uses may be associated with PFAS exposures. Too few Orange County EA adult participants self-reported ever using stain-resistant products (n=5) to conduct statistical analyses.

- **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 Orange County EA adult participants, reported frequency of fast food consumption was not statistically associated with blood PFAS levels. In recent years, fast food packaging has likely been reformulated to contain shorter chain PFAS compounds. This shift may make it more challenging to link PFAS exposure to fast food consumption.
- **Kidney disease.** The exposure history questionnaire asked about kidney disease because it can affect blood PFAS levels [Barry et al. 2013; Watkins 2013]. Only two adults reported a diagnosis of kidney disease, so statistical analyses were not conducted. Note also that kidney disease was self-reported and there may be misclassification with this variable.
- **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. Only six adults identified working in at least one job with potential exposures to PFAS in the past 20 years, so statistical analyses were not conducted.
- **Breastfeeding.** During breastfeeding, some PFAS in the breast milk might be transferred from mother to child. Therefore, breastfeeding can reduce PFAS levels in mothers and increase PFAS levels in their breastfed children [Kim 2020; Kingsley 2018]. Accordingly, the adult and child exposure history questionnaires included questions about breastfeeding. A question was also included for children about their consumption of formula (as opposed to breast milk), if was made using tap water. Only adult female data were evaluated. Among adult female EA participants, 47% reported that they had breastfed a child. No statistically significant associations were observed between ever breastfeeding or the duration of breastfeeding and PFAS blood 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 Orange County EA, ATSDR randomly selected 7 participants' urine samples for analysis. These samples were provided by 7 adults, and these individuals lived in 7 different households. No PFAS were detected in any of the urine samples. 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 the analyzed samples, geometric means were not calculated for any PFAS in urine and ATSDR did not analyze the remainder of the urine samples.

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

PFAS in Tap Water

As noted previously, ATSDR collected 11 tap water samples from six randomly selected participant households and analyzed these samples for PFAS. PFAS were not detected in any of the 6 unfiltered and 5 filtered water samples collected from these homes. Therefore, summary statistics were not calculated for any PFAS. The detection limits were far below EPA's HA of 70 ppt for PFOA and PFOS combined and New York State standards for PFAS in drinking water. Detection limits were 2 ppt for all PFAS, except for HFPO-DA (5 ppt).

PFAS in Household Dust

ATSDR collected dust samples from the same six 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 10 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 10 (i.e., PFNS, PFDoS, PFOSA, N-MeFOSA, N-EtFOSA, N-EtFOSE, FtS 4:2, HFPO-DA, DONA, 9CL-PF3ONS, and 11CL-PF3OUdS).

Table 10. Summary statistics for dust samples (n=6) collected in Orange County

PFAS	FOD (%)	Maximum Detected Result (ng/g)	Geometric Mean (ng/g)	95% Confidence Interval for Geometric Mean (ng/g)	Percentiles (ng/g)		
					50th (Median)	90th	95th
PFBS	67	20.0	3.50	1.34–9.17	2.56	10.3	15.2
PFPeS	17	3.5	NA*	NA*	1.41	2.93	3.19
PFHxS	50	560	NA*	NA*	2.31	227	393
PFHpS	17	3.1	NA*	NA*	1.41	2.79	2.97
PFOS	83	383.0	12.4	1.59–95.9	3.97	178	281
PFDS	33	4.3	NA*	NA*	1.42	3.33	3.82
PFBA	50	40.8	NA*	NA*	10.3	28.8	34.8
PFPeA	33	6.1	NA*	NA*	2.81	6.02	6.06
PFHxA	67	30.7	6.16	1.72–22.0	3.00	23.0	26.8
PFHpA	50	20.3	NA*	NA*	2.56	14.6	17.5
PFOA	83	57.5	10.7	2.39–47.4	4.10	41.6	49.6
PFNA	50	178.0	NA*	NA*	2.56	102	140
PFDA	50	30.5	NA*	NA*	2.56	17.9	24.2
PFUnA	50	56.0	NA*	NA*	1.96	31.0	43.5
PFDoA	50	9.5	NA*	NA*	2.56	7.76	8.63
PFTrA	33	6.9	NA*	NA*	1.41	5.63	6.25
PFTA	50	8.1	NA*	NA*	2.56	6.34	7.23
MeFOSAA	33	32.8	NA*	NA*	1.42	17.8	25.3
N-MeFOSE	33	102.0	NA*	NA*	14.2	90.9	96.5

PFAS	FOD (%)	Maximum Detected Result (ng/g)	Geometric Mean (ng/g)	95% Confidence Interval for Geometric Mean (ng/g)	Percentiles (ng/g)		
					50th (Median)	90th	95th
EtFOSAA	83	73.5	16.1	4.51–57.6	17.4	50.8	62.2
FtS 6:2	17	25.7	NA*	NA*	5.06	15.8	20.7
FtS 8:2	33	25.2	NA*	NA*	5.69	19.0	22.1

FOD = frequency of detection, ng/g = nanograms per gram, NA = not applicable
A total of 6 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.

PFBS, PFOS, PFHxA, PFOA, and EtFOSAA were detected in more than 60% of the households evaluated. Of these, PFOS, PFOA, and EtFOSAA were measured at the highest levels on average, with geometric mean values of 12.4 nanograms/gram (ng/g)[7] (95% confidence interval = 1.6–95.9 ng/g), 10.7 ng/g (2.4–47.4 ng/g), and 16.1 ng/g (4.5–57.6 ng/g), respectively. The other PFAS had geometric mean concentrations less than 6.2 ng/g. Geometric means were not calculated for any other PFAS because these PFAS were detected in less than 60% of samples.

To provide some context to the results summarized above, average levels of PFAS measured in the six samples collected as part of this EA were compared to average dust levels reported in other U.S.-based studies (in areas with or without known PFAS contamination). This includes evaluations of indoor dust collected at 30 homes in the greater Boston area [Fraser et al. 2013], 124 homes in California [Wu 2015], 15 U.S. homes [Karásková et al. 2016], and 19 homes in Minnesota cities with PFAS-contaminated soil and drinking water [Scher et al. 2018]. Across these studies and as in this EA, PFOA and PFOS were consistently reported at the highest concentrations. Geometric mean concentrations ranged from 24 to 45 ng/g for PFOA and 27 to 35 ng/g for PFOS (Fraser et al. 2013; Wu et al. 2015]. Two of the studies did not report geometric means; for these studies, median concentrations were reported at 9 ng/g and 51 ng/g for PFOA and 14 ng/g and 67 ng/g for PFOS [Karásková et al. 2016 and Scher et al. 2018, respectively]. Geometric mean and median concentrations for PFOA and PFOS measured in the 6 samples collected as part of this EA were generally in the range of 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 Orange County 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 6 dust samples summarized above and from the 7 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.

[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.

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 0.14 to 0.75, indicating potential correlation between concentrations measured in dust and blood. Note that the sample size for dust measurements in Orange County is small. ATSDR will further explore these findings, as well as correlations between different PFAS measured in dust and blood (e.g., the correlation between PFOA in dust and PFOS in blood) in the report for all ATSDR PFAS EA sites.

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

Discussion

At least one PFAS was detected in the blood of all Orange County EA participants (100%). Because of the widespread use of PFAS, such high detection frequencies are common in the general U.S. population [CDC 2019]. PFHxS, PFOS, PFOA, PFNA, PFDA, and PFUnA were the most frequently detected compounds for Orange County (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 were statistically higher than the national geometric mean (3.0 times the national level), and age-adjusted blood concentrations of PFOS, PFOA, PFNA, and PFDA were similar to or lower than national geometric means. EA participants had statistically higher blood PFHxS levels than national levels.

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

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

- For PFHxS, blood levels among Orange County EA participants are higher than those observed in other communities with contaminated drinking water. The levels reported here are also higher than the national geometric mean PFHxS levels for 1999–2000 (2.1 ppt respectively), the time NHANES first measured PFAS and the time the highest PFAS levels were observed [CDC 2019].
- PFOS and PFOA, on the other hand, did not exhibit these trends. These substances' blood levels in Orange County EA participants were withing the range of those observed in other communities with contaminated drinking water. PFOS and PFOA blood levels reported here are

[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 report analyzing data across all sites.

lower than the national geometric mean levels for 1999–2000 (30.4 ppt and 5.2 ppt respectively) [CDC 2019].

Generalizability of Orange County 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., City of Newburgh and a small portion of Town of Newburgh households). Although the population invited to participate was likely representative of the sampling frame, the population that ultimately enrolled was older, contained more White participants, and contained fewer Black and Hispanic participants. Specifically, adults aged 50 or older represented 78% of the EA population compared with 21% of the sampling frame. White participants represented 78% of the EA population and 39% of the sampling frame population, Black participants represented 7% of the EA population and 30% of the sampling frame population, and Hispanic participants represented 15% of the EA population and 48% of the sampling frame population. Given the 1.6% response rate, it is also possible that other factors were present at different rates than the community as a whole.

Since both age and ethnicity were associated with blood PFAS levels in univariate analyses, the summary statistics for blood PFAS (Table 5) may be biased, or deviate from the true value, when generalizing to the entire sampling frame. ATSDR believes that any bias caused by differences in ethnicity would be minimal because 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 74% and 73%, respectively. Therefore, the sampling frame age-adjusted geometric means for PFHxS and PFOS may be more representative of the average levels in the community. However, since very few young adults or children participated in the EA, these age-adjusted calculations may still not be fully representative of the sampling frame population. The biases caused by the older EA population for the remaining PFAS were between 34% and 62%.

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 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) and breastfeeding were not found to be statistically associated with PFAS blood levels among adult women in multivariate analyses.

Blood PFAS levels were statistically higher in older female adults than younger female adults. However, the reverse association was seen in males: older adult males had lower PFAS levels than younger adult males. Positive associations of blood PFAS levels with age in adults have been observed in other studies

[ATSDR 2013; NH DPHS 2016; CDC 2019]. Generally, increasing blood levels in adults are due to the long biological half-lives of PFAS and diminishing excretion rates with increasing age. The half-life of a chemical is the amount of time it takes for 50% of the substance to be eliminated from the body. Most studies estimate a half-life of PFHxS between 4.7 and 8.5 years, although some have estimated half-lives as long as 35 years [ATSDR 2021]. Most half-life estimates for PFOS are between 3.3 and 7.4 years, with a maximum of 27 years [ATSDR 2021]. For PFOA, most studies estimate the half-life between 2.1 and 3.9 years with a maximum of 10.1 years [ATSDR 2021]. In the presence of continued exposures that exceed clearance rates, PFAS will accumulate in the human body over time. In this EA, this association was only observed in female participants. As noted previously, the decreasing association with age in males was not expected and possibly due to the small number of young adults in the study.

Blood PFAS levels were statistically lower in univariate analyses 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]. In this EA, the associations between PFAS and race/ethnicity was not significant in multivariate analyses.

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:

- Three PFAS (PFHxS, PFOS, and PFOA) were detected in City of Newburgh's water supply as early as 2013. We do not know if contamination began earlier because no data are available before 2013. In 2013, the maximum concentrations observed in the City of Newburgh drinking water supply were 70 ppt for PFHxS, 170 ppt for PFOS, and 27 ppt for PFOA. In 2016, the City of Newburgh mitigated the contamination; however, these PFAS have very long biological half-lives (on the order of years). Therefore, even though drinking water PFAS exposures in the Newburgh area were significantly reduced in May 2016, past drinking water exposures were likely a contributing factor to the EA participants' elevated blood PFAS levels, observed 4 years and 5 months later. Furthermore, in this EA, PFHxS had the largest deviation from national levels and was the only PFAS with statistically elevated blood levels in comparison to the 2015-2016 NHANES geometric mean, which is what would be expected given that PFHxS has the longest half-life of the three PFAS.
- PFHxS, PFOS, and PFOA were highly correlated in blood (*r* between 0.78 and 0.93), 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 Orange County EA participants. In addition, the correlations between PFHxS, PFOS, and PFOA in this EA are much higher than the correlations observed for PFNA and PFDA, two compounds that were not found in City of Newburgh'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 and around the City of Newburgh. 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, PFOS, PFOA, and PFUnA levels. However, multivariate models conducted separately for males and females suggest that the relationships for PFOS, PFOA, and PFUnA were primarily observed in male participants. Multivariate regression models explained a large portion of the variability in participants' blood PFHxS and PFOS levels (R^2 = 0.65 in the "all adult" models), indicating the strength of residency duration as a predictor of blood levels of these two PFAS.
- One line of evidence that ATSDR considered and dismissed was the association between EA participants' self-reported drinking water source (public water or bottled water) and blood PFHxS 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 City of Newburgh'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. 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 observed in the Orange County EA participants.

Other Exposure Characteristics

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

- **Consumption of selected local food items.** Some PFAS accumulate in plants, fish, and animals. In univariate models, participants who reported eating locally grown fruits or vegetables (49%) had significantly higher blood levels of PFHxS and PFUnA. This finding remained statistically significant in multivariate regressions for PFUnA. While higher levels of PFUnA were higher in participants who consumed local produce, PFUnA blood levels were not elevated in the community.

Orange County Community-Wide Findings

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

Geometric means (i.e., averages) for PFHxS blood levels were statistically higher ($p<0.05$) in Orange County EA participants when compared to CDC's NHANES (2015–2016) data, which was limited to people over 12 years old. The statistically higher blood PFHxS 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, only PFHxS was elevated when compared to national levels. The age-adjusted geometric mean blood PFHxS level among all Orange County EA participants was 3.0 times the national level. Blood PFHxS levels were above the national geometric mean for 95% of the Orange County EA participants and above the NHANES 95th percentile for 70%.

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

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

PFHxS, PFOS, and PFOA were detected in the City of Newburgh drinking water as early as 2013. Because no data are available prior to 2013, we do not know if contamination began earlier. Only one of these PFAS (PFHxS) had statistically elevated blood levels compared to national geometric means. The maximum concentrations observed in finished City of Newburgh drinking water were 70 parts per trillion (ppt) for PFHxS, 170 ppt for PFOS, and 27 ppt for PFOA in 2013 and 2014.

In 2016, the City of Newburgh reduced concentrations of PFAS below U.S. EPA HA levels (70 ppt for PFOA and PFOS combined) by switching its water source. 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 (on the order of years). There were 4 years and 5 months between when the City of Newburgh changed water sources to reduce exposure to contaminated drinking water and collection of biological samples during the EA. Because of the long half-lives of PFHxS, PFOS, and PFOA, past drinking water exposures may have contributed to the EA participants' blood levels. PFHxS has the longest estimated half-life of the three compounds (up to 35 years), which may contribute to why it exceeded the NHANES 2015-2016 geometric mean by the largest margin.

An additional observation supports the finding that past exposure to contaminated drinking water may have contributed to the elevated blood levels. In univariate and multivariate models, a consistent and statistically significant predictor of participant blood levels for PFHxS was how long the resident had lived in the sampling frame (City of Newburgh and a small portion of the Town of Newburgh) before January 2016. Those who lived in the area longest likely drank, in total, a larger volume of contaminated water. Each year of residence in the sampling frame over the past 20 years was associated with a 19% increase in PFHxS levels. Multivariate models conducted separately for males and females suggest that

the relationship between blood levels and residency duration were primarily observed in female participants.

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

Finding 3. Age, sex, and local fruit and vegetable consumption 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 Orange County EA data set were observed in adult participants (and are consistent with those reported in other non-ATSDR PFAS studies):

- Blood levels of PFHxS, PFOS, and PFOA changed with age, but the size and direction of the effect varied by sex. In females, blood levels for these compounds increased by 2.4% to 5.4% for every year of participant age. In males, blood levels for these compounds decreased by 0.58% to 1.3% for every year of participant age. The decreasing association with age in males was unexpected, possibly due to the small number of young adults in this EA (no adults under 30 years of age participated).
- Males had higher blood levels of PFHxS, PFOS, and PFOA than females. The difference between males and females was larger in younger people.
- PFUnA blood levels were 44% higher among adult EA participants who reported any locally grown produce consumption when compared to participants who reported no such consumption. While PFUnA levels were higher in participants who consumed local produce, PFUnA blood levels were not elevated in the community.

Demographic and exposure variables could not be evaluated in children because of the small number of child participants. The final report on all EA sites will include a more robust analysis of children.

Finding 4. PFAS concentrations in blood are declining over time in Orange County EA participants.

Twenty-three EA participants shared previous (2016 or 2017) blood PFAS blood results. A comparison of these results with those collected as part of this EA showed that levels decreased in all participants, between 17%-80% for PFHxS, 34%-86% for PFOS, and 17%-80% for PFOA.

Finding 5. No PFAS were detected in urine.

ATSDR analyzed 7 (10%) of the urine samples collected. No PFAS were detected in any of the samples. ATSDR did not analyze all participants' urine samples because none of the species were detected in more than 60% of the samples analyzed.

Finding 6. All Orange County tap water samples collected during the EA in 2021 met the EPA's HA and New York State public health standards for PFAS in drinking water.

This is based on 6 unfiltered and 5 filtered tap water samples collected in 6 households during the EA. No PFAS were detected in any of these samples. These results are consistent with recent data collected by the City of Newburgh.

Finding 7. 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=6) were generally in the concentration ranges reported in a few published studies of other U.S. communities (with or without known PFAS contamination). None of the PFAS measured in this EA's household dust samples were statistically correlated with the same PFAS measured in participants' blood. The final report on all EA sites will 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 Orange County residents who lived in the area served by the City of Newburgh's public drinking water supply. However, the EA participant sample may not be fully representative of the community. Only 1.6% 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, more likely to identify as White, and less likely to identify as Black or Hispanic. ATSDR addressed some of these differences by calculating geometric mean estimates that were adjusted to the age distribution of the community.
- Very few young adults and children participated in this EA (e.g., one child participant and no adults under 30 years). Therefore, age-adjusted estimations may still not be fully adjusted to the NHANES or sampling frame populations.
- The significant associations reported here between blood PFAS levels and certain demographic and exposure characteristics should be interpreted with caution as they are sometimes based on a limited number of participants.
- Measurement of blood, urine, and environmental PFAS concentrations for EA participants may improve the understanding of exposure in this community but will not provide discrete information about all sources of exposure. Identifying every source of exposure is not possible.
- While multivariate regression models explained a moderate portion of the variability in participants' blood PFAS levels (R-squared or R^2, a measure of model goodness-of-fit, ranged between 0.21 and 0.65, in the "all adult" models), other factors not identified could still influence the relationships reported in this assessment (see "Statistical Analysis" section for details).
- This EA did not directly assess participants' tap water consumption prior to the reduction of PFAS in the municipal water system.
- This EA was not designed to investigate health outcomes. Without additional information about exposure-response relationships, the results of this EA cannot be used to assess current or past health problems or predict the future occurrence of disease. PFAS found in a person's blood or urine means that exposure has occurred. The presence of PFAS in blood or urine does not tell us how, where, when, or for how long a person was exposed to PFAS. Exposure to PFAS does not mean adverse health effects will result, either now or in the future.

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

Recommendations

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

Although the exposure contribution from PFAS in City of Newburgh drinking water in Orange County 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 Newburgh's public drinking water system, ATSDR does not recommend an alternate source of drinking water at this time.

1. What the City of Newburgh can/should do:
    a. Operators of the public drinking water system should continue to monitor concentrations of PFAS in drinking water delivered to the Newburgh community to ensure that concentrations of PFAS remain below the EPA's HA or other applicable guidelines and New York State standards 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.cityofnewburgh-ny.gov/196/Water-Quality-Reports).
    b. Any treatment systems to remove PFAS from the City of Newburgh drinking water should be maintained appropriately to ensure that PFAS concentrations remain below the EPA's HA or other applicable guidelines and New York State standards for specific PFAS in drinking water.
2. What community members can/should do:
    a. Become familiar with Consumer Confidence Reports (https://www.cityofnewburgh-ny.gov/196/Water-Quality-Reports) for information on the City of Newburgh'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.health.ny.gov/environmental/water/drinking/private_wells.htm. To learn more about previous testing for PFAS in private wells in the Newburgh area visit: https://www.health.ny.gov/environmental/investigations/newburgh/index.htm. Global public health organization NSF International has developed a test method to verify a water filter's ability to reduce PFOA and PFOS to below the HA levels set by the EPA. NSF International-approved devices can be found at: https://info.nsf.org/Certified/DWTU/ Click on "reduction devices" at the bottom of the page for PFOA and PFOS.
    c. Nursing mothers should continue breastfeeding. Based on current science, the known benefits of breastfeeding outweigh the potential risks for infants exposed to PFAS in breast milk.
    d. When possible, eliminate or decrease potential exposure to PFAS in consumer products such as stain-resistant products and food packaging materials. To learn more visit: https://www.fda.gov/food/chemical-contaminants-food/questions-and-answers-pfas-food

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

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

g. At this time, ATSDR does not have plans to conduct additional blood testing for PFAS or recommend PFAS EA participants get individually retested for PFAS in blood. The biological half-lives of many of the PFAS measured in people's blood are long. PFHxS, in particular, has one of the longest half-lives—some estimates range in the decades. This means that PFAS blood levels are not expected to change significantly in the near-term, even if exposure stops. Additionally, it is unclear what an individual's PFAS test results mean in terms of possible health effects.

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

h. ATSDR is funding a multi-site PFAS health study in the Orange County area (Hoosick Falls and Newburgh) that is being conducted by the New York State Department of Health and the University of Albany's School of Public Health. The study will evaluate PFAS levels in serum as well as health markers and neurobehavioral outcomes in children. If you are interested in being included in the study or want further information, please contact Multi-Site PFAS Health Study | University at Albany

i. 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.

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

For More Information

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

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

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