Participant Demographics and Serum PFAS Summary Report

Report 1 of the North Kent County Exposure Assessment

DIVISION OF ENVIRONMENTAL HEALTH
MICHIGAN DEPARTMENT OF HEALTH AND HUMAN SERVICES
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Introduction

Per- and poly-fluoroalkyl substances (PFAS) are a class of thousands of organic fluorinated chemicals that are resistant to heat, water, and oil. They have been used for decades in hundreds of industrial applications and consumer products.[1] Several types of PFAS are associated with health effects in people including pregnancy-induced hypertension, liver damage, high cholesterol, thyroid disease, decreased vaccine response, decreased fertility, asthma, small decreases in birth weight, and testicular and kidney cancer.[1]

In 2016, the U.S. Environmental Protection Agency (EPA) established a Lifetime Health Advisory (LHA) of 70 parts per trillion (ppt) for two PFAS, perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS), individually or in combination.[2] The Michigan Department of Health and Human Services (MDHHS) published non-enforceable public health drinking water screening levels for PFAS in February 2019. Public health drinking water screening levels were developed for five PFAS analytes: PFOA (9 ppt), PFOS (8 ppt), PFNA (9 ppt), PFHxS (84 ppt), and PFBS (1,000 ppt).[3] These screening levels represent the level at which scientists have determined there is minimal risk of health problems to the most vulnerable populations. Effective August 3, 2020, the Michigan Department of Environment, Great Lakes, and Energy (EGLE) (previously named Michigan Department of Environmental Quality, or DEQ) promulgated maximum contaminant levels (MCLs) for seven PFAS, which provide drinking water standards for public water systems in Michigan. These standards are 8 ppt for PFOA, 16 ppt for PFOS, 6 ppt for PFNA, 51 ppt for PFHxS, 420 ppt for PFBS, 400,000 ppt for PFHxA, and 370 ppt for HFPO-DA.

EGLE found PFAS in samples of private drinking water wells in areas near former waste disposal sites in northern Kent County, Michigan, in 2016. Throughout the resultant investigation, EGLE found concentrations of PFOS and PFOA ranging from below lab detection limits to concentrations exceeding 50,000 ppt; these values are orders of magnitude above the EPA LHA and MDHHS's screening levels. As of September 2018, 1,783 private drinking water wells in the northern Kent County area were tested for PFAS. Of these, 982 had detections of any of the PFAS for which the water was tested, and 299 had detections of total measured PFAS over 70 ppt.

While exceedances of health-based screening levels do not confirm that harm to human health will occur, they warrant further investigation of the extent of human exposure to these chemicals. The U.S. Centers for Disease Control and Prevention (CDC), Agency for Toxic Substances and Disease Registry (ATSDR) developed an approach for investigating PFAS exposure called the PFAS Exposure Assessment Technical Tools (PEATT).[4] The PEATT is designed to investigate PFAS exposures resulting from contaminated municipal water. In spring 2018, MDHHS and the Kent County Health Department (KCHD) committed to investigate PFAS exposure from private residential drinking water wells using a modified version of the PEATT protocol.

The objectives of the exposure assessment were to:

1. Determine the mean concentration of 30 PFAS in participants' serum.
2. Determine the mean concentration of 30 PFAS in participants' unfiltered private well water and filtered private well water (for those with drinking water filters).
3. Describe the data on individual characteristics that could affect PFAS exposure or elimination.

4. Compare concentrations of PFAS in participants' serum to those among participants in the National Health and Nutrition Examination Survey (NHANES), a national survey representative of PFAS concentrations in the U.S. general population.

This preliminary report describes the demographics of people who participated in the exposure assessment and provides a preliminary description of the results of serum testing (the first objective above). It does not describe PFAS in water samples or how PFAS found in water samples relate to PFAS found in serum. This report also compares participants' serum PFAS concentrations to those of other populations.

Future reports will characterize PFAS concentrations in private drinking water wells, examine the association between private drinking water well PFAS concentrations and serum PFAS concentrations, describe self-reported factors that could affect PFAS exposure or elimination, and make additional comparisons between participants' PFAS serum concentrations and NHANES (objectives 2, 3, and 4 above).

Methods

Eligibility and Sampling

A random sample of eligible households were invited to participate in the exposure assessment. Addresses were eligible for inclusion in the exposure assessment sampling frame if all of the following applied:

- They were residential properties.
- They had a private drinking water well in the EGLE North Kent County environmental investigation area.
- They had their private drinking water well tested for PFAS by or at the direction of EGLE prior to September 1, 2018.
- They had validated detectable levels in their private drinking water well of any measured PFAS analytes reported to MDHHS by EGLE.

Of the 1,783 addresses that were sampled in the EGLE North Kent County environmental investigation area, 773 households met the eligibility criteria. This sampling frame was then divided into two strata: households whose pre-filter private drinking water well sample contained less than 70 ppt total PFAS (n=591) and households whose pre-filter private drinking water well sample contained greater than or equal to 70 ppt total PFAS (n=182). All households in the higher exposure stratum (n=182) were selected for recruitment and a simple random sample from the low stratum households was selected for recruitment (n=235). The number of households selected was based on calculations using estimated parameters for the sample size needed to detect a mean difference in serum PFOS concentrations of at least 4 µg/L between the North Kent County and NHANES samples using a two-sample t-test at $\alpha=0.05$ with 80% power. Serum PFAS is measured in µg/L, which is equivalent to parts per billion (ppb).

Current residents of all ages living in the selected households at the time of recruitment were eligible for participation if they:

- Lived at the selected address on or before January 1, 2018
- Used the private well water for drinking, and
- Weighed at least 16 pounds.

Potential participants must have lived at the selected address on or before January 1, 2018 because filters were distributed to many households with PFAS detections starting August 2017 and were continuing to be distributed at the time recruitment for the study began. Setting a residency period requirement helped ensure that individuals participating in the exposure assessment were those who had consumed non-filtered water with PFAS detections. In consultation with the Kent County Medical Director, the minimum participant weight was set based on the weight needed to safely collect the minimum amount of blood for PFAS analysis (2 mL).

Recruitment and Intake

Targeted recruitment of eligible individuals began in November 2018 and continued through the spring of 2019. Selected houses were first sent an introductory letter inviting residents to call MDHHS to determine their eligibility. Households that did not respond to the introductory letter were sent a follow-up letter. Households that did not respond to the second letter were contacted by phone as many as three times to elicit participation. The households that were not reached via phone were visited at the door by MDHHS staff.

If MDHHS staff made contact with residents at the home, they gave them study materials and encouraged them to call MDHHS to determine their eligibility. If MDHHS staff were not able to make contact with residents of the home, they left study materials encouraging residents to call MDHHS. Non-targeted recruitment efforts included press releases, public meetings, and MDHHS staff presence at public events in the community, such as farmers' markets.

When MDHHS staff reached residents by phone or when potential participants called MDHHS, MDHHS staff took a census of the household (i.e., number of residents and their ages and sexes), administered a brief eligibility questionnaire for each interested member of the household, and then scheduled one clinic appointment per interested and eligible resident. MDHHS staff also scheduled an appointment for water sample collection with an adult member of each participating household. Participants were then mailed a packet that included directions to the clinic, information about what to expect at their appointment, a copy of informed consent forms and, as applicable, minor assent forms. MDHHS texted or emailed participants (depending on the person's communication preference) with reminders about their scheduled appointment.

Data Collection

At the clinic appointment, MDHHS staff reviewed the informed consent (and minor assent forms, if applicable) with participants before data or sample collection. MDHHS required consent from the legal guardians of all minors eligible to participate in the study.

An exposure questionnaire was administered verbally by trained MDHHS and KCHD staff, who recorded participant answers electronically on iPads using REDCap electronic data capture tools hosted at the Michigan Public Health Institute.[5] All participants were asked questions about their history of living in

the North Kent County area, water consumption habits, diet, and demographics. Adults were asked about health conditions that may affect PFAS excretion and their occupational history in the North Kent County area, as they may have had exposure to PFAS from drinking the water at their workplace or by working directly with PFAS. Adult women were also asked about menstruation, menopause, parity, and breastfeeding. Parents or guardians with young children participating in the study were asked about each participating child's breastfeeding history, formula feeding history, and history of school and daycare attendance in the North Kent County area.

Participants weighing more than 56 pounds had 20 mL of blood drawn; participants weighing less than 56 pounds had a reduced volume drawn commensurate with their weight. Each 10 mL tube was centrifuged to produce the 5 mL serum each. Trained phlebotomists collected blood in 10 mL red top serum separator tubes recommended by CDC for blood samples collected for PFAS analyses in exposure assessments. From each 10 mL of blood, approximately 5 mL of serum was extracted from the blood, aliquoted, and frozen at the KCHD clinic facility in Grand Rapids. Five (5) mL of the serum was used for PFAS testing and 5 mL was reserved for follow-up testing if there were quality issues with lab procedures. The frozen serum specimens were packed on ice and transported to the MDHHS laboratory facilities in Lansing.

Laboratory Analyses and Results Dissemination

The MDHHS laboratory analyzed the serum specimens for PFAS using a high-pressure liquid chromatography tandem mass spectrometry (HPLC-MS/MS) method.[6] There were 24 types of PFAS measured, three of which were measured as linear isomers and branched isomers, making a total of 30 analytes reported. The full names, abbreviations, and CAS numbers of the analytes are provided in Supplemental Table 1. The instruments used were the Shimadzu Nexera X2 Series HPLC system (using a 50 mm x 2.1 mm, 3 µm Supelco Ascentis® C8 RP column as an analytical column and a second as a guard/delay column placed before the autosampler) interfaced to a Shimadzu LCMS-8060 triple quadrupole mass spectrometer with thermally assisted electrospray ionization (ESI) source run in the negative ion mode.

Results were evaluated by MDHHS laboratory chemists and MDHHS toxicologists for quality. After this review, MDHHS sent a letter to each participant with their serum PFAS results. The letters included comparison values (the geometric mean and 95th percentile) for their age group from the most recent cycle of NHANES for each analyte for which NHANES data are available.

Statistical Analysis

Descriptive statistics for serum concentrations of the PFAS were calculated at the individual level and the household level (Table 2). For comparison with NHANES estimates, analyses were limited to participants who met all eligibility criteria, provided a blood specimen, and were at least 12 years old (n= 360), where comparison data are available from NHANES.[7] In accordance with NHANES methods,[7] for analytes that were not detected for at least one member of 60% or more participating households, two types of statistics were reported: 1) percent of individuals with a detection, and 2) percent of households with at least one household member with a detection. For analytes that *were* detected among at least one member of 60% or more participating households, three types of statistics were

reported: 1) percent of individuals with a detection, 2) percent of households with at least one household member with a detection, and 3) geometric mean of household-level serum concentrations. For all analytes where NHANES comparison results are available, the percent of individuals exceeding the NHANES 95th percentile was calculated.

Consistent with NHANES methods,[7] values for PFAS analyte concentrations below the laboratory limit of quantification (LOQ) were substituted by the LOQ divided by the square root of two. The LOQ was determined by calculating the standard deviation at each standard concentration following repeated measurements of the low concentration standards in methanol. These standard deviations were then plotted against concentration, with the y-intercept of the least squares fit of this line equaling signal at 0 concentration (S_0) and the concentration at 10 times S_0 equaling the LOQ. LOQs for each analyte are listed in Supplementary Table 1.

For PFAS analytes for which both linear and branched isomers were measured (PFOS, PFOA, and PFHxS), results were reported as the sum of isomers. If the value for any isomer was below the LOQ, the LOQ of that isomer was divided by the square root of two and substituted. If both isomers were reported as less than the LOQ, then two imputed values were summed.[7] Calculations of geometric means (the *n*th root, usually the positive *n*th root, of a product of *n* factors) and 95% confidence intervals from the sample of households were performed using SAS© PROC SURVEYMEANS. The household was the primary sampling unit and individual residents within households represent repeated measurements; hence the unit of analysis for the purpose of estimating a population mean is the household.

To calculate the geometric mean for each analyte for the total population, the arithmetic mean of the analyte concentration for participants in each household was calculated. These household arithmetic means were used to calculate the geometric mean of households within each stratum. No results are provided by stratum in this report; future reports will contain this information. The stratum-level geometric means were then averaged using sampling weights. The household was the primary sampling unit and individuals in the household were treated as repeated measures within the household. Sampling weights (w_{ijk}) were determined by the following equation—

$$w_{ijk} = N_j/N/n_j/m_{ij}$$

— where N_j is number of households in each stratum, N is the total number of households, n_j is the number of households with at least one participant, and m_{ij} is the number of participants within each participating household. The jackknife method was used for variance estimation.

All analyses were done using SAS © 9.4 (Cary, NC).[8] Minor changes in summary statistics may occur as a result of further analysis.

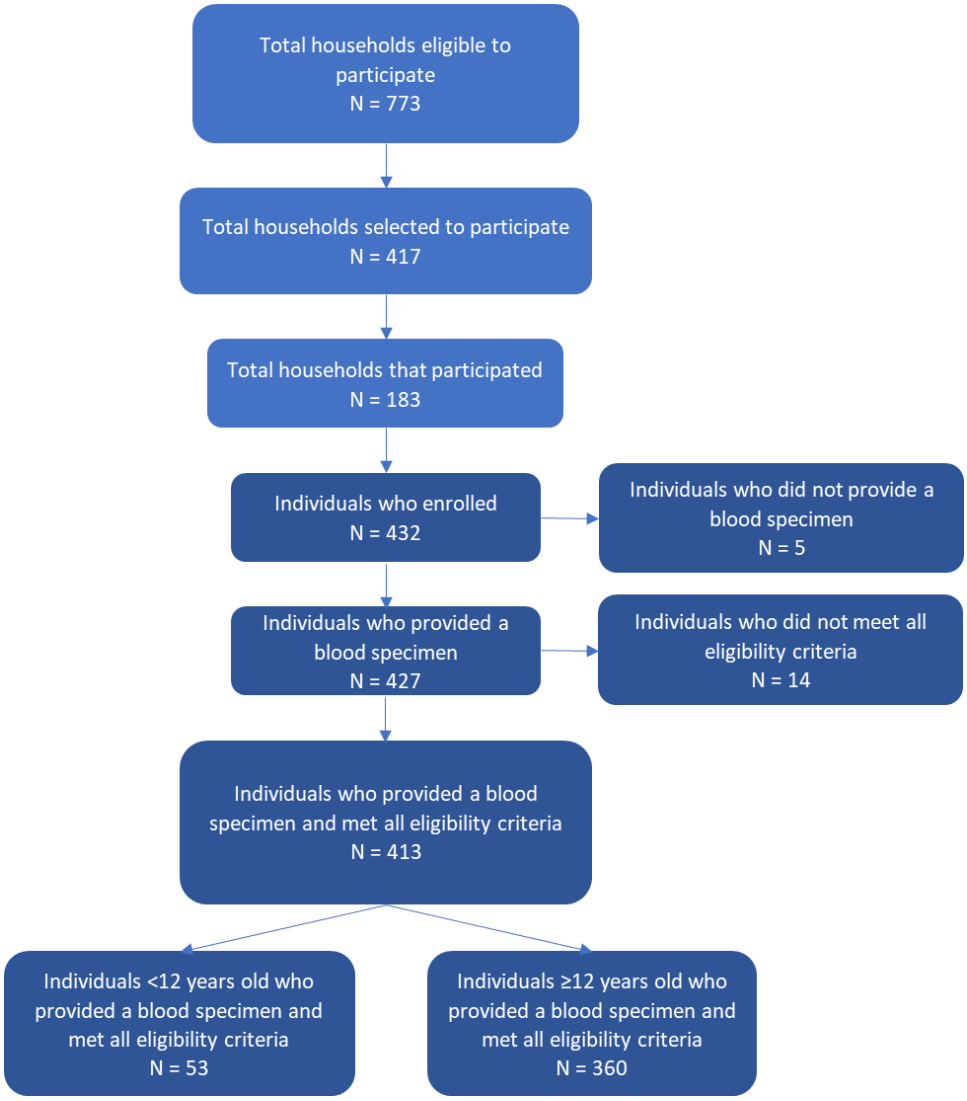
All study activities were approved by the MDHHS Institutional Review Board (201807-06-EA).

Results

Enrollment

Figure 1 summarizes the eligibility and enrollment of households and individuals in the exposure assessment. A total of 773 households were eligible; among these, 417 were selected as described in the methods. By the end of data collection, 183 households had enrolled; 95 were high stratum households and 88 were low stratum households. Among these households, 432 individuals enrolled – 250 from high stratum households and 182 from low stratum households. Of these individuals, 413 individuals provided a blood specimen and met all eligibility requirements. Of the 432 individuals, 19 were excluded from research analyses because they are not current residents of an eligible household (n=14) or they did not provide a blood specimen (n=5). This report describes demographic data for the remaining 413 participants. It also provides serum PFAS results for the 360 individuals in this category who were also greater than or equal to 12 years old.

Figure 1. Enrollment of participants in the exposure assessment.



Demographic Characteristics

Demographic information for participants who provided a blood specimen and met all eligibility criteria (n= 413) is shown in Table 1. Results are presented by age group (less than 12 years, 12 years and older) and include participant-reported age, sex, annual household income, and level of education.

Table 1. Demographic information for participants who provided a blood specimen and met all eligibility criteria by age group (n=413).

	≥12 years (n=360) Count (%)	**<12 years (n=53) Count (%)**	**Total (n=413) Count (%)**
***Average age* (standard deviation)**	49.9 (17.8)	6.4 (2.9)	44.3 (22.1)
Sex			
Male	172 (47.8%)	23 (43.4%)	195 (47.2%)
Female	188 (52.2%)	30 (56.6%)	218 (52.3%)
***Annual household income*[1]**			
<$25,000	17 (5.1%)		
$25,000-$34,999	8 (2.4%)		
$35,000-$49,999	23 (6.9%)		
$50,000-$74,999	44 (13.3%)	Not available	Not available
$75,000-$99,999	52 (15.7%)		
≥$100,000	141 (42.6%)		
Don't know or no answer	45 (13.6%)		
***Education*[1]**			
High school or less	61 (18.4%)		
Some college or technical school	97 (29.3%)		
Four years or more of college	110 (33.2%)	Not available	Not available
Graduate or professional degree	58 (17.5%)		
Don't know or no answer	5 (1.5%)		

[1]Asked of adults age 18 years or older only (n=331).

The average age of participants 12 years and older was about 50; the average age of those 12 years and under was about 6. Most adult participants attended at least four years of college and reported an income above $75,000. More females than males participated. The vast majority of adult participants were white (97.2%) and non-Hispanic (98.1%) (data not shown).

PFAS Exposure Results

Table 2. Summary of serum PFAS at the participant level and household level for eligible participants ≥12 years old who provided a blood specimen (n=360)

	Participant Level (N = 360)			**Household Level (N = 183)**		
Analyte	Percent of participants with analyte detection	Maximum participant-level serum analyte concentration, µg/L	Percent of participants above NHANES 95th percentile*	Percent of households with at least one detection	Geometric mean of household-level serum analyte concentrations (95% confidence interval), µg/L [2]	Maximum of household-level serum analyte concentrations, µg/L [1]
Total PFOA	100.0	433.3	ᵛ28.6	100.0	2.06 (1.79-2.36)	347.7
†L-PFOA	100.0	433.3	28.6	100.0	2.07 (1.73-2.47)	347.7
†Br-PFOA	49.7	40.9	^§NA	31.7	0.018 (0.015-0.022)	40.9
Total PFOS	99.4	3,173.0	ᵛ17.2	100.0	6.33 (5.38-7.46)	3,173.0
†L-PFOS	99.2	589.4	11.7	100.0	3.23 (2.63-3.96)	589.4
†Br-PFOS	99.7	2,583.7	§32.5	100.0	3.37 (2.59-4.39)	2,583.7
PFNA	99.7	3.1	1.7	100.0	0.45 (0.39-0.51)	2.3
Total PFHxS	99.2	884.5	ᵛ33.1	100.0	2.33 (1.98-2.75)	884.5
†L-PFHxS	99.7	884.5	‡NA	100.0	2.37 (1.90-2.95)	884.5
†Br-PFHxS	70.3	12.7	‡NA	39.7	0.033 (0.025-0.043)	11.5
PFBS	23.6	0.6	^NA	19.2	NC	0.6
PFTeA	11.9	0.2	‡NA	10.8	NC	0.2
PFTriA	53.6	0.3	‡NA	34.4	0.016 (0.01-0.02)	0.2
PFDoA	68.6	0.3	^NA	42.2	0.014 (0.01-0.02)	0.3
PFUnA	93.3	0.5	0.6	49.2	0.06 (0.05-0.07)	0.4
PFDA	98.3	1.9	1.9	100.0	0.15 (0.13-0.17)	1.1
PFHpA	84.2	1.5	1.9	45.8	0.04 (0.03-0.04)	0.5
PFHxA	17.5	0.1	‡NA	13.1	NC	0.1
PFPeA	43.6	0.2	‡NA	28.9	NC	0.2
PFBA	85.3	10.0	‡NA	46.4	0.03 (0.03-0.04)	3.4
PFDS	30.0	0.1	‡NA	23.3	NC	0.5
PFNS	13.6	2.2	‡NA	10.6	NC	2.2
PFHpS	95.8	337.1	‡NA	49.7	0.27 (0.22-0.33)	337.1
PFPeS	86.4	17.8	‡NA	47.2	0.05 (0.04-0.06)	14.1
PFOSA	42.8	0.1	^NA	25.8	NC	0.1
FtS 8:2	31.7	0.4	‡NA	25.6	NC	0.4
FtS 6:2	0.6	0.1	‡NA	0.6	NC	0.1
FtS 4:2	4.2	0.1	‡NA	4.2	NC	0.1

Analyte	Percent of participants with analyte detection	Maximum participant-level serum analyte concentration, µg/L	Percent of participants above NHANES 95th percentile*	Percent of households with at least one detection	Geometric mean of household-level serum analyte concentrations (95% confidence interval), µg/L [2]	Maximum of household-level serum analyte concentrations, µg/L [1]
EtFOSAA	30.8	0.6	1.1	21.9	0.01 (0.009-0.01)	0.6
MeFOSAA	93.1	4.8	7.2	48.6	0.11 (0.09-0.13)	3.0

*Centers for Disease Control and Prevention. Fourth National Report on Human Exposure to Environmental Chemicals Updated Tables, January 2019, Volume One. 2019. https://www.cdc.gov/exposurereport/index.html. Accessed March 16, 2020.
ND = Not detected.
NC = Not calculated because the analyte was not detected for at least one member of 60% or more participating households.
NA = Not available from NHANES.
† Analytes with an L- prefix are linear isomers and analytes with a Br- prefix are branched isomers.
‡ Not available from NHANES because the analyte was not measured in NHANES.
^ Not available because the NHANES 95th percentile was below the NHANES limit of detection.
§ The MDHHS laboratory is evaluating the comparability of branched isomers between the NHANES laboratory method and the MDHHS laboratory method.
v The MDHHS laboratory is evaluating the comparability of sums of linear and branched isomers between the NHANES laboratory method and the MDHHS laboratory method.
[1] Serum PFAS from all eligible participants in each household was averaged (arithmetic mean) to generate a household-level concentration.
[2] A geometric mean of all household-level serum PFAS concentrations.

Descriptive statistics for serum PFAS concentrations are shown in Table 2. All PFAS tested in NKCEA were detected in the serum of at least one participant (Table 2). For Total PFOA, L-PFOA, Total PFOS, L-PFOS, Br-PFOS, PFNA, Total PFHxS, L-PFHxS, and PFDA, 100% of households had at least one detection.

To see if there are any PFAS for which there are much higher levels than is typically seen in the U.S. population, we calculated the percentage of participants with levels above the 95th percentile. Among the PFAS that had a 95th percentile value available for comparison from NHANES, PFOA, L-PFOA, PFOS, L-PFOS, Br-PFOS, PFHxS, and MeFOSAA had greater than 5% of exposure assessment participants with serum PFAS levels higher than those of the top 5% of NHANES participants (Table 2, Percent of participants above NHANES 95th percentile). In addition, for these PFAS, the maximum household-level serum analyte concentration was up to three orders of magnitude higher than the geometric mean.

The distribution of blood levels of these PFAS (geometric mean and maximum) was compared to other populations. In Table 3, the NKCEA geometric mean of participant-level serum analyte concentrations for Total-PFOA, Total-PFOS, and Total-PFHxS are compared against NHANES and across studies that have measured PFAS in other populations. NKCEA participants' average PFAS blood levels were lower than the averages measured in workers and in other communities with PFAS-contaminated drinking water, but slightly higher or equal to NHANES participants. The maximum blood levels for PFOS and PFHxS measured in NKCEA study participants were higher than those of other communities exposed to PFAS through drinking water, but lower than workers in PFAS industries.

The frequency with which levels of each analyzed PFAS are detected in NKCEA study participants is shown in Figure 2. Twelve of the detected PFAS are compared against serum PFAS levels from NHANES participants. For the remaining PFAS, the levels are shown without any comparison because no comparison data from NHANES are available.

Table 3. Summary of average and maximum serum PFAS levels (µg/L) across different populations.

	PFHxS Mean	PFHxS Maximum	PFOA Mean	PFOA Maximum	PFOS Mean	PFOS Maximum
Workers in PFAS industries[1]	65	1,880	1,231	92,030	692	10,600
Communities with contaminated drinking water[2]	6	116	23	17,557	18	759
NKCEA Study Participants[3]	**2**	**884**	**2**	**433**	**6**	**3,173**
NHANES Participants[4]	1	23	2	20	5	110

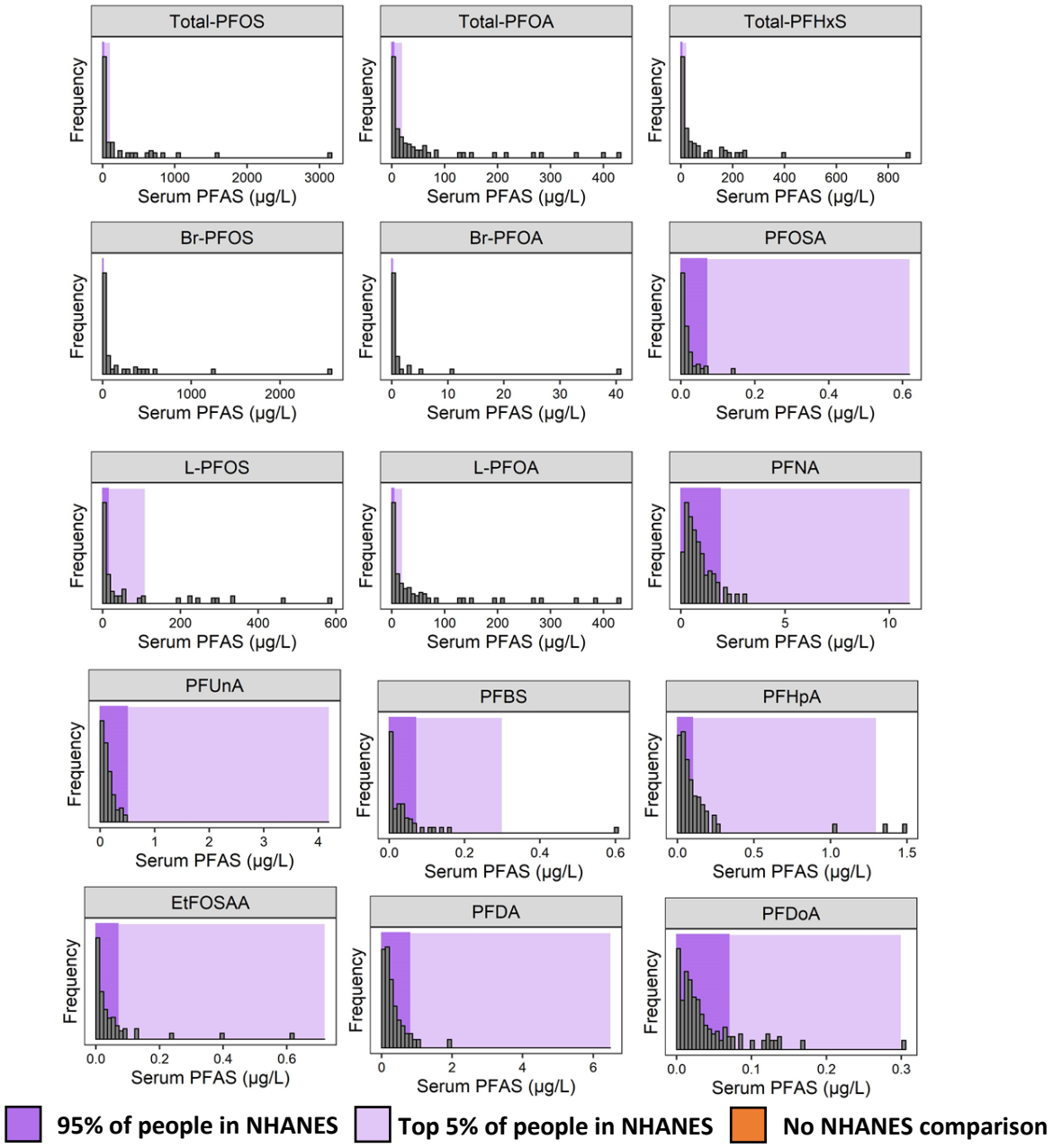
[1] Studies of workers in PFAS industries measured PFAS among workers in fluorochemical production[16,17,18,20] and firefighters.[19] Each of these studies calculated a geometric mean of participants' PFHxS, PFOA, and PFOS levels. The arithmetic mean of these geometric means is presented in the table.

[2] Studies of other populations with PFAS in their drinking water measured PFAS among: Ohio River Valley C8 study participants;[9] Minnesota East Metro study participants;[10] New Hampshire PEAS study participants;[11] Bennington and North Bennington, Vermont, study participants;[12] Hoosick Falls, New York study participants;[13] Ronneby, Sweden study participants;[14] and northern Alabama study participants.[15] Each of these studies calculated a geometric mean of participants' PFHxS, PFOA, and PFOS levels. The arithmetic mean of these geometric means is presented in the table.

[3] "NKCEA Study Participants" represents the 360 individuals whose data are summarized in this report. The geometric mean of arithmetic means of households for PFHxS, PFOA, and PFOS is presented in the table.

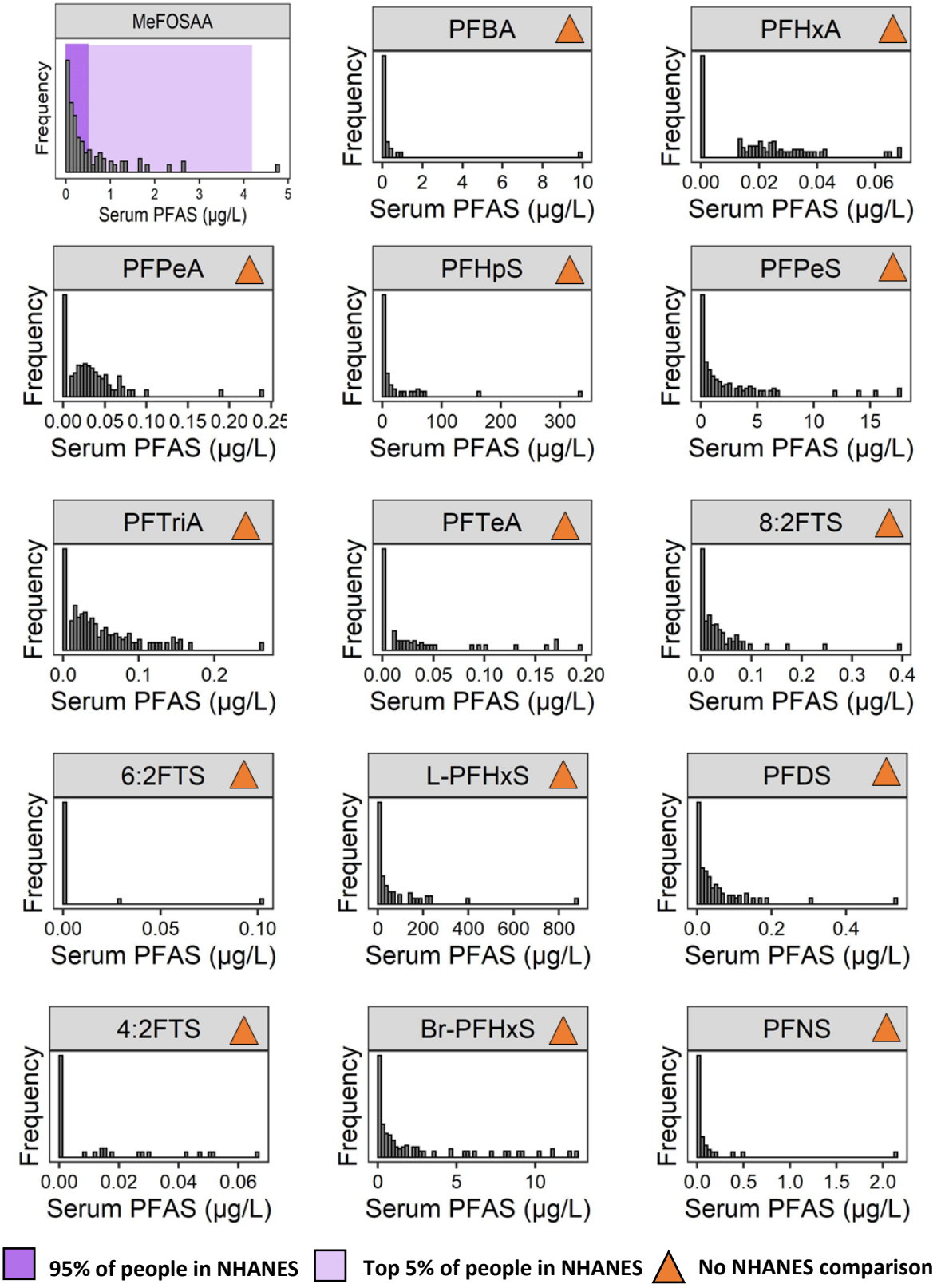
[4] The geometric mean of 2015-2016 NHANES participants is presented in the table.

Figure 2. Frequency histogram of serum perfluoro-alkyl substances (PFAS) levels in micrograms per liter (µg/L) for North Kent County Exposure Assessment participants 12 years old and greater (gray bars).[1] The dark purple shading indicates the range of serum PFAS levels for 95% of participants from the most recently available NHANES data for each analyte. The years of the most recent available NHANES data are shown in Supplementary Table 1. The light purple shading indicates the range of serum PFAS levels for the top 5% of participants (i.e. participants greater than the 95th percentile up to the maximum level) from the most recent NHANES data; the end of the light purple shaded area is the maximum serum level observed in NHANES. Any bars in the unshaded area represent participants with serum PFAS levels higher than the NHANES maximum level. Graphs with orange squares do not have an NHANES comparison available.



[1] Note: For Br-PFOA and Br-PFOS, the MDHHS laboratory is evaluating the comparability of branched isomers between the NHANES laboratory method and the MDHHS laboratory method. For Total PFOA and Total PFOS, the MDHHS laboratory is evaluating the comparability of sums of linear and branched isomers between the NHANES laboratory method and the MDHHS laboratory method.

Figure 2, continued



Discussion

This exposure assessment measured serum and drinking water concentrations of 30 PFAS among a sample of residents in the North Kent County area who previously had validated detectable PFAS levels in their private drinking water wells as reported to MDHHS by EGLE. Serum PFAS levels in participants of the North Kent County Exposure Assessment show a wide range of detected PFAS. For seven PFAS – PFOA, L-PFOA, PFOS, L-PFOS, Br-PFOS, PFHxS, and MeFOSAA – notable percentages of exposure assessment participants have serum levels above the top 5% of NHANES participants. These percentages are: 28.6% for PFOA, 28.6% for L-PFOA, 17.2% for PFOS, 11.7% for L-PFOS, 32.5% for Br-PFOS, 33.1% for PFHxS, and 7.2% for MeFOSAA (see Table 2). For four other PFAS, PFUnA, PFDA, PFHpA, and EtFOSAA, more than 95% of exposure assessment participants, serum levels are below those of 95% of NHANES participants. Future reports will describe PFAS concentrations in private drinking water wells, address the relationship between private drinking water well PFAS concentrations and participant serum PFAS concentrations, and report serum PFAS concentrations by self-reported factors that could affect PFAS exposure or elimination, addressing all objectives of the study.

The PFAS studied in the exposure assessment are a small subset of the thousands of known PFAS. The results cannot be generalized to all types of PFAS. For many PFAS, validated analytical methods and standards did not exist at the time of this assessment. It is not known whether any of these other unmeasured PFAS are present in the North Kent County investigation area or whether residents in the area could have been exposed to them.

There are also limitations related to who is included in the analysis. First, residents were eligible for random selection if their private drinking water well was tested by EGLE or at the direction of EGLE as part of the environmental investigation, and the well had detectable levels of PFAS. If houses that have PFAS in their drinking water but were not part of EGLE's environmental investigation had been included, the results of the study could have been different. Second, the participation rate for households randomly selected for inclusion in the study was 44%. If someone's participation in the study was related to how much PFAS is in their drinking water, the participation rate could affect the accuracy of our findings. Results in this report are not corrected for non-response bias.

Similarly, the distributions depicted in Figures 2 represent only the individuals who participated in the exposure assessment and do not account for the stratified sampling design and any non-response bias. Therefore, these distributions do not represent the population of North Kent County residents with PFAS detected in their private drinking water wells and cannot be extrapolated to the rest of the community. Further, because the study was designed to assess the exposure of individuals living in households with private drinking water wells with detections of PFAS, findings from the study can never be said to represent the entire population throughout the North Kent County area.

It is also important to note that physiological and behavioral factors can affect PFAS exposure and elimination, and that the distribution of these factors may differ between the exposure assessment participants, the population of North Kent County residents with PFAS detected in their private drinking water wells, and the U.S. population. For example, women on average eliminate some PFAS from blood more rapidly than men due to physiological differences.[9] This report did not adjust PFAS serum levels for

the proportion of women in the population. If the proportion of participants in the study who are women is not taken into account during analysis, the results may not be representative of the population of North Kent County residents with PFAS detected in their private drinking water wells. Similarly, the results may not be comparable to the U.S. population in terms of the ratio of men to women. Future reporting will describe self-reported factors that could affect PFAS exposure and elimination.

It is also worth noting that while analysis of data from this exposure assessment can address serum PFAS levels and factors that are associated with elevated serum levels, it cannot address any associations between PFAS exposure and health outcomes.

Summary

For some types of PFAS (including PFOA, PFOS, and PFHxS), blood levels found in some NKCEA participants were high in comparison to the 95th percentile of NHANES participants. For the rest of the participants, blood levels of PFAS fall mostly within the range found in a sample of the U.S. population.

Future reporting will explore potential sources of PFAS exposure by reporting PFAS concentrations in private drinking water wells and by examining associations between private drinking water well PFAS concentrations and participant serum PFAS concentrations. Future work will also report serum PFAS concentrations by other potential exposure sources, such as diet and occupation, and by other factors that may affect PFAS retention or elimination.

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Supplemental Table 1. PFAS analytes and their abbreviations

Abbreviation	Name	CAS Number	Method LOQ (µg/L)	Most recent NHANES data year[7]
	Perfluorocarboxylic acids			
PFBA	Perfluorobutanoic acid	375-22-4	0.0106	^NA
PFPeA	Perfluoropentanoic acid	2706-90-3	0.0112	^NA
PFHxA	Perfluorohexanoic acid	307-24-4	0.0126	^NA
PFHpA	Perfluoroheptanoic acid	375-85-9	0.0124	2013-2014
PFOA	Perfluorooctanoic acid (branched and linear)	335-67-1	NA	2015-2016
L-PFOA	Perfluorooctanoic acid (linear)	335-67-1	0.0098	2015-2016
Br-PFOA	Perfluorooctanoic acid (branched)	335-67-1	0.0101	2015-2016
PFNA	Perfluorononanoic acid	375-95-1	0.0103	2015-2016
PFDA	Perfluorodecanoic acid	335-76-2	0.0087	2015-2016
PFUnA	Perfluoroundecanoic acid	2058-94-8	0.0109	2015-2016
PFDoA	Perfluorododecanoic acid	307-55-1	0.0082	2015-2016
PFTeA	Perfluorotetradecanoic acid	376-06-7	0.0102	^NA
PFTriA	Perfluorotridecanoic acid	72629-94-8	0.01	^NA
	Perfluorosulfonic acids			
PFBS	Perfluorobutanesulfonic acid	375-73-5	0.0089	2013-2014
PFPeS	Perfluoropentanesulfonic acid	2706-91-4	0.0104	^NA
PFHxS	Perfluorohexanesulfonic acid (branched and linear)	355-46-4	NA	2015-2016
L-PFHxS	Perfluorohexanesulfonic acid (linear)	355-46-4	0.009	^NA
Br-PFHxS	Perfluorohexanesulfonic acid (branched)	355-46-4	0.009	^NA
PFHpS	Perfluoroheptanesulfonic acid	375-92-8	0.0113	^NA
PFOS	Perfluorooctanesulfonic acid (branched and linear)	1763-23-1	NA	2015-2016
L-PFOS	Perfluorooctanesulfonic acid (linear)	1763-23-1	0.0095	2015-2016
Br-PFOS	Perfluorooctanesulfonic acid (branched)	1763-23-1	0.0081	2015-2016
PFNS	Perfluorononanesulfonic acid	68259-12-1	0.0101	^NA
PFDS	Perfluorodecanesulfonic acid	335-77-3	0.0095	^NA
	Fluorotelomer sulfonic acids			
4:2 FTS	1H, 1H, 2H, 2H, perfluorohexane sulfonic acid	757124-72-4	0.0089	^NA
6:2 FTS	1H, 1H, 2H, 2H, perfluorooctane sulfonic acid	27619-97-2	0.0113	^NA

Abbreviation	Name	CAS Number	Method LOQ (µg/L)	Most recent NHANES data year[7]
8:2 FTS	1H, 1H, 2H, 2H, perfluorodecane sulfonic acid	39108-34-4	0.0095	^NA
	Perfluorosulfonamido acetic acids			
EtFOSAA	N-Ethylperfluorooctane sulfonamidoacetic acid	2991-50-6	0.0095	2011-2012
MeFOSAA	N-Methylperfluorooctane sulfonamidoacetic acid	2355-31-9	0.0107	2015-2016
	Perfluorosulfonamides			
PFOSA	Perfluorooctanesulfonamide	754-91-6	0.0072	2013-2014

^NA = The analyte was not measured in NHANES.
NA = There is no limit of quantification for totals of isomers.

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