MiPEHS

Michigan PFAS Exposure & Health Study

Technical Appendix to Phase 1 Summary Report

May 2023

MDHHS

Michigan Department of Health & Human Services

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Table of Contents

1.0 Introduction

1.1 Background

Per- and polyfluoroalkyl substances (PFAS) are a large group of thousands of fluorinated compounds that have been manufactured around the world for wide-ranging consumer and industrial uses [1]. Some PFAS are used in the food packaging, cookware, and textiles industries because they repel both water and oil (i.e., they have both hydro- and lipophobic properties). PFAS are also used as a key constituent in the aqueous film forming foams (AFFF) used during firefighting and firefighter training. Due to their widespread use and minimal degradation under environmental conditions, some PFAS are known to have accumulated in the environment. High environmental concentrations of PFAS in media relevant to human exposure are well-documented and numerous health effects are associated with high levels of exposure [2-4]. Notably, changes in immune [5-7], cardiovascular [8], kidney [9,10], liver [11,12] and thyroid function [13] have been linked with exposure to some PFAS individually or in combination. Emerging evidence shows that other health effects, including cancer [14] and reproductive health problems [15,16] are also potential consequences from exposure to some PFAS.

Significant data gaps in the existing scientific literature remain, and the relationships between serum PFAS concentrations and health effects are not fully understood. These gaps are particularly apparent for questions about the impact of exposure to low and moderate concentrations of PFAS; the latency between exposure and adverse health outcomes and what, if any, impact exposure to PFAS mixtures alone or in combination with other persistent environmental contaminants has on health. Another key data gap emerges when questions are asked about PFAS other than "legacy" PFAS such as perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS). Toxicological and epidemiological research to date is heavily biased, appropriately so, toward these historically common and highly prevalent PFAS. The consequence: less common and replacement PFAS remains under-researched in human health literature. Carefully designed epidemiological research projects can begin to fill these gaps and will eventually usher in a new era of understanding PFAS toxicity.

1.2 Purpose of the Michigan PFAS Exposure and Health Study (MiPEHS)

Michiganders affected by drinking water contaminated with PFAS have many important questions and concerns about their health. MiPEHS was launched in response to these concerns and is one of the first longitudinal research projects on PFAS and health in the United States. MiPEHS is the first such project to measure 39 PFAS (note, **45 PFAS** are reported when including the branched, linear, and total summations for PFOA, PFOS and PFHxS). This research will advance scientific knowledge, which benefits all people – not just those who participate.

Because MiPEHS was designed to both inform the community and gain sufficient and meaningful data that will move the science on PFAS and health effects forward, results will be reported in two ways:

1. Summary reports with accompanying technical appendices like this one will be made publicly available on the Michigan Department of Health and Human Services (MDHHS) website following each phase of MiPEHS. These MDHHS summary reports will cover key topic areas, like participant demographics and serum PFAS concentrations, among others. They will be released soon after each phase of data collection ends.

2. Other research topics, like statistical associations among serum PFAS concentrations and health effects, will be prepared and submitted for peer review and publication in scientific journals. The peer review process ensures high research quality and validity of results; it invites insight and critique from subject matter experts in relevant field(s) around the world.

Published research journal articles about MiPEHS will be made freely available, and links will be posted on MDHHS's website. MDHHS will create community-facing fact sheets describing the findings presented in research journal articles and as needed, hold community forums to discuss them. Currently, research journal articles covering health effects and other information gained during MiPEHS are planned to follow each phase, as appropriate. Following the end of Phase 3 data collection, articles are planned that will cover the duration of MiPEHS, reporting on longitudinal findings. At that point, questions about the latency, scope, and magnitude of health effects following PFAS exposure can be answered more fully.

1.3 Specific Objectives of this Technical Appendix

1. Summarize past and current PFAS concentrations and frequencies in drinking water among MiPEHS Phase 1 participants.
2. Detail the concentrations and detection frequencies of 39 PFAS in serum among MiPEHS Phase 1 participants impacted by recent PFAS contamination of drinking water.
    a. Compare participants serum PFAS concentrations to the National Health and Nutrition Examination Survey (NHANES) results.
3. Describe how serum concentrations of 30 PFAS have changed over time for a subset of participants.

NOTE: Reporting on additional objectives will occur as Phase 1 data continue to become final and as Phases 2 and 3 of MiPEHS are completed in the coming years. Consider the following:

- Whole blood PFAS concentrations from dried blood spots and serum polychlorinated biphenyls (PCBs) concentrations are **not yet available** from Phase 1.
- Detailed analyses on relationships between PFAS water and serum concentrations, and between PFAS blood concentrations and health **will be conducted**. As appropriate, these findings will be submitted for publication in scientific journals, which will be available on MDHHS's MiPEHS website and summarized in community factsheets. Community forums will be held to discuss these findings.
- Longitudinal PFAS and health data combining all three phases of MiPEHS is not possible until the end of MiPEHS data collection.

See **Attachment A** for a description of the full objectives of MiPEHS, including all testing conducted on blood during Phase 1. See **Supplemental Table 1** for a list of abbreviations used in this document.

2.0 Methods

2.1 Study Setting

2.1.1 Belmont/Rockford area

Several PFAS, but predominately perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS), were discovered in the groundwater in parts of northern Kent County, Michigan, in 2017. An environmental investigation of the area identified private residential wells in the Belmont and Rockford areas that were contaminated with PFAS. Among private residential wells, the combined PFOA and PFOS concentration ranged from below the limit of detection to over 50,000 parts per trillion (ppt, or nanograms per liter (ng/L)). The highest concentration found in a residential well was over 700 times higher than the EPA's Lifetime Health Advisory of 70 ppt of PFOA and PFOS combined, which was the screening level used at the time for drinking water [17,18]. Ultimately, around 1,600 homes were thought to be impacted by PFAS-contaminated groundwater and residents were offered alternate water sources. The source of PFAS contamination in the Belmont and Rockford areas is believed to be historic landfill leachate containing waste from a leather tannery. For information on the environmental investigation in this area see the Michigan PFAS Action Response Team's (MPART) webpage at PFAS Response - House Street Disposal Area, Belmont, Kent County (Michigan.gov).

2.1.2 City of Parchment and Cooper Township

Several PFAS, again predominately PFOA and PFOS, were discovered in the municipal water supply serving the city of Parchment, Michigan, in 2018. The combined PFOA and PFOS concentration was 1,410 ppt, which was presumed to homogenously represent all residential taps on the supply. Data from the water supplier and the environmental investigation support the conclusion of homogeneity throughout the supply network. In addition to the homes on the municipal water system, outlying areas of private residential wells in Cooper Township were contaminated. The PFAS concentrations discovered in these residential wells were lower than the concentrations found in the municipal supply and appeared to decrease with distance from the municipal wells (see link to site investigation information below). Approximately 2,455 homes were believed to be impacted by PFAS-contaminated groundwater and many residents were offered alternate drinking water sources. This included nearly 1,530 homes[a] on municipal water and 925 private well owners within a 1.5-mile radius of the municipal supply wells. For the analyses described later in this report, residents on the former Parchment municipal supply are grouped separately from residents on private wells in Cooper Township. The source of contamination is believed to be historic landfill leachate containing waste from a paper mill. For information on the environmental investigation in this area see the MPART webpages at PFAS Response - Kalamazoo County, Parchment, Crown Vantage Property (Michigan.gov) and Parchment / Cooper Township Drinking Water Response (Michigan.gov).

2.2 Study Population

The study population was drawn from all members of all households within the two geographic regions described above (section **2.1.1**, section **2.1.2**,and **Figure 1**), where groundwater used as drinking water was contaminated with PFAS. Eligibility was open to those living in these areas between 2005-2018 (estimated n=6,200). Additional inclusion criteria were specific to each study site and included the following:

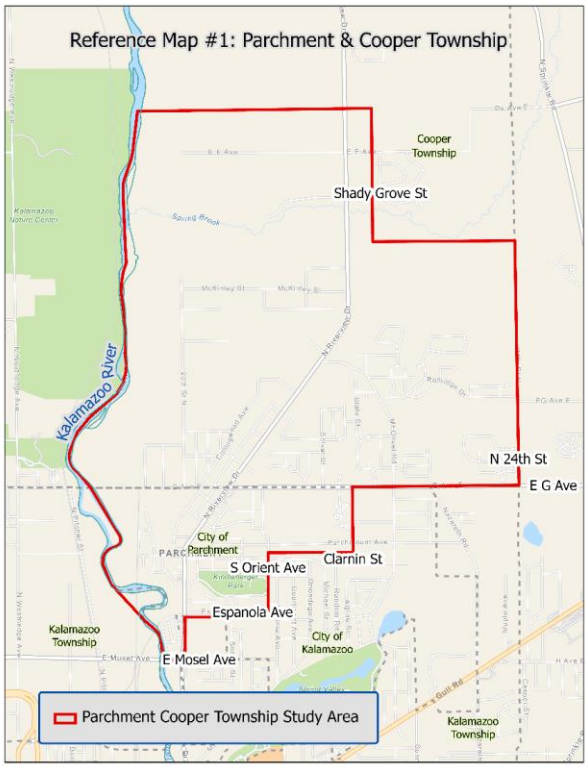
[a]Estimated based on the number of residential connections or residential equivalent connections to the Parchment municipal water system at the time PFAS was discovered in the area.

- At the time of entry into the study, Parchment/Cooper Township area residents must have lived in a household that was served by the Parchment municipal water supply or a private drinking water well within the targeted geographic region. They must have lived there on or before July 27, 2018.
- At the time of entry into the study, Belmont/Rockford area residents must have lived in a household within the targeted geographic region and have had a private drinking water well that was previously tested for PFAS by or at the direction of a State of Michigan agency.

Residents meeting the above criteria were invited to join MiPEHS if they also self-reported using their tap as a source of drinking water during the 15 years before the study began (2005 or after). Current and former dependents of those residing in eligible households were also eligible to participate if their last exposure to the eligible household's drinking water was self-reported to have occurred during the 15 years before the study began (2005 or after).

Residents of all ages who met these criteria were invited to participate in the exposure survey and anthropometric measurements, but only participants ages 12 years and older were eligible to participate in the blood draw portion of the study.

Figure 1. Study area maps.



2.2.1 Recruitment

A variety of direct and indirect modes of recruitment were deployed in advance of and during the data collection period for MiPEHS Phase 1.

- **Direct recruitment methods** included multiple mailings (e.g., letters, postcards, factsheets), phone calls, door knocks, and flyer distribution to residences (via door hangers and door bags) for the household addresses within geographical study boundaries.
- **Indirect recruitment methods** included geotargeted social media, print advertising (e.g., billboards in the study areas) and radio advertising. Additionally, study posters were hung in local businesses and health care centers, study staff attended local events and venues, and a web-based "Contact Us" form was used, among other indirect recruitment strategies.

2.2.2 Enrollment and appointment scheduling

An independent nonprofit research institute, RTI International, was contracted to build and manage a participant management system for study enrollment, scheduling, appointment reminders and other follow-up activities. Participants completed a short intake survey via phone assessing eligibility and willingness to participate in the study. Study appointment reminders were sent via text message or email, depending on participant preferences.

Appointments for participants were scheduled at the nearest of two local study offices, each of which was centrally located in the study areas and had on-site parking available. Study offices were also accessible via public transportation and/or free Uber Health rides, arranged upon request by study staff. Study offices were staffed by certified phlebotomists, nurse assistants, field interviewers, laboratory technicians, and office managers. Technical staff from MDHHS and RTI were available by phone and video call during all scheduled appointments.

2.2.3 Consenting procedures

All participants completed and signed an informed consent form electronically during their study visit after being given the opportunity to ask questions of study office staff. If participants opted to take their survey (one of the data collection modalities for the study) ahead of their study visit, they were required to read and affirmatively acknowledge an introductory section to the survey that explained the purpose of the study and risks and benefits of participating. Accommodations were made for all participants who requested them, which they could specify at the time of enrollment or during their study office visits. Examples of accommodations include translation of study materials into Spanish or appropriate revisions of study materials for adult participants with a legal guardian.

2.3 Data Components

Four sources of data were collected, as available, from each MiPEHS participant: a fasting venous blood sample, a fasting capillary blood sample, anthropometric measurements (body weight, hip/waist circumference, blood pressure), and an exposure and health survey. Other data, such as prior PFAS blood levels, vital records data, and immunization records, are collected as applicable. A household water sample and accompanying water-use survey were also requested from all households with a private well and from a representative subgroup of households on the municipal water supply in the City of Parchment. Not all results from each of these data sources were available at the time this technical appendix was prepared and released.

2.4 Blood and Drinking Water Sample Collection, Processing, and Laboratory Methods

2.4.1 Blood sample collection and processing

Blood samples were drawn from willing adults and adolescents by trained and certified phlebotomists at local study offices. A maximum volume of 53 milliliters (mL) of blood was drawn from adult participants and a maximum of 33 mL of blood was drawn from adolescents (aged 12 through 17). Blood samples were centrifuged (spun), aliquoted (divided into vials), and refrigerated (or frozen, as needed) at the local study office until being shipped to laboratories for analyses. The blood collection tubes (PFAS-free glass 10 mL redtop tubes, BD (Franklin Lakes, New Jersey, USA)), transfer pipettes (PFAS-free polypropylene, BD) and aliquot vials (PFAS-free polypropylene 2 mL vials, BD) used for PFAS analyses were pre-screened for PFAS contamination, and handling protocols were in place to prevent cross-contamination.

PFAS testing on serum samples was performed at the accredited MDHHS Bureau of Laboratories in Lansing, Michigan, USA. Clinical laboratory tests (biomarkers of health) on serum samples were performed at an accredited clinical diagnostic laboratory (Mayo Clinic Laboratory, Rochester, Minnesota, USA) or the accredited MDHHS Bureau of Laboratories. Protocols were in place to ensure all blood samples were processed at the laboratory within specified holding times.

2.4.2 Water sample collection

An adult from each selected household voluntarily allowed trained MDHHS sanitarians to collect drinking water samples from their home for PFAS testing. When possible, sanitarians collected both current drinking water samples and a sample of water that represented water treatment at the time PFAS was discovered in the area. For example, before the addition of a whole-house water filtration system. However, the collection of this representative sample of water (meant to represent how water was treated at the time of PFAS discovery) was often not possible due to limited access to home water infrastructure or other issues. All water data reported here reflects the *current* drinking water samples that correspond to conditions during MiPEHS participation, as identified by the participant. Water samples were collected in PFAS-free 250 mL high-density polyethylene (HDPE) bottles with screw caps and were packed on ice and transported to MDHHS's accredited Bureau of Laboratories in Lansing, Michigan, USA. Protocols were in place to ensure all water samples were processed at the laboratory within the specified hold-times.

2.4.3 PFAS measurement and laboratory methods

2.4.3.1 Serum PFAS

Thirty-nine PFAS were measured in serum (**Supplemental Table 1** in **Attachment A**). Acetonitrile was added to a serum aliquot to precipitate the protein from the serum matrix. The sample was then processed through a 96-well filtration plate to further clean samples prior to analysis by reverse-phase high performance liquid chromatography (RP-HPLC) tandem mass spectrometry (MS/MS). Both linear and branched isomers of three of these PFAS (PFOA, PFOS and PFHxS) were quantified. Isotopic dilution was performed with labeled analogs of 20 analytes before the extraction. The extraction and clean-up process used to isolate PFAS from the serum matrix improves the limits of detection (LOD) by facilitating enrichment of the analytes with respect to the matrix. PFAS were further separated from extraneous compounds in the extract by RP-HPLC. Protonated analyte ions are generated by electrospray ionization, and fragment ions, specific to each analyte, are produced by collision-induced dissociation (CID).

Comparison of relative response factors (analyte area/analog area) with known standard concentration/internal standard concentration ratios yields individual analyte concentrations. This method is applicable to the measurement of PFAS in serum with Method Limits of Quantitation (LOQ) in the low ppt range.

2.4.3.2 Water PFAS

Thirty-nine PFAS were measured in water (**Supplemental Table 1** in **Attachment A**). Both linear and branched isomers of three of these PFAS (PFOA, PFOS and PFHxS) were quantified. Isotopic dilution was performed with labeled analogs of 20 analytes before the extraction. Solid phase extraction (SPE) using a Weak Anion Exchange (WAX) sorbent in a 96-well plate format was used to isolate PFAS from the water matrix and to improve the LOD by facilitating enrichment of the analytes with respect to the matrix. PFAS were further separated from extraneous compounds in the extract by reverse-phase HPLC. Protonated analyte ions are generated by electrospray ionization, and fragment ions, specific to each analyte, are produced by CID. Comparison of relative response factors (analyte area/analog area) with known standard concentration/internal standard concentration ratios yields individual analyte concentrations. This method is applicable to the measurement of PFAS in water with LOQ in the low ppt range.

2.5 Data Handling and Analysis

2.5.1 Data quality assurance and control

Quality assurance steps were taken during survey, study office and at-home data collection that included the programming of branching logic on electronic instruments, the setting of upper and lower bound limits on free response numeric fields, and the use of automated warning messages for skipped or missed questions. Quality checks on all study office data collection instruments were performed weekly during data collection. Biospecimen, anthropometric, water, and other data were collected and stored using Research Electronic Data Capture (REDCap) tools. REDCap is a secure, web-based software platform designed to support data capture for research studies [19,20].

2.5.2 Analytical methods

Descriptive statistics were used to understand the demographic characteristics of MiPEHS participants from the study areas (Belmont/Rockford, City of Parchment, and Cooper Township residents) as well as their serum PFAS concentrations and household water PFAS concentrations. These descriptive analyses included frequencies, geometric means (GM), standard deviations (SD), percentiles and 95% confidence intervals (CI). All analyses were performed using SAS 9.1.4 (Cary, NC) or R version 4.0.4. Density plots were made with R version 4.0.4 and the packages ggplot2 version 3.3.5 and ggridges 0.5.3. The area under the density curve for each plot was calculated by using the *..ndensity..* option.

The suppression of counts between 1 and 5 (along with complementary suppression) was used for all result reporting. Any cells with counts between 1 and 5 are reported as “<6” or are otherwise noted as suppressed. Survey response options with fewer than 6 respondents were combined with other, similar response options, when possible, and suppressed when not possible. Water and serum PFAS measurements that were reported as non-detect (ND) were recoded to a numerical value generated using the following equation:

$$\frac{Limit\ of\ Quantitation\ (LOQ)}{\sqrt{2}}$$

Values reported as below the reporting limit but above the LOQ were recoded using the formula:

$$\frac{Reporting\ Limit\ (RL)}{\sqrt{2}}$$

2.6 Participant Results Reporting

MiPEHS participants were mailed their personal test results, including serum PFAS and household drinking water PFAS results, if applicable. Health education and explanatory factsheets were included in all test result mailings and technical staff were available to answer questions from participants about their results. MiPEHS participants received or will receive all personal results collected during MiPEHS, unless they requested otherwise.

2.7 Ethical Statement

This study was approved by the Institutional Review Board of the Michigan Department of Health and Human Services (IRB Log Number: 202003-03-FC).

3.0 Results

3.1 Participant Characteristics

See the section titled "Over 1,000 people participated in MiPEHS Phase 1" on page 3 of the Summary Report.

Demographic characteristics of MiPEHS participants are summarized for the overall cohort and according to each area (the Belmont/Rockford area, City of Parchment, and Cooper Township) in **Table 1**. In general, the 1,054 individuals who participated in MiPEHS Phase 1 were a middle-aged group; on average they were 50 years old, and the standard deviation was 22 years. The racial-ethnic homogeneity of this part of Michigan was represented among MiPEHS participants and evidenced by 95.9% of participants identifying as non-Hispanic and 91.9% identifying as white. Most adults (83.9%) had at least some college education and about one third of adults (30.1%) reported household income at or above $100,000 per year. Over 90% of participants reported having health insurance in the 12 months prior to MiPEHS. Almost 70% of participants reported living in the study areas for 10 years or longer. Very few young children joined MiPEHS; only 8.4% of participants were under the age of 12 years.

Overall, adults from Cooper Township and the Belmont/Rockford area were more likely to have attended graduate school compared to participants from the City of Parchment (25.3% and 23.3% vs. 11.5%). Participants from the Belmont/Rockford area were more likely than participants from the City of Parchment or Cooper Township to report household incomes at or above $100,000 (39.2% vs 17.9% and 20.1%).

Table 1. Demographic information for MiPEHS participants.

Participant Characteristics	City of Parchment (n=296)[a]	Cooper Township (n=174) [a]	Belmont/ Rockford Area (n=584)[a]	Total (n=1,054) [a]
	Count (%)	Count (%)	Count (%)	Count (%)
Age at the time of informed consent				
Average age (standard deviation)	50 (21)	53 (21)	49 (23)	50 (22)
Under 12	18 (6.1%)	12 (6.9%)	59 (10.1%)	89 (8.4%)
12-19 years	21 (7.1%)	10 (5.8%)	50 (8.6%)	81 (7.7%)
20-39 years	50 (16.9%)	18 (10.3%)	55 (9.4%)	123 (11.7%)
40-49 years	31 (10.5%)	17 (9.8%)	70 (12.0%)	118 (11.2%)
50-59 years	47 (15.8%)	37 (21.3%)	106 (18.2%)	190 (18.1%)
60-69 years	92 (31.1%)	36 (20.7%)	134 (23.0%)	262 (24.9%)
70-79 years	27 (9.1%)	31 (17.8%)	88 (15.1%)	146 (13.9%)
80 years or older	10 (3.4%)	13 (7.5%)	22 (3.8%)	45 (4.3%)
Sex				
Male	133 (44.9%)	73 (42.0%)	268 (45.9%)	474 (45.0%)
Female	160 (54.1%)	99 (57.0%)	309 (52.9%)	568 (53.9%)
Race				

Participant Characteristics	City of Parchment (n=296)[a]	Cooper Township (n=174) [a]	Belmont/ Rockford Area (n=584)[a]	Total (n=1,054) [a]
Black, Indigenous, or person of color (BIPOC)	14 (4.7%)	7 (4.1%)	9 (1.5%)	30 (2.9%)
White	260 (87.8%)	157 (90.2%)	552 (94.5%)	969 (91.9%)
Two or more races	17 (5.7%)	8 (4.6%)	11 (1.9%)	36 (3.4%)
Ethnicity[b]				
Not of Hispanic, Latino, or Spanish origin		444 (94.5%)	567 (97.1%)	1,011 (95.9%)
Hispanic, Latino, or Spanish origin		12 (2.6%)	7 (1.2%)	19 (1.8%)
Household income				
Less than $20,000	19 (6.4%)	13 (7.5%)	15 (2.6%)	47 (4.5%)
$20,000 to less than $35,000	32 (10.8%)	12 (6.9%)	27 (4.6%)	71 (6.7%)
$35,000 to less than $50,000	50 (16.9%)	16 (9.2%)	34 (5.8%)	100 (9.5%)
$50,000 to less than $75,000	60 (20.3%)	30 (17.2%)	68 (11.6%)	158 (15.0%)
$75,000 to less than $100,000	34 (11.5%)	38 (21.8%)	80 (13.7%)	152 (14.4%)
$100,000 or more	53 (17.9%)	35 (20.1%)	229 (39.2%)	317 (30.1%)
Insured status				
No	19 (6.4%)	8 (4.6%)	43 (7.4%)	70 (6.6%)
Yes	272 (91.9%)	164 (94.3%)	530 (90.8%)	966 (91.7%)
Total years living in study area				
Less than 4 years	16 (5.4%)	6 (3.5%)	7 (1.2%)	29 (2.8%)
4 years up to 6 years	23 (7.8%)	12 (6.9%)	36 (6.2%)	71 (6.7%)
6 years up to 8 years	16 (5.4%)	9 (5.2%)	47 (8.1%)	72 (6.8%)
8 years up to 10 years	26 (8.8%)	12 (6.9%)	43 (7.4%)	81 (7.7%)
10 years or more	202 (68.2%)	124 (71.3%)	399 (68.3%)	725 (68.8%)
Education level (adults only, n=898)				
High school graduate or equivalent (GED) or less	48 (18.5%)	25 (16.2%)	58 (12.0%)	131 (14.6%)
Some university, college, technical, or trade school	79 (30.4%)	33 (21.4%)	97 (20.0%)	209 (23.3%)
Technical or trade school, university or college graduate	100 (38.5%)	55 (35.7%)	207 (42.8%)	362 (40.3%)
Graduate school or higher	30 (11.5%)	39 (25.3%)	113 (23.4%)	182 (20.3%)

[a]Percentages may not sum to 100% in all categories as results for participant who did not specify an answer to that question are not shown.

[b]To protect participant privacy, results have been combined for the City of Parchment and Cooper Township participants.

3.2 Water PFAS Concentrations

See the section titled "MiPEHS participants' exposure to PFAS through drinking water was greatly reduced before they joined MiPEHS" on page 5 of the Summary Report.

Historically (meaning around the time PFAS was discovered in the areas), PFAS were detected above health-based comparison values in the drinking water of almost half of MiPEHS households for which past PFAS concentrations are available. The prevalence of elevated PFAS concentrations in current drinking water samples was less than 1%. **Table 2** shows how many households from each area previously had PFAS in their drinking water at concentrations higher than the current health-based comparison values for PFAS compared to the number of households that still had PFAS in drinking water above these screening levels at the time of MiPEHS Phase 1 sampling. This comparison is, therefore, between "past" and "current" drinking water concentrations. These concepts are defined as follows:

- "Past" drinking water: the Belmont/Rockford study area and the City of Parchment/Cooper Township study area were selected for MiPEHS because PFAS was previously found in the drinking water of many people who lived there. Most MiPEHS participants were exposed to PFAS in their drinking water until 2017 or 2018, depending on their location. Past drinking water concentrations of PFAS ranged from not detected at all to very high concentrations (e.g., tens of thousands of ppt). These measurements were taken before MiPEHS, when PFAS contamination was first discovered in the areas.
- "Current" drinking water: many participants provided a sample of their current drinking water near the time of their MiPEHS Phase 1 study office visit.

Knowing both the past and current drinking water PFAS concentrations helps researchers better understand the amount of PFAS currently in the blood of participants.

Table 2. Households in MiPEHS with PFAS found in drinking water at concentrations higher than health-based comparison values

Study Area	"Past" Number of Households (%)	"Current" Number of Households (%)
Belmont/Rockford Area[a]	68 out of 251 (27%)	0 out of 283 (0%)
City of Parchment	108 out of 108 (100%)	Estimated 0%[b]
Cooper Township	<6[c,d]	<6[d]

Table Notes. The MDHHS health-based comparison values are the lower of these two sets of values: 1) EGLE maximum contaminant levels (MCLs) and 2) MDHHS 2019 public health drinking water screening levels for PFAS. Comparison values are currently available for PFOA, PFOS, PFHxS, PFNA, PFHxA, PFBS, and GenX (GenX was not tested in "Past" historic samples).

[a]283 households from the Belmont/Rockford Area provided a water sample as part of MiPEHS ("Current"). Out of those 283, 251 had past water sampling data from the time of the environmental PFAS investigation ("Past"). Of the 251 households with past data, 68 (or 27%) had at least one water sample with at least one PFAS detected above its health-based comparison value.

[b]A representative sample of 16 former Parchment municipal customers provided current water samples during MiPEHS ("Current"). These 16 households were located at various points in the supply network and are used to understand all households served by the supply system in Parchment. There are no currently known

areas in the supply network with unique water characteristics. All 16 households sampled were below the health-based comparison values.

[c]Fewer than 6 participants in MiPEHS from Cooper Township lived in homes that were previously sampled for PFAS at the time of the initial discovery of PFAS in the Parchment municipal supply. Therefore, there is very little past data available in this area for MiPEHS participants ("Past"). Additional efforts to collect samples that could approximate past PFAS concentrations, taken at the time of MiPEHS, yielded little additional information. For more information on the scope of PFAS contamination historically in Cooper township, visit https://www.Michigan.gov/PFASResponse/0,9038,7-365-86511_82704_87495---,00.html.

[d]Counts of fewer than 6 households are censored to protect participant privacy.

3.3 Serum PFAS Frequencies and Concentrations

See the section titled “Like most people in the U.S., all MiPEHS participants had PFAS in their blood” on page 6 of the Summary Report.

The next four sections of this Technical Appendix describe the distribution of 39 serum PFAS concentrations and their detection frequencies among all MiPEHS participants (Table 3 and Figure 2) followed by area-specific summaries (Table 4, Table 5, Table 6, and Figure 3). When possible, comparisons to data from NHANES are made. Describing how different the MiPEHS population is to NHANES, which represents the general U.S. population, can be useful for putting the scope and magnitude of PFAS exposure among MiPEHS participants into perspective. The serum PFAS concentrations from NHANES can be thought of as “background” or even as the “expected” concentrations of PFAS for people living in the U.S. All comparisons to NHANES data included here are descriptive in nature, and any differences noted are meant to highlight the likelihood of large or particularly meaningful departures from what is expected. This is also true for any comparisons made between subpopulations, or study areas, within MiPEHS.

Table 3. Summary of serum PFAS detection frequencies and concentrations for MiPEHS participants who provided a blood specimen (n=932).

Analyte	Percentage of participants with analyte detection*	Participant geometric mean serum analyte concentration, µg/L	Participant 95th percentile serum analyte concentration, µg/L¶	Percentage of participants above NHANES 95th percentile**
11Cl-PF3OUdS	<0.5%	NC	<LOQ	NA^
3:3 FTCA	<0.5%	NC	<LOQ	NA‡
4:2FTS	<0.5%	NC	<LOQ	NA‡
5:3 FTCA	11.5%	NC	0.03 (0.03-0.04)	NA‡
6:2FTS	0.8%	NC	<LOQ	NA‡
7:3 FTCA	12.7%	NC	0.03 (0.03-0.04)	NA‡
8:2FTS	8.7%	NC	0.04 (0.03-0.05)	NA‡
9Cl-PF3ONS	7.1%	NC	0.03 (0.03-0.03)	3.0%
ADONA	<0.5%	NC	<LOQ	NA^
Br-PFHxS†	19.6%	NC	0.17 (0.13-0.20)	NA‡
Br-PFOA†	16.0%	NC	0.34 (0.21-0.67)	35.6%§
Br-PFOS†	100.0%	4.81 (4.41-5.25)	57.11 (47.91-71.22)	46.9%§

Analyte	Percentage of participants with analyte detection*	Participant geometric mean serum analyte concentration, µg/L	Participant 95th percentile serum analyte concentration, µg/L¶	Percentage of participants above NHANES 95th percentile**
EtFOSAA	13.3%	NC	0.05 (0.04-0.06)	NA^
HFPO-DA	<0.5%	NC	<LOQ	NA^
L-PFHxS†	99.1%	1.45 (1.32-1.58)	14.15 (9.84-18.48)	NA‡
L-PFOA†	99.9%	3.18 (2.86-3.53)	65.28 (55.14-77.47)	36.8%
L-PFOS†	100.0%	3.84 (3.57-4.13)	24.34 (21.77-29.47)	18.2%
MeFOSAA	86.9%	0.10 (0.09-0.11)	0.87 (0.79-0.99)	9.5%
NFDHA	<0.5%	NC	<LOQ	NA‡
PFBA	44.6%	NC	0.24 (0.20-0.27)	NA‡
PFBS	22.5%	NC	0.07 (0.06-0.08)	NA^
PFBSA	<0.5%	NC	<LOQ	NA‡
PFDA	95.0%	0.10 (0.1-0.11)	0.42 (0.38-0.46)	1.7%
PFDoA	7.5%	NC	0.04 (0.03-0.04)	NA^
PFDS	4.4%	NC	<LOQ (<LOQ-0.04)	NA‡
PFecHS	72.0%	0.04 (0.03-0.04)	0.14 (0.12-0.18)	NA‡
PFEESA	0.8%	NC	<LOQ	NA‡
PFHpA	57.0%	NC	0.11 (0.1-0.14)	3.0%
PFHpS	94.5%	0.34 (0.31-0.37)	4.41 (4.07-4.89)	22.8%
PFHxA	0.6%	NC	<LOQ	NA^
PFHxSA	<0.5%	NC	<LOQ	NA‡
PFMBA	<0.5%	NC	<LOQ	NA‡
PFMPA	<0.5%	NC	<LOQ	NA‡
PFNA	98.7%	0.35 (0.33-0.37)	1.18 (1.08-1.35)	3.3%
PFNS	<0.5%	NC	<LOQ	NA‡
PFOSA	<0.5%	NC	<LOQ	NA‡
PFPeA	0.6%	NC	<LOQ	NA‡
PFPeS	51.1%	NC	0.24 (0.21-0.31)	NA‡
PFPrS	<0.5%	NC	<LOQ	NA‡
PFTeA	0.6%	NC	<LOQ	NA‡
PFTriA	11.2%	NC	0.04 (0.03-0.04)	NA‡
PFUnA	75.4%	0.05 (0.05-0.05)	0.24 (0.22-0.28)	1.3%
PFHxS	99.1%	1.46 (1.34-1.60)	14.15 (10.18-18.48)	21.8%v
PFOA	99.9%	3.19 (2.87-3.54)	65.76 (55.14-78.52)	36.6%v
PFOS	100.0%	9.11 (8.42-9.86)	88.62 (70.35-96.64)	29.1%v

*Complementary suppression is in place to prevent back calculation of suppressed counts (counts greater than 0 and less than 6)

** Centers for Disease Control and Prevention, U.S. Department of Health and Human Services. National Report on Human Exposure to Environmental Chemicals. Updated March 2022. Accessed 05/02/2022. https://www.cdc.gov/exposurereport/

NC = Not calculated. Geometric means for analytes detected in fewer than 60% of participants are not calculated.
NA = Not available from NHANES.

Analyte	Percentage of participants with analyte detection*	Participant geometric mean serum analyte concentration, µg/L	Participant 95th percentile serum analyte concentration, µg/L¶	Percentage of participants above NHANES 95th percentile**

† 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.

¶ LOQ is the limit of quantitation for each analyte and is noted for every PFAS in Supplemental Table 1.

Figure 2. Distribution of select serum PFAS concentrations (µg/L) for MiPEHS participants that provided a blood sample.

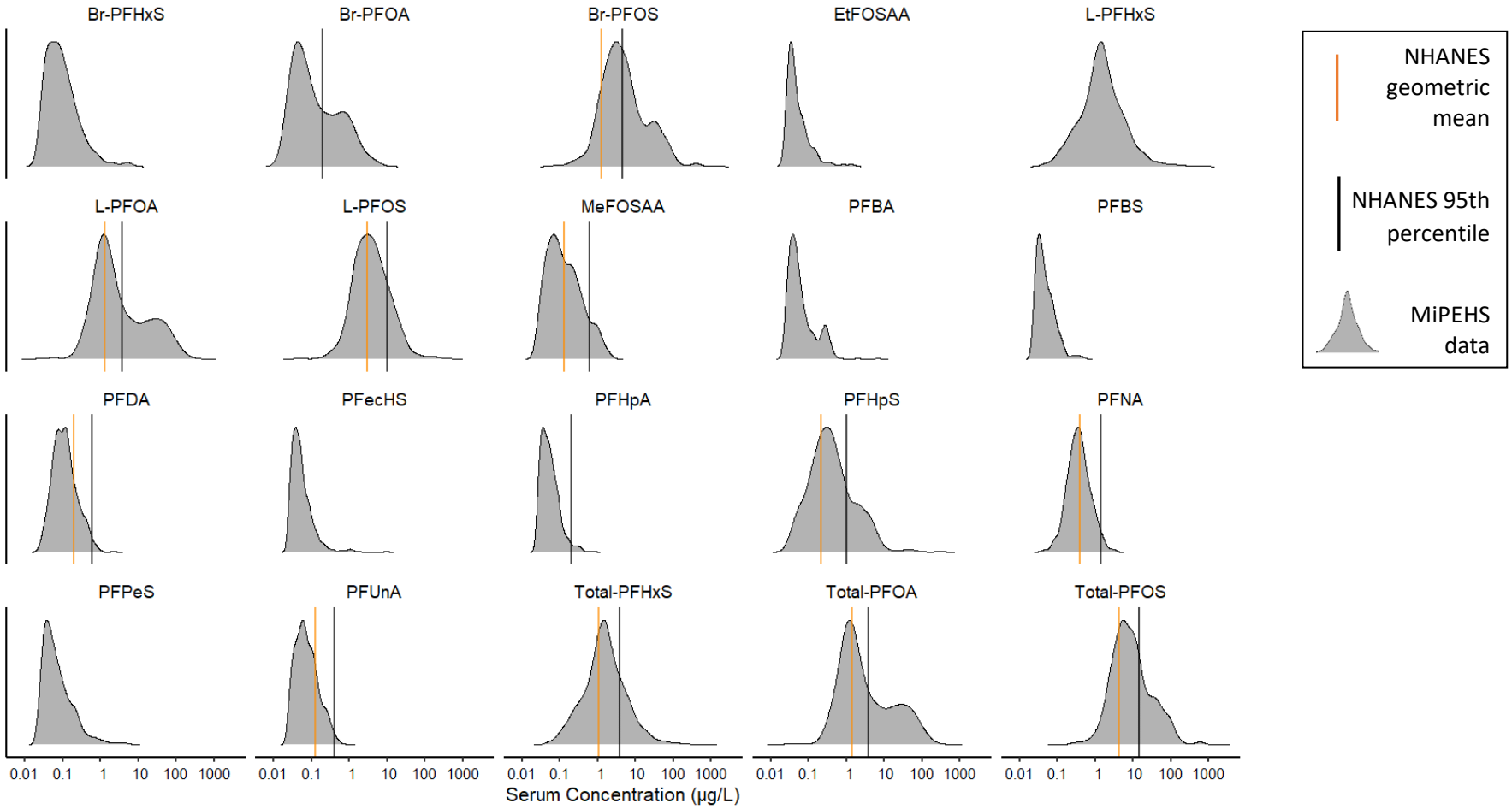


Figure Notes. The height of each graph represents the number of people who had the concentration of PFAS listed on the X axis detected in their serum. Serum concentration is expressed as microgram per liter (µg/L) which is equivalent to parts per billion (ppb). The areas of the graph that have higher peaks indicate that relatively more people had that concentration measured in their serum and the low areas indicate relatively less people had that concentration. The height of each graph is scaled to the number of people with detectable PFAS concentrations. Orange lines represent the NHANES geometric mean, and black lines represent the NHANES 95th percentile for the last year that data was available for that specific PFAS. If there are no lines on the graph, it means that NHANES did not measure that specific analyte and does not have data for these PFAS.

Table 4. Summary of serum PFAS detection frequencies and concentrations for Belmont/Rockford participants who provided a blood specimen (n=505).

Analyte	Percent of participants with analyte detection*	Participant geometric mean serum analyte concentration, µg/L	Participant 95th percentile serum analyte concentration, µg/L¶	Percent of participants above NHANES 95th percentile**
11Cl-PF3OUdS	<1.2%	NC	<LOQ	NA^
3:3 FTCA	<1.2%	NC	<LOQ	NA‡
4:2FTS	<1.2%	NC	<LOQ	NA‡
5:3 FTCA	11.1%	NC	0.03 (0.03-0.05)	NA‡
6:2FTS	1.0%	NC	<LOQ	NA‡
7:3 FTCA	12.3%	NC	0.03 (0.03-0.04)	NA‡
8:2FTS	8.3%	NC	0.03 (0.03-0.05)	NA‡
9Cl-PF3ONS	6.5%	NC	0.03 (0.02-0.03)	0%
ADONA	<1.2%	NC	<LOQ	NA^
Br-PFHxS†	18.2%	NC	0.17 (0.12-0.38)	NA‡
Br-PFOA†	10.5%	NC	0.07 (0.04-0.10)	11.3%§
Br-PFOS†	100.0%	2.89 (2.61-3.20)	17.81 (11.28-46.92)	28.5%§
EtFOSAA	13.8%	NC	0.05 (0.04-0.07)	NA^
HFPO-DA	<1.2%	NC	<LOQ	NA^
L-PFHxS†	99.0%	1.18 (1.03-1.34)	22.09 (14.32-39.47)	NA‡
L-PFOA†	99.8%	1.45 (1.31-1.59)	13.93 (8.62-23.33)	13.3%
L-PFOS†	100.0%	2.96 (2.68-3.26)	18.14 (14.32-31.83)	9.5%
MeFOSAA	86.9%	0.12 (0.11-0.13)	0.91 (0.81-1.08)	10.5%
NFDHA	<1.2%	NC	<LOQ	NA‡
PFBA	46.5%	NC	0.27 (0.24-0.30)	NA‡
PFBS	18.4%	NC	0.06 (0.05-0.09)	NA^
PFBSA	<1.2%	NC	<LOQ	NA‡
PFDA	94.9%	0.11 (0.10-0.12)	0.42 (0.37-0.48)	1.7%
PFDoA	7.7%	NC	0.04 (0.03-0.05)	NA^
PFDS	3.6%	NC	<LOQ (<LOQ -0.04)	NA‡
PFecHS	75.2%	0.04 (0.04-0.04)	0.17 (0.14-0.26)	NA‡
PFEESA	<1.2%	NC	<LOQ	NA‡
PFHpA	59.6%	NC	0.1 (0.09-0.11)	1.0%
PFHpS	92.7%	0.22 (0.20-0.25)	3.88 (2.29-7.42)	11.7%
PFHxA	<1.2%	NC	<LOQ	NA^
PFHxSA	<1.2%	NC	<LOQ	NA‡
PFMBA	<1.2%	NC	<LOQ	NA‡
PFMPA	<1.2%	NC	<LOQ	NA‡
PFNA	98.6%	0.34 (0.32-0.37)	1.15 (1.03-1.43)	3.4%
PFNS	<1.2%	NC	<LOQ	NA‡

Analyte	Percent of participants with analyte detection*	Participant geometric mean serum analyte concentration, µg/L	Participant 95th percentile serum analyte concentration, µg/L¶	Percent of participants above NHANES 95th percentile**
PFOSA	<1.2%	NC	<LOQ	NA‡
PFPeA	<1.2%	NC	<LOQ	NA‡
PFPeS	46.9%	NC	0.43 (0.27-0.73)	NA‡
PFPrS	<1.2%	NC	<LOQ	NA‡
PFTeA	1.2%	NC	<LOQ	NA‡
PFTriA	12.3%	NC	0.04 (0.04-0.06)	NA‡
PFUnA	77.4%	0.05 (0.05-0.06)	0.26 (0.22-0.30)	1.5%
PFHxS	99.0%	1.20 (1.05-1.36)	22.57 (14.32-39.47)	15.8%[v]
PFOA	99.8%	1.45 (1.32-1.60)	13.93 (8.62-23.33)	13.1%[v]
PFOS	100.0%	6.12 (5.56-6.74)	37.98 (25.49-79.79)	12.5%[v]

*Complementary suppression is in place to prevent back calculation of suppressed counts (counts greater than 0 and less than 6)

** Centers for Disease Control and Prevention, U.S. Department of Health and Human Services. National Report on Human Exposure to Environmental Chemicals. Updated March 2022. Accessed 05/02/2022. https://www.cdc.gov/exposurereport/

NC = Not calculated. Geometric means for analytes detected in fewer than 60% of participants are not calculated.

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.

¶ LOQ is the limit of quantitation for each analyte and is noted for every PFAS in Supplemental table 1.

Table 5. Summary of serum PFAS detection frequencies and concentrations for City of Parchment participants who provided a blood specimen (n=273).

Analyte	Percentage of participants with analyte detection*	Participant average percentile serum analyte concentration, µg/L	Participant 95th percentile serum analyte concentration, µg/L	Percentage of participants above NHANES 95th percentile**
11Cl-PF3OUdS	<2.3%	NC	<LOQ	NA^
3:3 FTCA	<2.3%	NC	<LOQ	NA‡
4:2FTS	<2.3%	NC	<LOQ	NA‡
5:3 FTCA	12.5%	NC	0.03 (0.03-0.04)	NA‡
6:2FTS	<2.3%	NC	<LOQ	NA‡
7:3 FTCA	10.6%	NC	0.03 (0.03-0.04)	NA‡
8:2FTS	9.5%	NC	0.04 (0.04-0.06)	NA‡
9Cl-PF3ONS	6.6%	NC	0.03 (0.02-0.04)	5.6%
ADONA	<2.3%	NC	<LOQ	NA^
Br-PFHxS†	27.1%	NC	0.19 (0.14-0.25)	NA‡
Br-PFOA†	24.2%	NC	1.32 (0.87-1.77)	66.7%§
Br-PFOS†	100%	15.28 (13.18-17.70)	74.36 (71.22-87.1)	85.3%§
EtFOSAA	12.1%	NC	0.04 (0.03-0.07)	NA^
HFPO-DA	<2.3%	NC	<LOQ	NA^
L-PFHxS†	99.6%	2.33 (2.03-2.67)	11.81 (9.28-14.69)	NA‡
L-PFOA†	100%	17.56 (14.81-20.81)	101.78 (84.27-134.71)	86.8%
L-PFOS†	100%	7.56 (6.70-8.54)	26.84 (25.07-42.23)	42.1%
MeFOSAA	85.1%	0.1 (0.08-0.11)	0.63 (0.43-0.95)	6.8%
NFDHA	<2.3%	NC	<LOQ	NA‡
PFBA	39.6%	NC	0.12 (0.07-0.23)	NA‡
PFBS	31.5%	NC	0.08 (0.07-0.13)	NA^
PFBSA	<2.3%	NC	<LOQ	NA‡
PFDA	94.9%	0.09 (0.08-0.1)	0.41 (0.32-0.48)	1.2%
PFDoA	7.0%	NC	0.03 (0.02-0.05)	NA^
PFDS	5.9%	NC	0.03 (<LOQ-0.07)	NA‡
PFecHS	77.3%	0.04 (0.03-0.04)	0.13 (0.10-0.15)	NA‡
PFEESA	<2.3%	NC	<LOQ	NA‡
PFHpA	53.8%	NC	0.17 (0.11-0.26)	7.5%
PFHpS	98.2%	0.95 (0.82-1.11)	4.87 (4.52-6.06)	53.7%
PFHxA	<2.3%	NC	0.02 (<LOQ-0.02)	NA^
PFHxSA	<2.3%	NC	<LOQ	NA‡
PFMBA	<2.3%	NC	<LOQ	NA‡
PFMPA	<2.3%	NC	<LOQ	NA‡
PFNA	99.3%	0.39 (0.36-0.43)	1.31 (1.17-1.56)	3.7%
PFNS	<2.3%	NC	<LOQ	NA‡
PFOSA	<2.3%	NC	<LOQ	NA‡

Analyte	Percentage of participants with analyte detection*	Participant average percentile serum analyte concentration, µg/L	Participant 95th percentile serum analyte concentration, µg/L	Percentage of participants above NHANES 95th percentile**
PFPeA	<2.3%	NC	<LOQ	NA‡
PFPeS	71.8%	0.04 (0.04-0.05)	0.21 (0.18-0.24)	NA‡
PFPrS	<2.3%	NC	<LOQ	NA‡
PFTeA	<2.3%	NC	<LOQ	NA‡
PFTriA	8.4%	NC	0.03 (0.03-0.04)	NA‡
PFUnA	72.1%	0.04 (0.04-0.04)	0.21 (0.15-0.28)	0.0%
PFHxS	99.6%	2.36 (2.06-2.63)	11.81 (9.28-15.2)	37.1%[v]
PFOA	100%	17.64 (14.88-20.91)	101.78 (84.27-136.18)	86.4%[v]
PFOS	100%	23.52 (20.57-26.91)	101.10 (95.98-127.66)	70.0%[v]

*Complementary suppression is in place to prevent back calculation of suppressed counts (counts greater than 0 and less than 6)

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NC = Not calculated. Geometric means for analytes detected in fewer than 60% of participants are not calculated.

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.

¶ LOQ is the limit of quantitation for each analyte and is noted for every PFAS in Supplemental table 1.

Table 6. Summary of serum PFAS detection frequencies and concentrations for Cooper Township participants who provided a blood specimen (n=154).

Analyte	Percentage of participants with analyte detection*	Participant average percentile serum analyte concentration (95% CI), µg/L	Participant 95th percentile serum analyte concentration (95% CI), µg/L¶	Percentage of participants above NHANES 95th percentile**
11Cl-PF3OUdS	<3.9%	NC	<LOQ	NA^
3:3 FTCA	<3.9%	NC	<LOQ	NA‡
4:2FTS	<3.9%	NC	<LOQ	NA‡
5:3 FTCA	11.0%	NC	0.03 (0.03-0.03)	NA‡
6:2FTS	<3.9%	NC	<LOQ	NA‡
7:3 FTCA	17.5%	NC	0.04 (0.03-0.05)	NA‡
8:2FTS	8.4%	NC	0.05 (0.02-0.08)	NA‡
9Cl-PF3ONS	9.7%	NC	0.03 (0.03-0.08)	6.7%
ADONA	<3.9%	NC	<LOQ	NA^
Br-PFHxS†	11.0%	NC	0.06 (0.03-0.15)	NA‡
Br-PFOA†	19.5%	NC	0.15 (0.08-0.23)	10.0%§
Br-PFOS†	100.0%	3.29 (2.98-3.74)	9.53 (8.52-12.74)	39.0%§
EtFOSAA	13.6%	NC	0.06 (0.04-0.15)	NA^
HFPO-DA	<3.9%	NC	<LOQ	NA^
L-PFHxS†	98.7%	1.25 (1.05-1.49)	7.34 (5.12-14.73)	NA‡
L-PFOA†	100%	2.02 (1.72-2.37)	11.43 (7.97-15.96)	27.4%
L-PFOS†	100%	2.73 (2.38-3.13)	11.25 (8.86-15.13)	4.6%
MeFOSAA	89.8%	0.12 (0.1-0.14)	1.01 (0.68-1.64)	10.9%
NFDHA	<3.9%	NC	<LOQ	NA‡
PFBA	47.4%	NC	0.15 (0.09-0.33)	NA‡
PFBS	20.1%	NC	0.06 (0.05-0.09)	NA^
PFBSA	<3.9%	NC	<LOQ	NA‡
PFDA	95.5%	0.09 (0.08-0.11)	0.44 (0.30-0.65)	2.7%
PFDoA	7.8%	NC	0.03 (0.02-0.05)	NA^
PFDS	4.5%	NC	<LOQ (<LOQ-0.06)	NA‡
PFecHS	51.9%	NC	0.12 (0.06-0.99)	NA‡
PFEESA	<3.9%	NC	<LOQ	NA‡
PFHpA	53.9%	NC	0.10 (0.09-0.19)	2.4%
PFHpS	94.2%	0.22 (0.19-0.26)	0.75 (0.70-0.85)	4.0%
PFHxA	<3.9%	NC	<LOQ	NA^
PFHxSA	<3.9%	NC	<LOQ	NA‡
PFMBA	<3.9%	NC	<LOQ	NA‡
PFMPA	<3.9%	NC	<LOQ	NA‡
PFNA	98.1%	0.29 (0.26-0.34)	1.05 (0.80-1.84)	2.6%
PFNS	<3.9%	NC	<LOQ	NA‡
PFOSA	<3.9%	NC	<LOQ	NA‡

Analyte	Percentage of participants with analyte detection*	Participant average percentile serum analyte concentration (95% CI), µg/L	Participant 95th percentile serum analyte concentration (95% CI), µg/L¶	Percentage of participants above NHANES 95th percentile**
PFPeA	<3.9%	NC	<LOQ	NA‡
PFPeS	27.9%	NC	0.06 (0.05-0.07)	NA‡
PFPrS	<3.9%	NC	<LOQ	NA‡
PFTeA	<3.9%	NC	<LOQ	NA‡
PFTriA	12.3%	NC	0.04 (0.03-0.08)	NA‡
PFUnA	74.0%	0.05 (0.04-0.06)	0.24 (0.18-0.43)	2.6%
PFHxS	98.7%	1.37 (1.06-1.51)	7.34 (5.12-14.73)	13.8%[v]
PFOA	100.0%	2.03 (1.73-2.39)	11.52 (7.97-15.96)	25.3%[v]
PFOS	100.0%	6.26 (5.52-7.10)	17.21 (15.44-27.07)	11.0%[v]

Table notes.

*Complementary suppression is in place to prevent back calculation of suppressed counts (counts greater than 0 and less than 6)

**Centers for Disease Control and Prevention, U.S. Department of Health and Human Services. National Report on Human Exposure to Environmental Chemicals. Updated March 2022. Accessed 05/02/2022. https://www.cdc.gov/exposurereport/

CI = Confidence Interval.

NA = Not available from NHANES.

NC = Not calculated because the analyte was not detected for at least 60% of participants.

† 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.

¶ LOQ is limit of quantitation and are noted for every PFAS in Supplemental Table 1.

Figure 3. Distribution (density plots) of select serum PFAS concentrations (µg/L) for MiPEHS participants 12 years and older by geographical area.

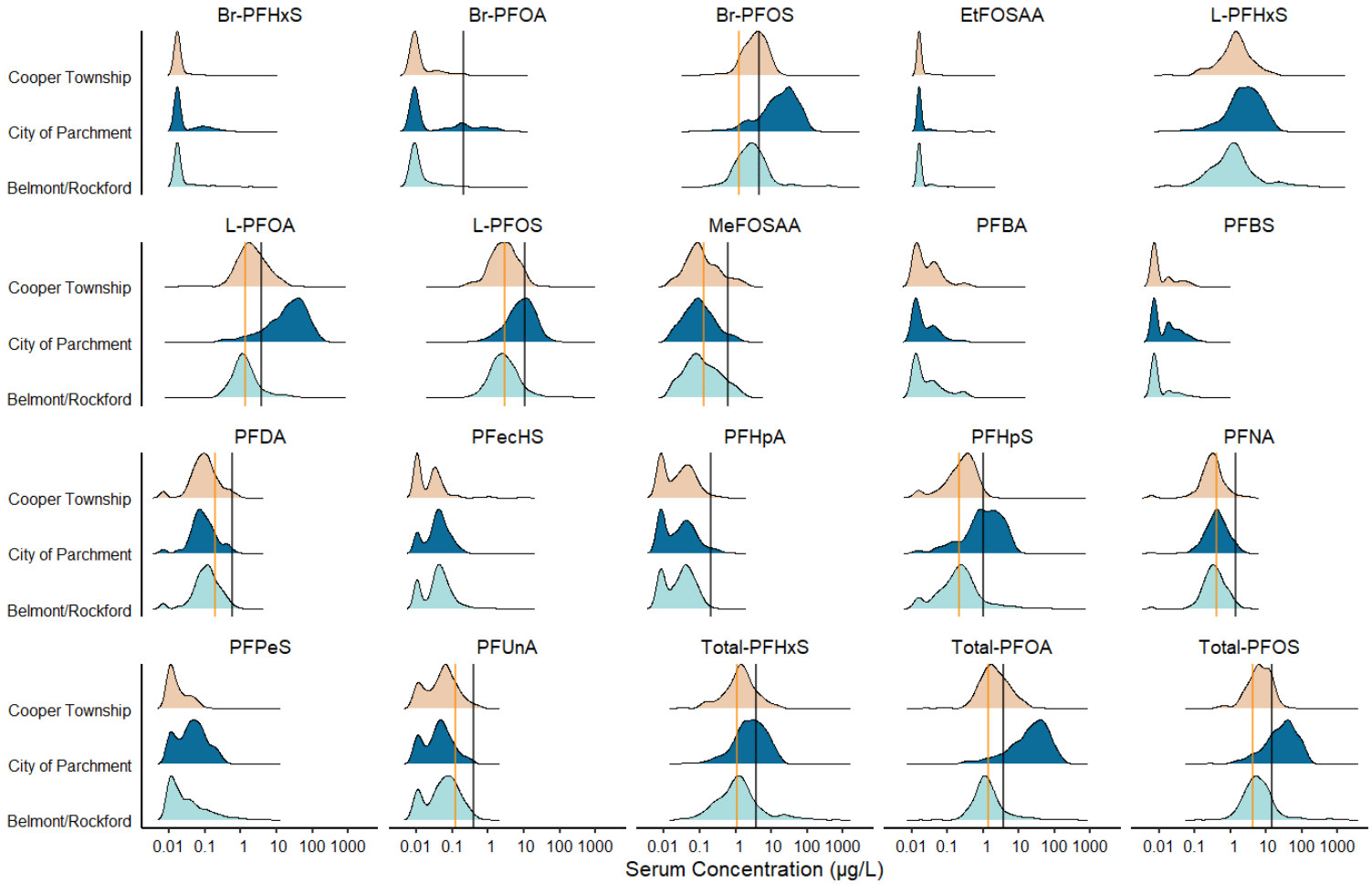


Figure notes. The height of each graph represents the number of people who had the concentration of PFAS listed on the X axis detected in their serum. The areas of the graph that have higher peaks indicate that relatively more people had that concentration measured in their serum and the low areas indicate relatively less people had that concentration. The height of each graph is scaled to the number of people with detectable PFAS concentrations. Orange lines represent the NHANES geometric mean, and black lines represent the NHANES 95th percentile for the last year that data was available for that specific PFAS. If there are no lines on the graph, it means that NHANES did not measure that specific analyte and does not have data for these PFAS.

3.3.1 Serum PFAS detection frequencies

Many important questions were asked to fully characterize exposure to PFAS among the participants of MiPEHS. The first question was, "How often was each PFAS found in the serum of MiPEHS participants?" Calculating the *detection frequency* of each PFAS measured can answer this question.

> The **detection frequency** of each PFAS describes how often that specific PFAS was found in the serum of MiPEHS participants who provided a serum sample (i.e., those 12 years and older). For example, if one type of PFAS had a detection frequency of 100%, that PFAS was detected in serum from everyone in MiPEHS. If another PFAS had a detection frequency of 0%, no one in MiPEHS had that PFAS detected in their serum.

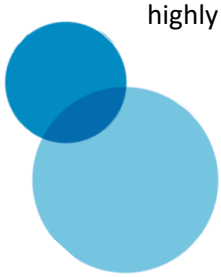
Detection frequencies varied considerably among the 39 PFAS measured in MiPEHS – some were commonly found while others were rarely detected (**Table 3**). PFOA, PFOS, PFHxS and PFNA were found in all or nearly all participants (i.e., over 98% detection frequencies). Many PFAS, including 11Cl-PF3OUdS, 3:3FTCA, 4:2FTS, 6:2FTS, ADONA, HFPO-DA (GenX), NFDHA, PFBSA, PFEESA, PFHxA, PFHxSA, PFMBA, PFNS, PFOSA, PFPeA, PFPrS, and PFTeA were detected in fewer than 1% of all participants. PFMPA was never detected among MiPEHS participants (i.e., <0.5% detection frequency). On average, 15 PFAS were found in the serum of MiPEHS participants, but the most found in a single serum sample was 35.

Many PFAS were detected among MiPEHS participants at frequencies similar to those found in the general U.S. population (according to the most recently available NHANES data; **Supplemental Table 1**). One of several exceptions is MeFOSAA, which was found in 86.9% of MiPEHS participants but in only 59% of the general U.S. population. A similar divergence in detection frequencies between MiPEHS participants and the general population was found for PFBS (22.5% in MiPEHS vs 0.7% in the US population) and PFBA (44.6% vs 11.1%). Interestingly, PFHxA was found less frequently among MiPEHS participants (0.6%) compared to the general U.S. population (23.7%).

Detection frequencies in the general U.S. population are not yet known for all the PFAS studied in MiPEHS. For example, four of the PFAS found in over half of MiPEHS participants—PFHpS (94.5%), PFecHS (72.0%), PFHpA (57.0%), and PFPeS (51.1%)—have no known comparison in the general U.S. population yet [21]. Detection frequencies of PFAS, when viewed by geographical area, show how some PFAS were more common among participants from one area or another. For example, PFPeS was found in 46.9% of Belmont/Rockford area participants, 71.8% of City of Parchment participants, and in only 27.9% of Cooper Township participants (**Table 4**, **Table 5**, **Table 6**).

3.3.2 Serum PFAS geometric means

When detection frequencies (**Section 3.3.1**) are viewed in combination with the average serum PFAS concentrations among MiPEHS participants, a more complete picture of PFAS exposure is observed. An examination of the serum PFAS concentrations among MiPEHS participants reveals how unique and highly exposed this study population is compared to the general U.S. population. There are several ways



to understand the study population's serum PFAS concentrations. One way is to calculate the **geometric mean.**

A **geometric mean** is a special type of average commonly used in epidemiological research (hereafter referred to as geometric mean or average). It can be used to compare the average blood concentrations in one group (e.g., MiPEHS participants) to another group (e.g., NHANES participants, representing the general U.S. population). Using a geometric mean rather than the more commonly known arithmetic mean helps to reduce the extreme effect of outliers and gives a more representative description of the average serum PFAS concentrations among study participants.

Geometric mean serum concentrations were calculated if the PFAS was detected in at least 60% of participants (Table 3). When comparing the geometric means of serum PFAS concentrations from each study area, large differences appear for a few of the PFAS measured (Table 4, Table 5, Table 6). For example, a large difference can be observed in average serum PFAS concentration between participants whose residences were served by the City of Parchment water supply compared to the participants from the other study areas (Figure 3). On average, participants from Parchment had serum concentrations of PFOA, PFOS, PFHxS and PFHpS higher than participants from the other areas. For example, average PFOA concentrations were 1.45 and 2.03 µg/L among participants who had private wells in the Belmont/Rockford area and Cooper Township area, respectively, compared to 17.64 µg/L among participants living in the City of Parchment, which is an approximately 10-fold difference. For the other PFAS, for which geometric means could be calculated, there were no large differences between participants from different study areas.

The geometric means of serum concentrations for several PFAS were higher among MiPEHS participants compared to the general U.S. population. The largest differences were seen for PFOA and PFOS, where the geometric means (and their 95% confidence intervals) among MiPEHS participants 12 years and older were 3.19 (2.87-3.54) µg/L for PFOA and 9.11 (8.42-9.86) µg/L for PFOS. The averages for the general U.S. population were 1.42 (1.33-1.52) µg/L for PFOA and 4.25 (3.90-4.62) µg/L for PFOS. This shows that on average, MiPEHS participants had over twice the amount of these two PFAS in their blood compared to the general U.S. population. For PFHxS, the geometric mean among all MiPEHS participants was 1.46 (1.34-1.60) µg/L compared to a U.S. population average of 1.08 (.996-1.18) µg/L. For other PFAS, average concentrations were only slightly different from the general U.S. population. For example, the MiPEHS average for PFNA was 0.35 (0.33-0.37) and the general U.S. population average was 0.41 (0.36-0.46). For still others, there is not yet a comparison available to the U.S. population.

When comparing the geometric means of serum PFAS concentrations among participants from each of the three MiPEHS study areas to the U.S. population it is clear that the geometric means of many serum PFAS concentrations from participants living in the City of Parchment area appears more unlike the geometric means associated with the general U.S. population [21] than do the geometric means of those living in Cooper Township or the Belmont/Rockford area (Table 4, Table 5, Table 6). This effect was observed among several PFAS, namely, PFOA, PFOS, PFHxS and PFHpS. However, geometric means of participants from all study areas for other PFAS such as PFNA, PFDA and MeFOSAA were very similar to or lower than those of the U.S. population.

3.3.3 Serum PFAS 95th percentiles

See section titled "The average and 95th percentile blood PFOS and PFOA concentrations were different for participants in each MiPEHS study location" on pages 10—11 of the Summary Report.

Describing the frequencies with which PFAS were detected (**Section 3.3.1**) and at what concentrations they were found (**Section 3.3.2**) characterizes most aspects of exposure among MiPEHS participants. However, the question "How highly exposed are those with the most PFAS in their serum?" can be answered by examining another calculation, a *percentile*. Specifically, the *95th percentile* can help us better understand how highly exposed the MiPEHS participants are at the highest end of the distribution (e.g., the top 5% of PFAS results among all MiPEHS participants). This in turn can inform whether the MiPEHS population may be considered a "highly exposed" population, or not, compared to the general U.S. population.

The **95th percentile** is a calculation commonly reported for PFAS measurements in the U.S. population and is a good indicator of the serum PFAS concentrations observed among those participants with the very highest exposure. The 95th percentile serum concentration is the concentration that 95% of results are below and 5% of results are above. Therefore, the 95th percentile is the PFAS serum concentration which the highest 5% of all MiPEHS participants are above. If that value is much higher for the MiPEHS population than it is for the general U.S. population, it can be concluded that the MiPEHS population is more highly exposed than the general U.S. population. Note: the 95th percentile is not the same as the highest serum PFAS concentration (or "maximum") measured in any given participant.

The 95th percentiles for some PFAS measured in the serum of MiPEHS participants were much higher than those observed among the general U.S. population [21]. This means the serum concentration that marks where the highest 5% of people fall is higher in MiPEHS compared to the U.S. population. The largest differences were seen for PFOA and PFOS, where the top 5% of MiPEHS participants had concentrations at or higher than 65.76 µg/L (PFOA) and 88.62 µg/L (PFOS). Compare this to the general U.S. population where the 95th percentiles are 3.77 µg/L (PFOA) and 14.6 µg/L (PFOS). The 95th percentiles of PFHxS and PFHpS were similarly observed to be higher among MiPEHS participants than the general population. The 95th percentile values for the U.S. population are not available for every PFAS measured in MiPEHS, but for the other PFAS where we can make that comparison, such as PFNA, PFHpA, PFDA, and others, MiPEHS participants were very similar to the general U.S. population.

Additionally, we report the percentage of MiPEHS participants with a serum PFAS concentration at or above the 95th percentile for the U.S. population. About a third of MiPEHS participants had elevated serum PFOA or PFOS concentrations (**Table 3** and purple box below**)**. About a third or more of participants also had elevated concentrations of linear and branched versions of PFHxS, PFHpS, and MeFOSAA. For other PFAS, the percentage of participants with concentrations above the NHANES 95th percentile was less than 5%, indicating the percentage of participants with elevated concentrations was similar or even lower than what we would expect in the general U.S. population.

How is the term elevated being used, and why?

The term **elevated** is used in this technical appendix to provide a relative indication of the magnitude of serum concentrations measured. It is a *relative* term because it uses data from NHANES that is representative of the general U.S. population as the value for what is expected in a Michigan population. Simply put, **the term elevated is defined here as a serum PFAS concentration higher than the 95th percentile value from NHANES** (See blue box on 95th percentiles, on previous page).

For example, the larger the percentage of MiPEHS participants with serum PFAS results at or above the 95th percentile value for the U.S. population, the more people in the MiPEHS cohort have what is considered a relatively elevated serum PFAS concentration. It is important to note that the concentration at which serum PFAS are considered elevated is not related to concentrations at which we expect to see adverse health outcomes. It is simply a way to compare two populations along a common reference point.

Comparing the 95th percentile serum PFAS concentrations among the three study areas revealed a similar pattern as that found among geometric means of each study area. The group with the highest 95th percentile values for most PFAS measured were those participants formerly served by the City of Parchment's municipal water supply. The 95th percentile serum PFOA and PFOS concentrations among participants from the City of Parchment were 101.78 µg/L (PFOA) and 101.10 µg/L (PFOS), which are considerably higher than the corresponding concentrations of 11.52 µg/L (PFOA) and 17.21 µg/L (PFOS) in Cooper Township, and 13.93 µg/L (PFOA) and 37.98 µg/L (PFOS) in the Belmont/Rockford area. For PFHxS, those in the Belmont/Rockford area had a 95th percentile value two times higher than both the City of Parchment and Cooper Township areas even though the average concentration was higher in the City of Parchment group. Belmont/Rockford area participants also had the highest 95th percentile values for PFBA and PFPeS out of the three areas, but there is not yet a comparison value for these to the general U.S. population.

Participants from the City of Parchment had the highest proportions of elevated serum PFOA (86.4%), PFOS (70.0%), and PFHxS (37.1%) concentrations compared to the other study areas where fewer people had elevated concentrations. However, both the Belmont/Rockford and Cooper Township areas had more than 5% of participants with elevated serum concentrations, showing that more people there are impacted by high PFOA, PFOS, and PFHxS serum concentrations compared to the general U.S. population. Additionally, all three study areas had a greater proportion of participants with elevated serum MeFOSAA concentrations compared to the general U.S. population (Belmont/Rockford with 10.5%, City of Parchment with 6.8%, and Cooper Township with 10.9%). A greater proportion than expected of participants in the City of Parchment (53.7%) and the Belmont/Rockford area (11.7%) also showed elevated concentrations of PFHpS. The City of Parchment (5.6%) and Cooper Township (6.7%) had slightly larger than expected proportions of participants with elevated serum 9Cl-PF3ONS concentrations.

3.3.4 Serum PFAS concentrations change over time

The previous sections (**Sections 3.3.1 – 3.3.3**) have described the prevalence, geometric means, and

See the section titled "Blood PFAS concentrations change over time, and information is gained when people participate in all three MiPEHS phases" on page 12 of the Summary Report.

95th percentiles for serum PFAS concentrations among participants in MiPEHS. This section moves beyond the insular MiPEHS dataset to include data from an earlier exposure assessment conducted by MDHHS in the Belmont/Rockford area. In so doing, this section describes how serum PFAS concentrations changed over time for some participants of MiPEHS.

One hundred and eight participants in MiPEHS were formerly enrolled in the North Kent County Exposure Assessment (NKCEA) between 2018 and 2019 and allowed their records from this period to be combined with their new data from MiPEHS. During NKCEA, 30 PFAS were measured in the serum of these participants. When they joined MiPEHS two years later, 39 PFAS were measured in their serum. These repeated PFAS measurements within participants allows us to describe the impact of *time* on serum PFAS concentrations (**Table 7** and **Table 8**).

Many of the same comparisons and descriptions of serum PFAS results that have been described in previous sections of this document for the MiPEHS-only dataset can be applied to this additional, repeated measures, dataset. When the change in detection frequencies between NKCEA and MiPEHS was examined, there were notable declines in the majority of the PFAS measured for most people. For example, PFPeA was observed in the serum of just under half of these participants during NKCEA, but when they returned two years later for MiPEHS, PFPeA was only found in 1% of participants. The same trend appears for detection frequencies of PFDoA (76% in NKCEA compared to 6% in MiPEHS) and PFTriA (57% in NKCEA and 7% in MiPEHS). That means most people went from having PFPeA, PFDoA, and PFTriA detected in their blood, to having none detected at all. For other PFAS (e.g., PFOA and PFOS), a similar decrease in detection frequencies among this group of participants was not observed. Among the 15 PFAS only measured during MiPEHS, just four (5:3 FTCA, 7:3 FTCA, 9Cl-PF3ONS, PFecHS) were detected in the serum of participants.

Serum PFAS concentrations are expected to **decline** with time once PFAS exposure has been reduced or ended altogether. The rate at which this decline happens is different for each PFAS and depends on its unique physicochemical properties. This decline can occur at different rates for different people depending on their own unique biology.

Despite maintaining a 100% detection frequency for PFOA and PFOS during both NKCEA and MiPEHS, the *concentrations* at which these were found in serum declined (**Table 8**). This means that for some PFAS, the change between NKCEA and MiPEHS was not a shift from low detections to no detections, but rather a shift from higher concentrations to relatively lower ones. This effect can be seen for many PFAS as a shift to the left on the density plots in **Figure 4.** An additional example is PFHxS where the change in average serum PFAS concentration went from 5.92 µg/L during NKCEA to 1.52 µg/L during MiPEHS.

The most striking declines were observed by comparing the 95th percentiles of serum PFAS concentrations for these participants from NKCEA to MiPEHS. This comparison shows how the highest 5% of all concentrations changed over time. For example, the 95th percentile serum PFHxS concentrations for these participants declined from 155.91 µg/L during NKCEA to just 14.27 µg/L during MiPEHS. That means, during NKCEA, 95% of these participants had serum concentrations at or below 155.91 µg/L and just two years later 95% of them had serum concentrations at or below 14.27 µg/L. Many other PFAS followed a similar pattern of decline (**Table 8**).

The change over time that occurs to the 95th percentile concentrations for these participants can be further understood by comparing them to the general U.S. population. If having a serum PFAS

concentration higher than the U.S. population's 95th percentile can be considered elevated (see purple box on the term "elevated", page 15), then we can describe how elevated these participants' concentrations were at the time of NKCEA compared to two years later during MiPEHS. This comparison reveals that the percentage of participants with elevated serum PFHxS concentrations, for example, dropped from 50.0% during NKCEA to 21.8% during MiPEHS (Table 8). Note: when making this comparison, MeFOSAA showed a small *increase* in the percent considered elevated even though it was detected less often among these participants (Table 8).

Table 7. Detection frequencies of PFAS among MiPEHS participants who participated in the North Kent County Exposure Assessment (n=108).

Analyte	NKCEA Detection Frequency*	MiPEHS Detection Frequency*
5:3 FTCA	NA‡	10%
6:2FTS	0%	<5%
7:3 FTCA	NA‡	16%
8:2FTS	0%	6%
9Cl-PF3ONS	NA‡	6%
ADONA	0%	0%
Br-PFHxS†	77%	31%
Br-PFOA†	53%	14%
Br-PFOS†	100%	100%
EtFOSAA	33%	14%
HFPO-DA (Gen-X)	0%	0%
L-PFHxS†	100%	99%
L-PFOA†	100%	100%
L-PFOS†	99%	100%
MeFOSAA	98%	83%
PFBA	92%	47%
PFBS	19%	13%
PFDA	100%	97%
PFDoA	76%	6%
PFDS	36%	<5%
PFecHS	NA‡	78%
PFHpA	87%	71%
PFHpS	98%	95%
PFHxA	15%	<5%
PFNA	100%	100%
PFNS	12%	<5%
PFOSA	39%	0%
PFPeA	46%	<5%
PFPeS	91%	69%
PFTeA	8%	0%
PFTriA	57%	7%
PFUnA	97%	82%

PFHxS	100%	99%
PFOA	100%	100%
PFOS	100%	100%

*Complementary suppression is in place to prevent back calculation of suppressed counts (counts greater than 0 and less than 6)

NA‡ = Not available from NKCEA.

† Analytes with an L- prefix are linear isomers and analytes with a Br- prefix are branched isomers.

Figure 4. Comparison of serum PFAS concentrations (µg/L) for 108 participants who participated in both MiPEHS (blue) and NKCEA (purple).

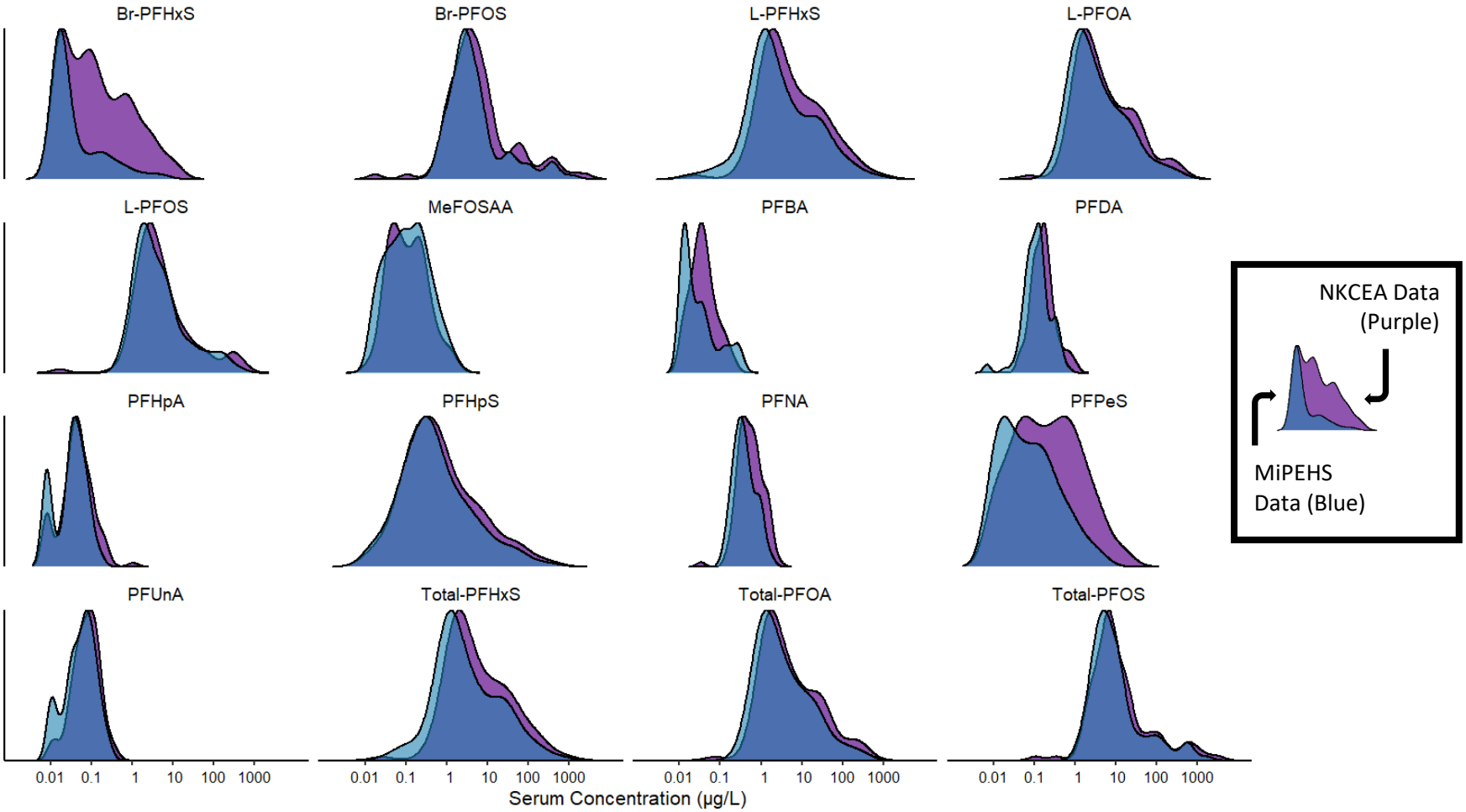


Figure notes. Purple shaded areas represent NKCEA participants and blue shaded area represent MiPEHS participants. The height of each graph represents the number of people who had the concentration of PFAS listed across the bottom axis detected in their serum. The areas of the graph that have higher peaks indicate that relatively more people had that concentration measured in their serum and the low areas indicate relatively less people had that concentration. The height of each graph is scaled to the number of people with detectable PFAS concentrations.

Table 8. Geometric mean and 95th percentile of serum PFAS concentrations in MiPEHS and NKCEA for 108 individuals who participated in both MiPEHS and NKCEA.

Analyte	NKCEA geometric mean (95% CI), µg/L	MiPEHS geometric mean (95% CI), µg/L	NKCEA 95th Percentile (95% CI), µg/L	MiPEHS 95th Percentile (95% CI), µg/L	Percentage of NKCEA participants over NHANES 95th percentile*	Percentage of MiPEHS participants over NHANES 95th percentile*
Br-PFHxS†	0.26 (0.19-0.35)	NC	4.57 (2.77-12.25)	NC	NA	NA‡
Br-PFOA†	0.10 (0.07-0.15)	0.13 (0.12-0.14)	NC	NC	35.0%	35.6%
Br-PFOS†	6.27 (4.41-8.92)	4.81 (4.41-5.25)	339.41 (80.8-2583.67)	57.11 (47.91-71.22)	50.9%	46.9%
EtFOSAA	NC	NC	NC	NC	NA	NA^
L-PFHxS†	5.70 (4.09-7.93)	1.51 (1.39-1.64)	145.79 (65.8-884.53)	14.27 (9.84-18.48)	NA	NA‡
L-PFOA†	5.14 (3.78-6.99)	3.19 (2.88-3.54)	147.36 (44.99-386.5)	65.39 (55.14-77.47)	48.1%	36.8%
L-PFOS†	5.67 (4.23-7.62)	3.84 (3.57-4.13)	235.57 (58.18-589.35)	24.34 (21.77-29.47)	25.2%	18.2%
MeFOSAA	0.11 (0.09-0.14)	0.13 (0.12-0.14)	0.73 (0.49-1.67)	0.93 (0.82-1.06)	6.6%	9.5%
PFBA	0.04 (0.04-0.05)	NC	0.14 (0.12-0.23)	NC	NA	NA‡
PFBS	NC	NC	NC	NC	NA	NA^
PFDA	0.16 (0.14-0.18)	0.11 (0.11-0.12)	0.63 (0.42-1.09)	0.42 (0.39-0.47)	6.5%	<4.6%
PFDoA	0.02 (0.02-0.02)	0.05 (0.04-0.05)	0.06 (0.04-0.09)	NC	NA^	NA^
PFDS	NC	NC	NC	NC	NA‡	NA‡
PFHpA	0.05 (0.05-0.06)	0.05 (0.05-0.05)	0.19 (0.13-1.02)	0.15 (0.13-0.19)	<4.6%	<4.6%
PFHpS	0.77 (0.53-1.13)	0.41 (0.37-0.45)	45.35 (11.59-337.08)	4.49 (4.14-5.15)	34.0%	22.8%
PFHxA	NC	NC	NC	NC	NA	NA^
PFNA	0.55 (0.48-0.63)	0.37 (0.35-0.38)	1.66 (1.47-2.78)	1.18 (1.08-1.36)	13.0%	<4.6%
PFNS	NC	NC	NC	NC	NA	NA‡
PFOSA	NC	NC	NC	NC	NA	NA‡
PFPeA	NC	NC	NC	NC	NA	NA‡
PFPeS	0.28 (0.21-0.39)	NC	4.49 (3.35-17.75)	NC	NA	NA‡
PFTeA	NC	NC	NC	NC	NA	NA‡
PFTriA	NC	NC	NC	NC	NA	NA‡
PFUnA	0.08 (0.07-0.09)	0.07 (0.07-0.08)	0.22 (0.16-0.40)	0.27 (0.24-0.30)	0.0%	<4.6%
PFHxS	5.92 (4.25-8.24)	1.52 (1.4-1.66)	155.91 (70.48-884.53)	14.27 (10.18-18.48)	50.0%	21.8%
PFOA	5.23 (3.84-7.13)	3.21 (2.89-3.56)	147.36 (46.12-396.9)	65.82 (55.14-78.52)	47.2%	36.6%

Analyte	NKCEA geometric mean (95% CI), µg/L	MiPEHS geometric mean (95% CI), µg/L	NKCEA 95th Percentile (95% CI), µg/L	MiPEHS 95th Percentile (95% CI), µg/L	Percentage of NKCEA participants over NHANES 95th percentile*	Percentage of MiPEHS participants over NHANES 95th percentile*
PFOS	12.25 (8.86-16.95)	9.11 (8.42-9.86)	590.39 (129.61-3173.02)	88.62 (70.35-96.64)	36.1%	29.1%

*Centers for Disease Control and Prevention. Fourth National Report on Human Exposure to Environmental Chemicals Updated Tables, January 2021, Volume One. 2021.

CI = Confidence Interval.

NA = Not available from NHANES.

NC = Not calculated because the analyte was not detected for at least 60% of participants.

‡ 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.

4.0 Key Findings

Data collected during MiPEHS Phase 1 have revealed the unique and diverse PFAS exposures experienced by Michiganders living in communities impacted by environmental contamination. This Technical Appendix and the accompanying Summary Report describes:

- The serum PFAS concentrations observed among participants in MiPEHS to date (Finding 1).
- Comparisons of serum PFAS concentrations in MiPEHS participants to those in the general U.S. population (Finding 1).
- An in-depth evaluation of how serum PFAS concentrations have changed over time, which was made possible for a subset of MiPEHS participants who allowed their prior serum PFAS data to be analyzed alongside new measurements taken during MiPEHS (Finding 2).
- Serum PFAS differences between and within study areas (Finding 3).

Additionally, a brief report on drinking water PFAS concentrations among participant households is also described here and will be elaborated upon in future work. The findings described here **underscore the critical importance of this public health research** and lay the groundwork for the additional planned follow-up reports and peer-reviewed journal articles that will cover health effects associated with the serum PFAS concentrations described here.

Finding 1. Serum PFAS Frequencies and Concentrations

Overall, PFOA, PFOS, and PFHxS were found in the serum from nearly all MiPEHS participants. This was expected, as national and international studies show serum from most people contain these three PFAS. However, although the detection frequencies of PFOA, PFOS and PFHxS from MiPEHS participants mirror those seen in the general U.S. population, the concentrations at which they were detected tended to be higher among MiPEHS participants than for the general U.S. population. The average concentrations of PFOA, PFOS, PFHxS and PFHpS in serum from MiPEHS participants were roughly double those observed in the U.S. population. This effect was not, however, seen among all PFAS quantified in MiPEHS.

MiPEHS data also show that some PFAS rarely found in the general population are common among this study population. For example, MeFOSAA was found in 86.9% of MiPEHS participants, but nationwide the detection rate of MeFOSAA in the general population is just 59%. Other PFAS with detection frequencies that were higher than expected included PFBS, PFDA, PFHpA, and PFUnA. These PFAS were detected in a much greater proportion of MiPEHS participants than expected when compared to the general U.S. population.

Finding 2. Serum PFAS Changes Over Time

When serum PFAS data was collected during MiPEHS Phase 1, it was approximately 3 years after participants' primary exposure to PFAS via contaminated drinking water ended or was greatly reduced. During this 3-year period, serum concentrations of many PFAS likely decreased. This could be understood by two key factors: 1) the reduction or elimination of PFAS from drinking water and 2) the subsequent removal of PFAS via normal bodily processes. Additionally, there is reason to believe that other relevant sources of environmental PFAS (including from consumer products) also declined during this time. Nationally, blood concentrations of some PFAS have been trending downward for several years [22] – likely because of the planned phase-outs of those PFAS by industry. Therefore, serum concentrations among MiPEHS participants in the past might have been higher than what was quantified

during MiPEHS. This would be especially true of PFAS with short half-lives of elimination (i.e., those that are removed from the body relatively quickly). Therefore, the concentrations in this report reflect current conditions only and should not be used as approximations of historic serum levels.

Not only are declining serum concentrations of some PFAS expected for the aforementioned reasons, data presented here are consistent with that understanding and suggest that the overall serum concentrations of some PFAS did decrease over time for many participants. Among those participants in MiPEHS who previously participated in NKCEA, 94% saw their serum PFOA and PFOS concentrations go down between the two sampling points of NKCEA and MiPEHS Phase 1. Again, this finding was consistent with known half-lives of elimination for these PFAS [22] and was expected given that the presumed dominant exposure pathway (i.e., drinking water) ended shortly before NKCEA was launched. For the group of these participants that had unchanging or increasing serum PFAS concentrations over time, numerous possible explanations can be considered. One possibility is that some sources of exposure may not yet be identified. Also, there is some expected variability in the analytical quantification of PFAS especially from samples taken at different times. Future reports and data will help inform these hypotheses.

Finding 3. Serum PFAS Differences Between and Within Study Areas

The results presented here suggest that group-level serum PFAS concentrations may be *distinct* between the different geographical study areas, each of which had their own distinct environmental contamination. The geometric mean of participants from the City of Parchment tended to be higher for some PFAS than the geometric means of participants from the other study areas. In many ways, this finding was expected and aligns closely with what is known about the environmental contamination in these distinct study areas. As a group, participants from the City of Parchment were expected to have a more homogeneous exposure because they all drank from the same municipal water source. Participants on private wells, however, tend to have levels of contamination that can vary widely from house to house, even within the same neighborhood. Some of those variations are due to the unique characteristics of their drinking water well (e.g., the depth to which it is drilled).

Not only are group differences between study areas reported here, but so too are differences among participants within the same study area, as evidenced by the wide distribution of serum PFAS concentrations found within each study area. The primary route of PFAS exposure for all participants in MiPEHS was through the consumption of contaminated drinking water, and the inclusionary criteria for MiPEHS participation ensured the consumption of that contaminated drinking water was relatively recent. Despite these similarities among participants, meaningful differences emerged in the data from the people living in these three areas. There can be several reasons for this. Primarily, differential exposures to PFAS among participants is a likely explanation. This includes differences in behavior that affects exposure (e.g., drinking bottled water), differences in other routes of exposure (e.g., use of consumer products containing PFAS), and individual biological differences that can impact serum PFAS concentrations (e.g., kidney disease). Other reasons include varied concentrations of PFAS in the drinking water used by participants and exposure to different mixtures of PFAS, some with very long and others with very short half-lives of elimination.

These differences between and within the geographical study areas described above do not weaken the design of MiPEHS, nor do they preclude the combined use of data from all participants. On the contrary, a wide range of serum PFAS concentrations, reflecting differences in exposure- and biological

parameters among MiPEHS participants, strengthens the ability to understand how health effects associated with PFAS emerge among a diverse population.

5.0 Limitations

Although representative of west Michigan (a population that overwhelmingly identifies as non-Hispanic white), MiPEHS participants are neither representative of the entire Michigan population nor the broader population of the U.S. Similarly, the specific ages, exposure histories and geographic locations targeted in MiPEHS constitute a unique population. Therefore, some caution may be needed in generalizing the data presented here to other populations. MiPEHS focuses largely on exposure via drinking water and extrapolation to areas where drinking water exposure is not the primary route of exposure may be inappropriate.

There are also unknowns related to the past PFAS exposure experienced by MiPEHS participants that limits some of the conclusions drawn. For instance, questions remain about the duration and magnitude of past PFAS environmental contamination within the study areas targeted. This limits our ability to accurately describe, with certainty, some elements of participants' exposure history. Although work is ongoing to historically reconstruct past groundwater conditions in these areas, those predictions are not currently available. Even once they are generated, some gaps may remain in those predictions. Similarly, all possible PFAS exposure routes relevant to all MiPEHS participants cannot be known with certainty. Therefore, understanding the precise contribution of different routes of PFAS exposure to serum PFAS concentrations may not be achievable.

Finally, because of the decline over time in serum PFAS concentrations among the general U.S. population, all comparisons in this report were made using the most recent NHANES data available. As of the writing of this report, the most recent data available is 2017-2018 or 2015-2016, depending on the specific PFAS analyte. In several years, PFAS data closer in time to when MiPEHS Phase 1 took place (e.g., 2020 and 2021) will become available and could change how MiPEHS data are understood.

6.0 Future Directions

The communities who have been identified as having PFAS in their drinking water have expressed concern about their exposures and health and are looking to MDHHS for answers – here in western Michigan and elsewhere throughout the state. Providing these answers is a unique challenge for the toxicologists and risk assessors because many gaps remain in the current understanding of PFAS toxicity. The consequences to health following exposure are thought to differ based on the specific PFAS and magnitude of exposure, with multiple, overlapping biological systems affected. Environmental epidemiology studies, like MiPEHS, are critical for improving our understanding of PFAS exposures from drinking water and how health changes as a consequence of that exposure. The exposure information (e.g., serum PFAS frequencies and concentrations) presented here lays the groundwork for further analyses within this dataset that will cover health outcomes, latency periods, and longitudinal analyses.

The summary statistics reported here are averages (e.g., geometric means) or other calculations made from the study population (e.g., 95th percentiles). Therefore, they do not reflect the serum PFAS concentrations of *every* study participant. By definition, many participants fall below an average or 95th percentile calculation. We caution against the incorrect interpretation that all MiPEHS study participants were more highly exposed than the U.S. population average. Technical staff from MDHHS are available to discuss or explain the contents of this report.

Reporting on **additional objectives** will occur as Phase 1 data continue to become final and as Phases 2 and 3 of MiPEHS are completed in the coming years. Consider the following:

- Whole blood PFAS concentrations from dried blood spots and serum PCBs concentrations are **not yet available** from Phase 1.
- Detailed analyses on relationships between PFAS water and serum concentrations, and between PFAS blood concentrations and health **will be conducted**. As appropriate, these findings will be submitted for publication in scientific journals, which will be available on MDHHS's MiPEHS website and summarized in community factsheets. Community forums will be held to discuss these findings.
- Longitudinal PFAS and health data combining all three phases of MiPEHS is not possible until the end of MiPEHS data collection.

See **Attachment A** for a description of the full objectives of MiPEHS, including all testing conducted on blood during Phase 1. See **Supplemental Table 1** for a list of abbreviations used in this document.

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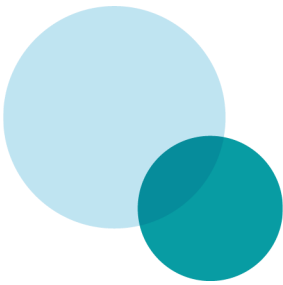

Attachment A: Longitudinal Research Objectives of MiPEHS

MiPEHS is a multi-year, longitudinal research study examining the associations among PFAS blood concentrations and health. However, the design of MiPEHS permits the inclusion of additional, complementary objectives. Thematic groupings of endpoints will be made, as appropriate, and submitted for peer-review in scientific journals.

Research Objectives: Longitudinal MiPEHS (Phases 1, 2, and 3)

- Describe the concentration and frequency of detection in serum of a select set of PFAS in current samples of venous blood and capillary blood, as well as in newborn dried blood spots (DBS), for persons residing in an area that has been identified as having PFAS contaminated groundwater.
    - Sub-objective: Determine the validity of capillary blood samples for quantifying PFAS analytes compared to venous blood samples.
    - Sub-objective: Determine the stability of PFAS analytes in capillary blood spots over 20 years.
    - Sub-objective: Quantify pre-natal exposure using newborn blood spots for persons born in 1987 or after residing in an area that has been identified as having PFAS-contaminated groundwater.
- Determine if self-reported risk factors are associated with high serum PFAS concentrations, such as occupational history, consumption of locally sourced foods, and consumption of PFAS-containing drinking water.
- Determine rate of decline in serum PFAS concentration by type of PFAS over time.
- Determine if serum PFAS concentrations are significantly higher than the U.S. general population as defined by the National Health and Nutrition Examination Survey (NHANES) results, where possible.
- Determine if current serum PFAS concentrations are associated with current clinical biomarkers or reported health outcomes, after controlling for potential confounders.
- Determine if current serum PFAS concentrations are predictive of change in clinical biomarkers or incidence of reported health outcomes over time, after controlling for potential confounders.
- Determine if serum PCB concentrations in the study area are significantly higher than the U.S. general population or Michigan background population.
- Determine if serum PCB concentrations or serum DLC concentrations confound or modify the relationship between serum PFAS concentrations and clinical biomarkers or health outcomes.

The following are examples of what can be learned through MiPEHS:

- How exposure to per-and polyfluoroalkyl substances (PFAS) in drinking water relates to the levels in people's blood.
- How PFAS levels in people's blood could be related to health.
- If a blood sample taken from your arm and a blood sample taken from your finger have similar PFAS test results.
- If PFAS exposure during pregnancy is related to birth outcomes, like low birth weight.
- If people's PCBs in blood changes the relationship between PFAS levels and health.
- If exposure to mixtures of PFAS is important for understanding health effects.

Use of Findings

MiPEHS findings will be used to:

- Provide communities involved in this study with a transparent, scientifically valid characterization of serum PFAS concentrations in the population that includes those who previously had, or currently have, detectable concentrations of a select set of PFAS in municipal or private drinking water wells (current and prenatal).
- Contribute to generalizable knowledge about PFAS exposure and health.
- Identify PFAS exposure sources that may contribute to increased blood concentrations.
- Provide participants with their personal PFAS analytical results.
- Develop health education materials that describe how to limit future exposure.
- Provide participants with their personal biomarker results, including a plain-language description to inform them of their health risk and facilitate conversations with their personal health care providers.
- Inform health care providers in the study areas about exposure factors, biological factors, and behavior that can result in higher serum PFAS concentrations, adding to their knowledge about PFAS and health.
- Identify valid and efficient methods for future PFAS exposure testing.
- Measure PFAS in a subset of participating households' drinking water and provide participants with their household's water test results along with health education, as needed.
- Inform the public and scientific communities. The results will be disseminated in reports, conference presentations, and peer reviewed manuscripts, as applicable.

Supplemental Table 1. PFAS analytes and their abbreviations

Abbreviation	Name	CAS Number	MDHHS Method LOQ (µg/L)	NHANES Method LOD (µg/L)	Most recent NHANES data year*
11Cl-PF3OUdS	11-chloroeicosafluoro-3-oxaundecane-1-sulfonate	763051-92-9	0.0235		^NA
3:3 FTCA	2H,2H,3H,3H-perfluorohexanoic acid (3-perfluoropropyl propanoic acid)	356-02-5	0.0213		^NA
4:2 FTS	1H, 1H, 2H, 2H, perfluorohexane sulfonic acid	757124-72-4	0.0075		^NA
5:3 FTCA	2H,2H,3H,3H-Perfluorooctanoic acid (3-perfluoropentyl propanoic acid)	914637-49-3	0.0217		^NA
6:2 FTS	1H, 1H, 2H, 2H, perfluorooctane sulfonic acid	27619-97-2	0.0160		^NA
7:3 FTCA	2H,2H,3H,3H-Perfluorodecanoic acid (3-perfluoroheptyl propanoic acid)	812-70-4			^NA
8:2 FTS	1H, 1H, 2H, 2H, perfluorodecane sulfonic acid	39108-34-4	0.1290		^NA
9Cl-PF3ONS	9-chlorohexadecafluoro-3-oxanonane-1-sulfonate	756426-58-1	0.0131	0.100	2017-2018
ADONA	Dodecafluoro-3H-4,8-dioxanonanoate *or* 4,8-dioxa-3H-perfluorononanoic acid *(ADONA)*	919005-14-4	0.0073	0.1	2017-2018
EtFOSAA	N-Ethylperfluorooctane sulfonamidoacetic acid	2991-50-6	0.0227	0.100	2011-2012
HFPO-DA	Hexafluoropropylene oxide dimer acid *(GenX)*	13252-13-6	0.0078		^NA
NFDHA	Nonafluoro-3,6-dioxaheptanoic acid	151772-58-6	0.0239		^NA
MeFOSAA	N-Methylperfluorooctane sulfonamidoacetic acid	2355-31-9	0.1320	0.1	2017-2018
PFBA	Perfluorobutanoic acid	375-22-4	0.0106		^NA
PFBS	Perfluorobutanesulfonic acid	375-73-5	0.0102	0.100	2013-2014
PFBSA	Perfluorobutanesulfonamide	30334-69-1	0.0163		^NA
PFDA	Perfluorodecanoic acid	335-76-2	0.0095	0.100	2017-2018
PFDoA	Perfluorododecanoic acid	307-55-1	0.0134	0.100	2015-2016
PFDS	Perfluorodecanesulfonic acid	335-77-3	0.0212		^NA
PFEESA	Perfluoro (2-ethoxyethane) sulfonic acid	113507-82-7	0.0160		^NA
PFHpS	Perfluoroheptanesulfonic acid	375-92-8	0.0219	0.100	2017-2018
PFHxA	Perfluorohexanoic acid	307-24-4	0.0104	0.1	2017-2018
PFHxS	Perfluorohexanesulfonic acid (branched and linear)	355-46-4	$$	0.1	2017-2018

L-PFHxS	Perfluorohexanesulfonic acid (linear)		0.0241		^NA
Br-PFHxS	Perfluorohexanesulfonic acid (branched)		0.0234		^NA
PFHxSA	Perfluorohexanesulfonamide	41997-13-1	0.0233		^NA
PFMBA	Perfluoro-4-methoxybutanoic acid	863090-89-5	0.0176		^NA
PFMPA	Perfluoro-3-methoxypropanoic acid	377-73-1	0.0135		^NA
PFNA	Perfluorononanoic acid	375-95-1	0.0086	0.1	2017-2018
PFNS	Perfluorononanesulfonic acid	68259-12-1	0.0174		^NA
PFOA	Perfluorooctanoic acid (branched and linear)	335-67-1	$$	$	2017-2018
L-PFOA	Perfluorooctanoic acid (linear)		0.0118	0.1	2017-2018
Br-PFOA	Perfluorooctanoic acid (branched)		0.0121	0.1	2017-2018
PFOS	Perfluorooctanesulfonic acid (branched and linear)	1763-23-1	$$	$	2017-2018
L-PFOS	Perfluorooctanesulfonic acid (linear)		0.0231	0.1	2015-2016
Br-PFOS	Perfluorooctanesulfonic acid (branched)		0.0239	0.1	2015-2016
PFOSA	Perfluorooctanesulfonamide	754-91-6	0.0086	0.1	2011-2012
PFPeA	Perfluoropentanoic acid	2706-90-3	0.0160		^NA
PFPeS	Perfluoropentanesulfonic acid	2706-91-4	0.0149		^NA
PFPrS	Perfluoropropanesulfonic acid	423-41-6	0.0169		^NA
PFTeA	Perfluorotetradecanoic acid	376-06-7	0.0106		^NA
PFTriA	Perfluorotridecanoic acid	72629-94-8	0.0195		^NA
PFUnA	Perfluoroundecanoic acid	2058-94-8	0.0147	0.1	2017-2018
PFHpA	Perfluoroheptanoic acid	375-85-9	0.0114		^NA
PFecHS	Perfluoroethylcyclohexane sulfonate	646-83-3	0.0143		^NA

^NA = The analyte was not measured in NHANES.

*Centers for Disease Control and Prevention. Fourth National Report on Human Exposure to Environmental Chemicals Updated Tables, January 2021, Volume One. 2021.

$ Beginning with NHANES 2013-14, there is no limit of detection (LOD) for PFOA and PFOS because these values are a calculated sum.

$$ Calculated sums do not have LODs.