

# Estimation of Serum PFOA Concentrations from Drinking and Non-Drinking Water Exposures

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## Introduction

Concern has increased over potential human health effects from per- and polyfluoroalkyl substances (PFAS) exposure as more toxicity and exposure data about PFAS have become available. In 2022, the National Academies of Sciences, Engineering, and Medicine (NASEM)<sup>1</sup> issued clinical care guidance for patients based on serum levels—the best exposure metric—for the sum of seven PFAS included in the “National Report on Human Exposure to Environmental Chemicals” published by the U.S. Centers for Disease Control and Prevention (U.S. CDC).<sup>2</sup> The serum guidelines are *a*) <2 ng/mL, adverse health effects are not expected; *b*) 2–20 ng/mL, potential adverse effects, especially in sensitive populations; and *c*) >20 ng/mL, increased risk for adverse effects. Infants and young children have been identified as especially sensitive to PFAS exposure.<sup>3</sup> The most recent data (2017–2018) from the National Health and Nutrition Examination Survey (NHANES) reported serum levels in a representative sample of Americans 12 y of age and older for five of the seven PFAS identified by NASEM. The sum of median and 95th percentile serum levels for the five PFAS were 7.37 and 23.87 ng/mL,<sup>4</sup> respectively.

The NASEM report also highlighted that multiple exposure routes exist for PFAS and how exposures might be reduced. When contaminated, drinking water can be a significant source of exposure; however, sources such as diet and consumer products predominate in communities where drinking water is not contaminated.<sup>4</sup> In the early 2000s, some drinking water sources in Twin Cities East Metro area in Minnesota were found to be contaminated with PFAS.<sup>5</sup> Drinking water treatment was initiated in 2006, and water samples taken after installation of treatment systems generally had PFOA concentrations below the limit of detection.

In 2008, adult longtime East Metro residents’ mean serum perfluorooctanoic acid (PFOA) level was ~15 ng/mL; by 2014, the mean had fallen by almost two-thirds.<sup>5</sup> Significant serum decreases for two other bioaccumulative PFAS—perfluorooctane sulfonate (PFOS) and perfluorohexane sulfonate (PFHxS)—were also observed in East Metro residents during this time frame. Adults who moved to the East Metro area after installation of water treatment had serum levels of PFOA, PFHxS, and PFOS similar to those of the corresponding NHANES population. No relationship between duration of residence and serum PFAS was observed for new residents, supporting our hypothesis that the serum levels measured in new residents after the addition of water treatment are predominantly the result of ongoing non-drinking water exposures.<sup>5</sup> This study also showed the efficacy of water treatment at reducing serum PFAS levels toward the national median in communities with contaminated drinking water.

In this analysis, we demonstrate a method for using chemical-specific toxicokinetic (TK) values to estimate the contribution of drinking water to serum PFOA levels, compare it to non-drinking water exposures, and discuss implications on public health policy.

## Methods

Mean and 95th percentile lifetime water intake rates (WaterIntake) of 0.017 and 0.044 L/kg/d, respectively, from the U.S. Environmental Protection Agency (U.S. EPA)<sup>6</sup> were used to estimate daily doses of PFOA from drinking water (PFOA<sub>DailyWaterDose</sub>) with varying PFOA water concentrations (PFOA<sub>WaterConc.</sub>; 0.001–100 ng/L) (Equation 1).

$$\text{PFOA}_{\text{DailyWaterDose}} \left( \frac{\text{ng}}{\text{kg} \times \text{day}} \right) = \left[ \text{PFOA}_{\text{WaterConc.}} \left( \frac{\text{ng}}{\text{L}} \right) \times \text{WaterIntake} \left( \frac{\text{L}}{\text{kg} \times \text{day}} \right) \right] \quad (1)$$

The daily drinking water PFOA doses were divided by the PFOA clearance rate (ClearanceRate) determined by California Environmental Protection Agency (0.28 mL/kg/d)<sup>7</sup> to estimate serum PFOA levels resulting solely from drinking water exposure (PFOA<sub>SerumFromWater</sub>) (Equation 2).<sup>8</sup>

$$\text{PFOA}_{\text{SerumFromWater}} \left( \frac{\text{ng}}{\text{mL}} \right) = \text{PFOA}_{\text{DailyWaterDose}} \left( \frac{\text{ng}}{\text{kg} \times \text{day}} \right) \div \text{ClearanceRate} \left( \frac{\text{mL}}{\text{kg} \times \text{day}} \right) \quad (2)$$

These calculations assume long-term exposure, attainment of steady state, and no large PFOA elimination events (e.g., childbirth, breastfeeding).<sup>8</sup>

To estimate total serum PFOA levels (PFOA<sub>TotalSerum</sub>), PFOA<sub>SerumFromWater</sub> was added to the 2017–2018 NHANES median serum level (PFOA<sub>NHANESMedianSerum</sub>; 1.47 ng/mL). This scenario assumes negligible PFOA contribution from drinking water at the NHANES median serum PFOA level.

PFOA is one of the most well-studied bioaccumulative PFAS chemicals and has well-characterized TK parameters. Although this analysis focuses on PFOA, it can be performed for any PFAS with the appropriate TK data.

## Results and Discussion

At steady state, we calculated that serum PFOA increases by ~0.06 ng/mL (mean water intake) or ~0.16 ng/mL (95th percentile water intake) per ng/L PFOA in the drinking water (Table 1; Figure 1A). This calculated relationship is consistent with a recently published study that compared PFAS drinking water concentrations to serum levels at four contaminated sites in Sweden.<sup>9</sup> Based on empirical data from these sites, serum PFOA increased by 0.05815 ng/mL per ng/L PFOA in the drinking water, identical to our calculated ratio using mean water intake.

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**Table 1.** Estimated contributions of PFOA from drinking water exposures to total serum PFOA levels.

Water PFOA concentration (ng/L)	Predicted serum PFOA level (ng/mL)					
	Mean water intake (0.017 L/kg/d)			95th percentile water intake (0.044 L/kg/d)		
	PFOA <sub>SerumFromWater</sub>	PFOA <sub>TotalSerum</sub>	Contribution of water to total	PFOA <sub>SerumFromWater</sub>	PFOA <sub>TotalSerum</sub>	Contribution of water to total
0	0	1.47	0%	0	1.47	0%
0.001	0.00006	1.47	0.004%	0.00016	1.47	0.011%
0.01	0.0006	1.47	0.04%	0.0016	1.47	0.11%
0.1	0.0061	1.48	0.41%	0.016	1.49	1.1%
1	0.061	1.53	4.0%	0.16	1.63	9.7%
3	0.18	1.65	11%	0.47	1.94	24%
4 <sup>a</sup>	0.24	1.71	14%	0.63	2.10	30%
5	0.30	1.77	17%	0.79	2.26	35%
10	0.61	2.08	29%	1.57	3.04	52%
20 <sup>b</sup>	1.21	2.68	45%	3.14	4.61	68%
40	2.43	3.90	62%	6.29	7.76	81%
100	6.07	7.54	81%	15.71	17.18	91%

Note: Predicted contributions to serum PFOA exclusively from drinking water (PFOA<sub>SerumFromWater</sub>) were calculated by first establishing a daily PFOA dose by multiplying the water PFOA concentration by the mean and 95th percentile lifetime water intake rates from the U.S. EPA *Exposures Factors Handbook*. The daily PFOA dose was then divided by the PFOA clearance rate (0.28 mL/kg/d) from California Environmental Protection Agency to calculate PFOA<sub>SerumFromWater</sub>. PFOA<sub>SerumFromWater</sub> was added to the 2017–2018 NHANES median serum PFOA concentration (1.47 ng/mL), representing non-drinking water PFOA exposures, to generate a total PFOA serum level (PFOA<sub>TotalSerum</sub>) inclusive of both drinking water and non-drinking water PFOA exposures. The contribution percentage of PFOA-containing drinking water to total PFOA exposure at each water PFOA concentration was calculated by dividing PFOA<sub>SerumFromWater</sub> by PFOA<sub>TotalSerum</sub> and multiplying by 100. U.S. EPA, U.S. Environmental Protection Agency; MCL, Maximum Contaminant Limit; NHANES, National Health and Nutrition Examination Survey; PFOA, perfluorooctanoic acid; UCMR3, Third Unregulated Contaminant Monitoring Rule; UCMR5, Fifth Unregulated Contaminant Monitoring Rule.

<sup>a</sup>Proposed MCL and UCMR5 Reporting Limit.

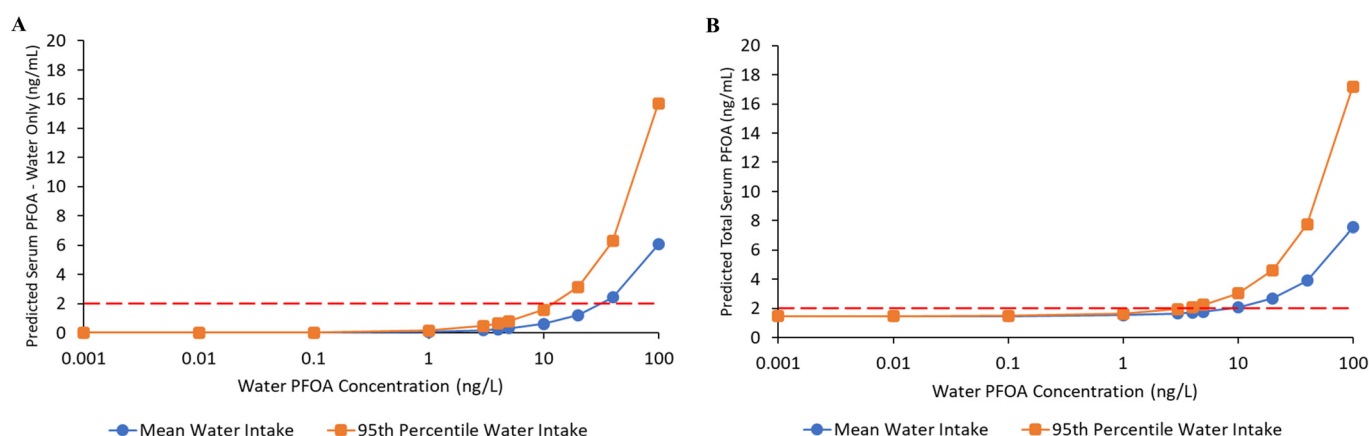
<sup>b</sup>UCMR3 Reporting Limit.

Assuming PFOA exposure occurred exclusively via drinking water, the NHANES median serum level (1.47 ng/mL) would not be reached until the drinking water PFOA concentration was ~30 ng/L (mean water intake) or ~10 ng/mL (95th percentile water intake). In the U.S. EPA's Unregulated Contaminant Monitoring Rule 3, only 2% of tested public water supplies had PFOA >20 ng/L,<sup>10</sup> suggesting drinking water is not the major contributor to the NHANES median.

The contribution of drinking water exposures to total serum PFOA was also evaluated. At 1 ng/L, drinking water is estimated to contribute ~4% (mean water intake) and ~10% (high-end water intake) of total serum PFOA. PFOA drinking water concentrations below 0.1 ng/L were calculated to have a negligible contribution (<1%) to total serum PFOA at steady state (Table 1; Figure 1B).

The U.S. EPA has proposed a Maximum Contaminant Level (MCL) for PFOA of 4 ng/L,<sup>3</sup> the lowest concentration that the U.S. EPA determined that PFOA can be reliably quantified. Drinking water containing PFOA at 4 ng/L would contribute ~14% (mean intake) and ~30% (high-end intake) to the total serum PFOA level.

Reducing PFOA exposures has broad public health impacts. This analysis indicates that, unless non-drinking water exposures are also addressed, treating drinking water to concentrations below 1 ng/L PFOA would have limited impact on lowering current serum PFOA levels in the United States. PFAS-contaminated sites should be remediated and drinking water containing PFAS should be treated; however, to achieve meaningful reductions in serum PFAS, a comprehensive national approach must be undertaken to



**Figure 1.** Predicted contributions of PFOA in drinking water on serum PFOA levels. (A) Predicted impact on serum PFOA levels exclusively from long-term consumption of drinking water with varying PFOA concentrations. Predicted serum PFOA levels were calculated for lifetime mean water intake (0.017 L/kg/d; blue circles and line) and lifetime 95th percentile intake (0.044 L/kg/d; orange squares and line) from the U.S. EPA *Exposures Factors Handbook*. Scenario assumes drinking water is the only source of PFOA exposure. (B) Predicted impact on total serum PFOA level from long-term consumption of PFAS-containing drinking water. Serum PFOA levels calculated in (A) were added to the 2017–2018 NHANES median serum level. Scenario assumes 2017–2018 NHANES median serum level is due to non-drinking water exposures. The red dotted line demarcates the NASEM border between no expected health effects (<2 ng/mL) and potential for health effects in sensitive populations (≥2 ng/mL). All inputs and predicted levels are shown in Table 1. Note: NASEM, National Academies of Science, Engineering, and Mathematics; NHANES, National Health and Nutrition Examination Survey; PFAS, per- and polyfluoroalkyl substances; PFOA, perfluorooctanoic acid; U.S. EPA, U.S. Environmental Protection Agency.

reduce PFAS exposures from all sources, including banning PFAS in food, consumer products, and other nonessential uses.

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