

# PFAS in Our Environment: Exploring Effects, Widespread Contamination, and Detection Methods

Expert Insights



Sponsored by:

**SARTORIUS**

**WILEY**



## Reliable Intermediate Water Storage That Protects Water Quality

### Arium® Bagtank Water Storage

The Arium® Bagtanks uses a closed system to store purified water and protect it from secondary contamination. Available in three different volumes of 20, 50 and 100 litres, it enables consistent water quality over an extended period, ensuring reproducible results. Instead of a regular tank, the Bagtanks utilize exchangeable bags to simplify maintenance and reduce the need for time-consuming cleaning procedures. The bag can be exchanged in 5 minutes without using any hazardous chemicals.



[Learn More](#)

Simplifying Progress

**SARTORIUS**

# Contents

- 4** Introduction
- 6** Occupational exposures to airborne per- and polyfluoroalkyl substances (PFAS) – A review  
*Adapted from Paris-Davila, T. et al 2023*
- 10** Analysis of a Passive Sampling Device to Assess the Behavior of Per- and Polyfluoroalkyl Substances in Sediments  
*Adapted from Atoufi, D. et al 2023*
- 13** A geospatial and binomial logistic regression model to prioritize sampling for per- and polyfluorinated alkyl substances in public water systems  
*Adapted from Ojha, S. et al 2022*
- 16** PFAS “Forever Chemicals”

## Further Readings and Resources

## Imprint

© Wiley-VCH GmbH  
Boschstr. 12,  
69469 Weinheim,  
Germany  
Email: [info@wiley-vch.de](mailto:info@wiley-vch.de)

Editor:  
Dr. Cecilia Kruszynski

Senior Account Manager:  
Jan Käppler

Sartorius  
<https://www.sartorius.com/>

# Introduction

This Expert Insight delves into the multifaceted realm of per- and polyfluoroalkyl substances (PFAS), a class of synthetic chemicals extensively employed in industrial processes and manufacturing for nearly a century. PFAS exhibit remarkable resistance to degradation, which has led to their pervasive environmental distribution and consequent human exposure. The repercussions of such exposure are far-reaching, encompassing adverse effects on fertility, developmental anomalies, cholesterol levels, immune function, and an elevated risk of certain cancers. In addition to their toxicological effects, PFAS has become a global concern, with regulatory agencies and researchers striving to understand the extent of their impact and develop effective methods for detection and mitigation. This article collection brings together research on the contamination and effects of PFAS in the air, soil, and water, shedding light on the complex challenges posed by these persistent substances in our environment.

This Expert Insight begins with a study on occupational exposures to airborne PFAS, emphasizing the importance of assessing PFAS levels in both air and dust within specific occupational settings [1].

Next, Atoufi, H.D. and Lampert, D.J [2] present an investigation into the behavior of PFAS in sediments, utilizing passive sampling devices to assess the bioaccumulation of these substances.

Finally, Ojha, S. et al. [3] introduce a geospatial and binomial logistic regression model aimed at prioritizing sampling for PFAS in public water systems, a crucial step in managing and mitigating PFAS contamination in drinking water sources.

Overall, this collection of articles endeavors to enhance researchers' knowledge regarding the dynamics, impacts, and detection of PFAS. We encourage further exploration of these topics on [Sartorius' website](#) to foster a deeper understanding of available options for improving research on PFAS-related issues.

Dr. Cecilia Kruszynski  
Editor at *Wiley Analytical Science*

## References

- [1] Paris-Davila, T. et al. (2023). Occupational exposures to airborne per- and polyfluoroalkyl substances (PFAS)—A review. *American Journal of Industrial Medicine*. DOI: 10.1002/AJIM.23461.
- [2] Atoufi, H.D. and Lampert, D.J. (2023). Analysis of a Passive Sampling Device to Assess the Behavior of Per- and Polyfluoroalkyl Substances in Sediments. *Environmental Toxicology and Chemistry*. DOI: 10.1002/ETC.5705.
- [3] Ojha, S. et al. (2023). A geospatial and binomial logistic regression model to prioritize sampling for per- and polyfluorinated alkyl substances in public water systems. *Integrated Environmental Assessment and Management*. DOI: 10.1002/IEAM.4614.

# Occupational exposures to airborne per- and polyfluoroalkyl substances (PFAS) – A review

Adapted from Paris-Davila, T. et al. 2023

Per- and polyfluoroalkyl substances (PFAS) are synthetically produced chemicals, used in industrial processes and manufacturing since the first half of the 20<sup>th</sup> century. Their resistance to degradation and widespread use facilitates environmental contamination and subsequent human exposure. They are known to decrease fertility, cause developmental effects such as accelerated puberty, affect cholesterol and the immune response, and increase the incidence of certain cancers. Exposure to PFAS can occur through aerosolization and/or volatilization during the application or use of products already contaminated with PFAS [1]. It is important to determine PFAS levels in aerosolized and/or volatilized substances (referred to as "air" exposure) as well as dust-containing PFAS (referred to as "dust" exposure) within certain occupational settings.

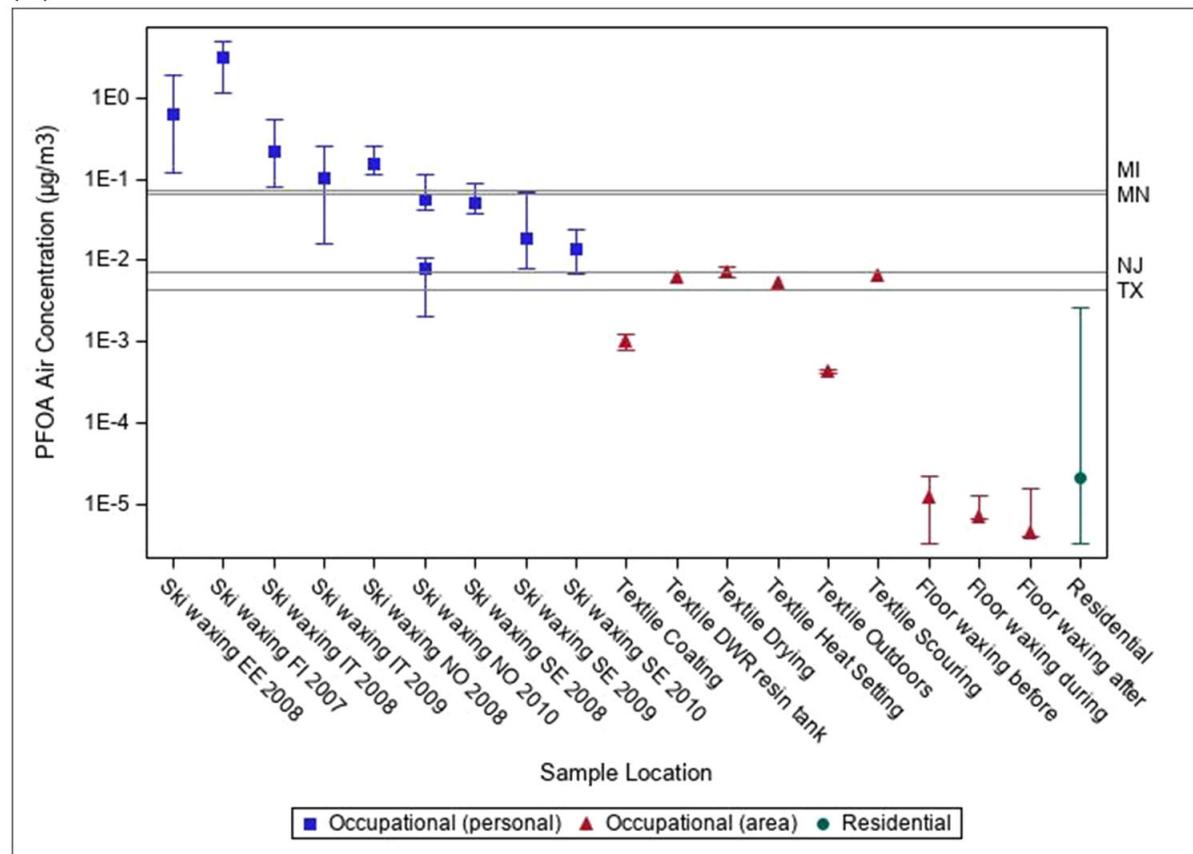
**Table 1: Literature search strings and the number of articles obtained for review of occupational PFAS exposures.**

Search string	Number of articles returned and reviewed
(perfluor* OR polyfluor*) AND "occupational" NOT "review"	32
(perfluor* OR polyfluor*) AND (wax OR waxing) NOT "review"	2
(perfluor* OR polyfluor*) AND ("worker") NOT "review"	2
(perfluor* OR polyfluor*) AND "occupation" NOT "review"	2
(perfluor* OR polyfluor*) AND firefighter*	4
(perfluor* OR polyfluor*) AND ("textile" OR "textiles")	4
(perfluor* OR polyfluor*) AND "nanocoating"	0
(perfluor* OR polyfluor*) AND "dust"	0
(perfluor* OR polyfluor*) AND "inhalation"	0
(perfluor* OR polyfluor*) AND "chrome plating"	0
(perfluor* OR polyfluor*) AND "metal plating"	0
(perfluor* OR polyfluor*) AND (ski OR skiing) NOT "review"	0
(perfluor* OR polyfluor*) AND "fluorinated repellent"	0
(perfluor* OR polyfluor*) AND "worker" NOT "plant"	0
(perfluor* OR polyfluor*) AND firefighter*	0
(perfluor* OR polyfluor*) AND "employment"	0

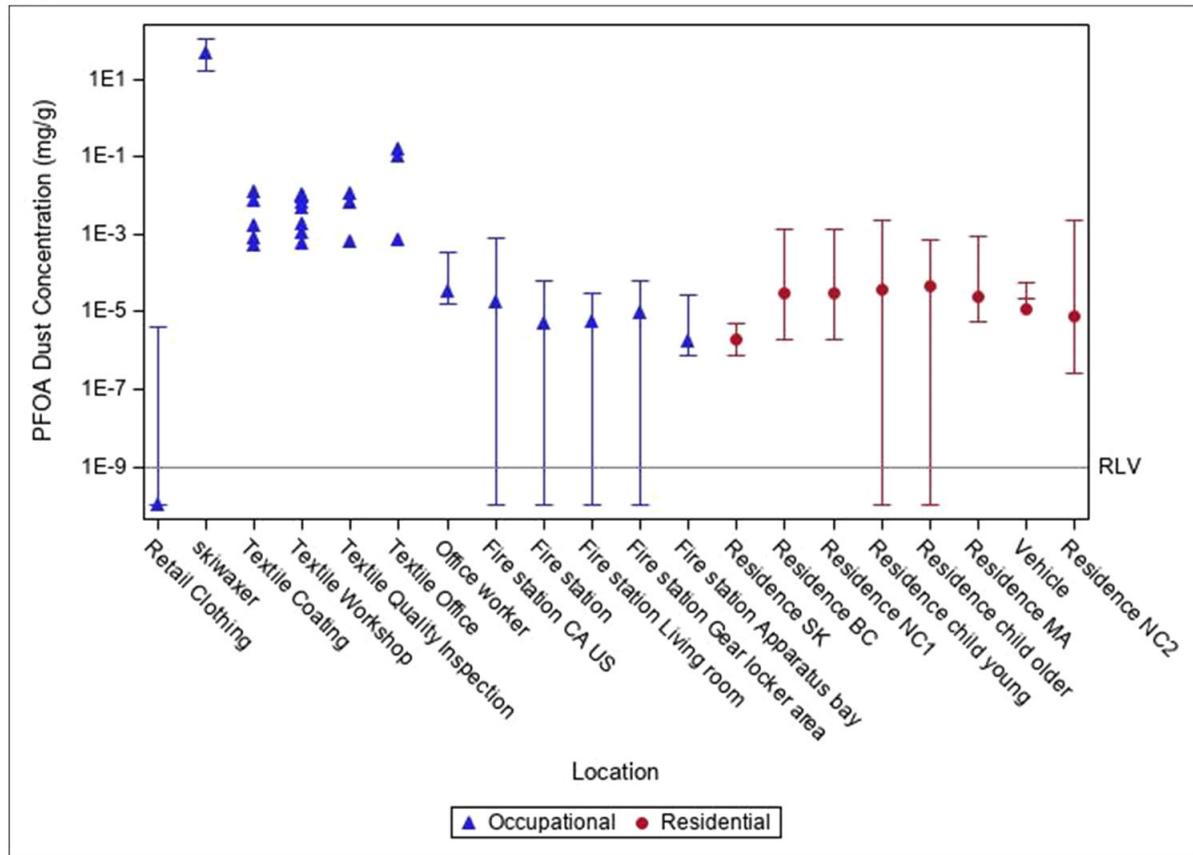
## Methods

A review of the literature was performed using different academic search engines to identify studies investigating PFAS and occupational exposure (Table 1), and 13 published scientific articles were identified. The following industries/occupational settings were identified: ski waxing, firefighting, education/office buildings, textile manufacturing plants, and retail textile stores. Methodology to detect PFAS included dust sampling with a photometric direct reading respicon, vacuum cleaners, and manual brushes, while air sampling was performed with solid phase cartridges with aerosol membrane filters, polyurethane foam (PUF) disk passive samplers, glass fiber filters, and PM2.0 samplers with quartz fiber filters and glass tubes fitted with GFF and PUF.

(A)



(B)



**Figure 1: (A) Perfluorooctanoic acid (PFOA) air concentrations in different occupations and residences. The TX, NJ, MN, and MI lines are screening levels of  $1.80E-2$ ,  $3.07E-2$ ,  $2.76E-1$ , and  $3.07E-1$   $\mu\text{g}/\text{m}^3$ , based on toxicity values from the states of Texas, New Jersey, Minnesota, and Michigan, respectively. (B) PFOA dust concentrations in different occupations and residences. The RLV line represents the reported limit value.**

## Data analysis

We compared only the PFAS types that were consistently measured in all the included studies. This included: perfluorooctanoic acid (PFOA), perfluorononanoic acid (PFNA), perfluorooctanesulfonic acid (PFOS), perfluorohexanoic acid (PFHxA), perfluorotetradecanoic acid (PFTet-DA), perfluorododecanoic acid (PFDoDA), and perfluorodecanoic acid (PFDA). When available, the median, minimum, and maximum air and/or dust concentrations were used from the different data sets.

## Results

Workers experience varying levels of PFAS exposure contingent upon the workplace/industry and the performed work tasks within the workplace. A total of 41 PFAS air and/or dust concentrations were reported in the nine occupational and four residential studies included in this review. The number of PFAS monitored for air levels varied from six to 14 and for dust levels from five to 27 in occupational studies, while 21 PFAS were

monitored in residential studies (15 and 21 for air and dust, respectively). Out of all occupations, ski waxing exhibited the highest total PFAS air concentrations when compared to all other reported occupational and residential exposures (Figs. 1A, B).

In contrast, floor waxing had the lowest area air concentrations; concentrations associated with ski waxing were similar to other occupations, and median PFOS dust concentrations at ski waxing facilities were similar to the median of  $1E-4 \mu\text{g}/\text{m}^3$  for the textile office and textile coating workshop.

## Discussion

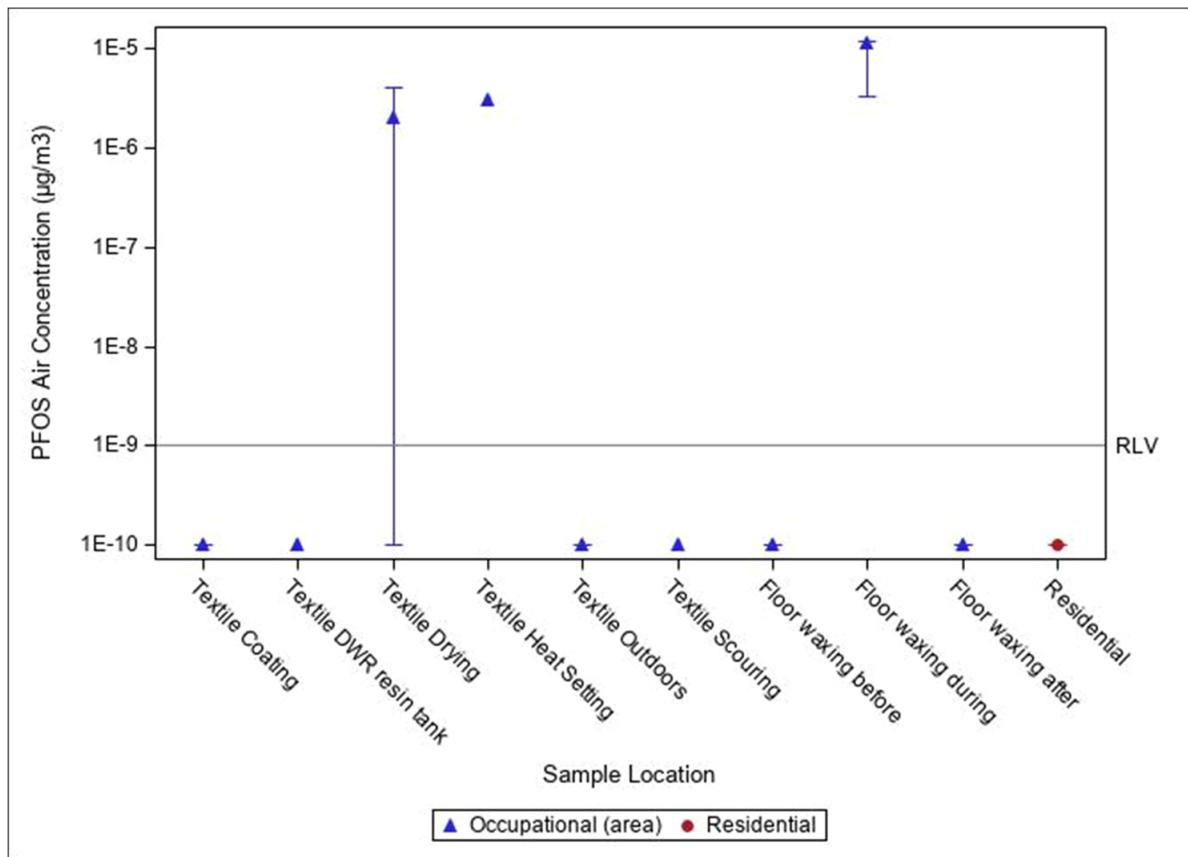
### Ski waxing

Ski waxing consistently had the highest values for both air and dust concentrations. This suggests that ski waxers experience the highest PFAS exposures of the occupations examined in this study. Ski waxers were observed to have PFAS serum levels similar to populations exposed to PFAS through contaminated water [2,3]. Our analysis shows

that air concentrations of PFDA, PFOA, PFNA, and PFDoDA in ski waxing facilities can exceed occupational indoor air screening levels calculated for this review. During ski waxing, no or limited ventilation system may be used, which may be insufficient to protect from these high levels of PFAS exposure. The published studies did not state whether ski waxers used respiratory protection, but given that ski waxers' exposures were among the highest in the reviewed literature, using full-face respirators with organic vapor cartridges and proper cartridge changeout is recommended while performing tasks where PFAS is present in the products used.

### Firefighting

As for the firefighter data, the dust samples provide a perspective of what PFAS firefighters may be exposed to during day-to-day operations in the fire station but do not account for exposures associated with firefighting activities. Because the levels measured in air and dust at fire stations are



**Figure 2: Perfluorooctanesulfonic acid (PFOS) air concentrations for occupations and residences. The RLV line represents the reported limit value.**

comparable to those measured in residential settings, firefighters are likely to be exposed to PFAS during firefighting activities. Other studies have shown higher levels of PFAS in firefighters' serum compared to the general population [2,3]. Because firefighters use respiratory protection while firefighting, this could suggest that either the protection is insufficient or there are other exposure pathways that should be explored.

#### **Textile manufacturing**

Textile manufacturing processes resulted in consistently high levels of most PFAS, but the air concentrations of PFTetDA were especially high for textile scouring, drying, and heat setting compared to the other PFAS sampled during the textile manufacturing process.

#### **Residential buildings**

Although residences have lower PFAS levels than most occupational settings, elevated exposures may still occur depending on various factors, such as cleaning products used within homes, coated hard surfaces, textiles impregnated with PFAS, and many other consumer products that contain PFAS [4].

Overall, the results obtained in our analysis are comparable because in most studies similar sampling devices were used to collect aerosol/volatile or dust samples.

#### **Limitation**

An important limitation of the comparisons drawn in this review is the lack of available studies. It is unknown how comparable the measured air and dust levels are across time and countries. Much of the data is from 10 to 15 years ago, but some of the data is from just a few years ago. As the science of PFAS has evolved, product formulations have changed both voluntarily and due to government regulations. Thus, which PFAS would be found and what their concentrations would be if some of the studies were replicated today may not be identical.

#### **Conclusion**

Our review and analysis provide a foundational assessment of the current knowledge of occupational PFAS exposures. The results from this review emphasize the need for further research to increase our knowledge of occupational exposure scenarios and the levels of exposure to PFAS. Quantitative exposure assessment research as well as recognizing the occupations at risk, the products containing PFAS, and the causes for PFAS exposures will aid in the development of informed recommendations for safety measures including administrative and engineering controls as well as appropriate PPE use to protect workers from adverse health effects due to PFAS exposure.

#### **References**

- [1] Gaines, L.G.T. (2023). Historical and current usage of per- and polyfluoroalkyl substances (PFAS): A literature review. *American Journal of Industrial Medicine*. DOI: 10.1002/ajim.23362.
- [2] Burgess, J.L. et al. (2023). Serum per- and polyfluoroalkyl substance concentrations in four municipal US fire departments. *American Journal of Industrial Medicine*. DOI: 10.1002/ajim.23413.
- [3] Lucas, K. et al. (2023). Occupational exposure and serum levels of per- and polyfluoroalkyl substances (PFAS): A review. *American Journal of Industrial Medicine*. DOI: 10.1002/ajim.23454.
- [4] Kotthoff, M. et al. (2015). Perfluoroalkyl and polyfluoroalkyl substances in consumer products. *Environmental Science and Pollution Research*. DOI: 10.1007/s11356-015-4202-7.

# Analysis of a Passive Sampling Device to Assess the Behavior of Per- and Polyfluoroalkyl Substances in Sediments

Adapted from Atoufi, H.D. and Lampert, D.J 2023

Various manufactured fluorinated compounds, including perfluoroalkyl and polyfluoroalkyl substances, are collectively referred to as PFAS. They are resistant to hydrolysis, degradation, and photolysis [1], and their fate and transport in the environment must be understood to mitigate potential adverse effects on human health. Following PFAS release into the environment, soil and sediments often act as a reservoir for PFAS, often entering the food chain via local benthic organisms.

Passive samplers can be used to estimate the bioaccumulation of PFAS in soils and sediments, reflecting the biological uptake process [2]. Integrative samplers keep the contaminant uptake at a linear level over time, providing a time-averaged concentration estimate over the exposure period [3]. The polar organic chemical integrative sampler (POCIS) is an integrative sampler that is placed into a medium for a sufficiently short period to allow uptake during the linear region. It has been used to assess aqueous concentrations of bioaccumulative polar compounds with higher water solubility, such as pharmaceuticals and pesticides [4]. Such samplers were developed to measure time-averaged PFAS concentrations in surface water, and new approaches are needed to perform

this analysis in soils and sediments [5]. The present study aimed to evaluate the use of POCIS to measure PFAS concentrations in saturated porous media. Successfully developing a passive sampler for PFAS-contaminated sediments would shed insight into PFAS release mechanisms, PFAS equilibrium partitioning between interstitial

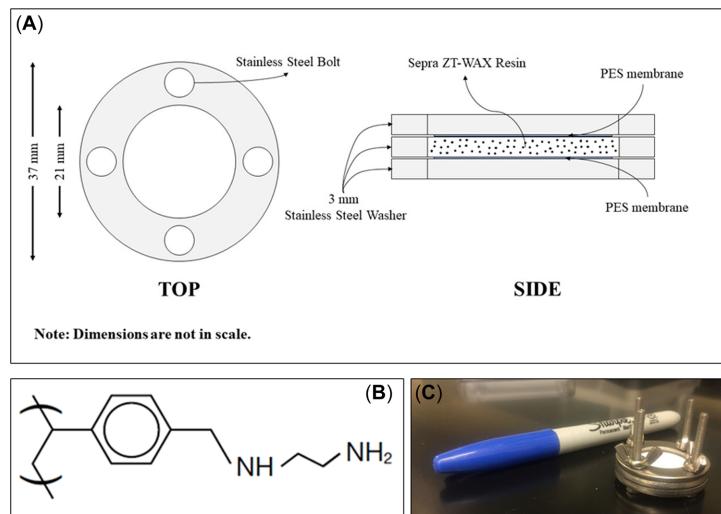
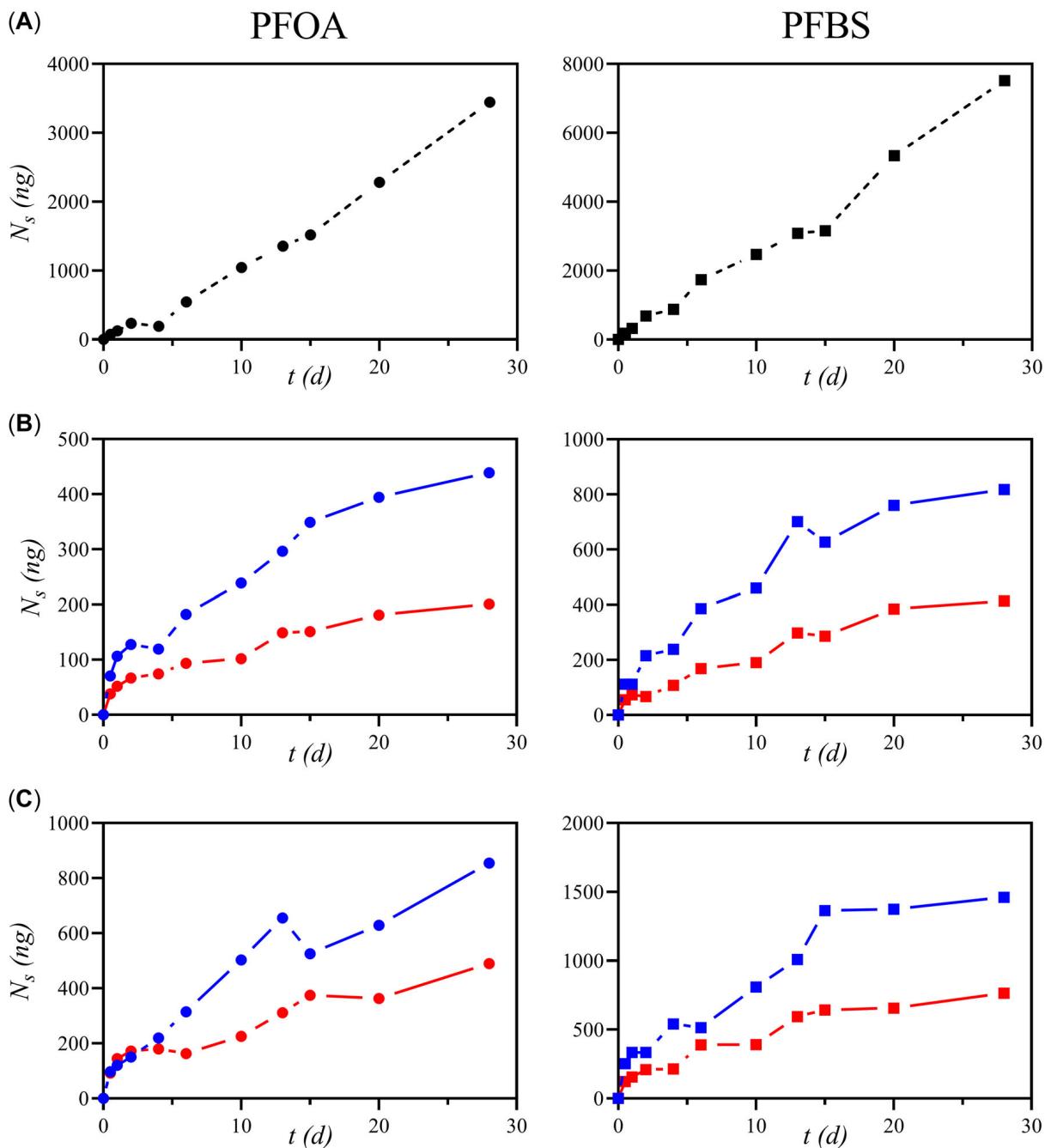


Figure 1: (A) Passive sampler design schematic, (B) resin functional group, and (C) assembled passive sampler. PES = polyethersulfone.



**Figure 2: Uptake profile of per- and polyfluoroalkyl substance compounds in samplers in (A) a water tank, (B) noncombusted soil, and (C) combusted soil. Blue and red lines indicate reactors spiked with one and two compounds, respectively. PFOA = perfluorooctanoic acid; PFBS = perfluoro butane sulfonic acid;  $N_s$  = mass of components on the sorbent;  $t$  (d) = time in days.**

water, solid and material phases, and sorption kinetics.

The main objectives of the present study were to (1) assess the sorption uptake of PFAS into the passive samplers deployed in two different saturated sediments in laboratory experiments, (2) compare the uptake of PFAS into the passive samplers in different reactors that contain a mixture of PFAS compounds and a single-analyte solution, and

(3) develop a sorption kinetics mass transport model to explain PFAS transport from sediments into the sampler.

#### Materials and Methods

The passive sampling device utilizes 400 mg of Sepra ZT-WAX as a PFAS sorbent, using an amine-based functional group (Fig. 1B). The sorbent material is enclosed by two 30-mm microporous membranes made of polyethersulfone (PES). The sampling device was

constructed from three stainless steel washers with an inside diameter of 21 mm, an outer diameter of 37 mm, and a thickness of 3 mm to secure and provide structural support for the membranes (Fig. 1A). After deploying the sampler (Fig. 1C) in the environment and ensuring that the saturated soil layer has covered it, PFAS begins to accumulate through diffusion via the microporous membrane onto the resin.

The soil used in this study was from the Tallgrass Prairie Preserve in northeastern Oklahoma. The organic matter content of the soils was analyzed by the loss-on-ignition method [6]. Experiments were performed on the soils spiked with PFAS. Six experimental reactors filled with soil, water, and PFAS were monitored for behavior. Approximately 500 µg of PFOA, PFBS, or the mixture (PFOA + PFBS) were added per kilogram of dry soil to each reactor. The aqueous-phase PFAS concentration and the soil-phase PFAS concentration were analyzed at the beginning and end of the experiments. Samplers were taken out and analyzed at 0.5, 1, 2, 4, 6, 10, 13, 15, 20, and 28 days for PFAS concentrations. Concentrations of PFAS were determined using liquid chromatography/tandem mass spectrometry (LC-MS/MS). A method based on USEPA 533 was developed for six PFAS compounds, including the two target PFAS [7]. Sample preparation used solid-phase extraction (SPE) cartridges to enrich PFAS and to remove matrix interferents. Concentrations of PFAS in soils and sediments were measured based on a previously published technique [8].

## Results and Discussion

The POCIS-based passive sampling device showed consistent uptake of PFAS compounds into Sepra ZT-WAX resin in water and in contaminated sediments over time, which demonstrates its feasibility for sediment porewater passive sampling applications, in addition to integrative sampling of surface water. The sorbent captures PFAS compounds with shorter chains like PFBS more rapidly because of their lower sorption potential and more rapid diffusion. All of the samplers demonstrate increasing PFAS levels over time, which provides evidence for the technology to passively sample the surrounding environment (Fig. 2).

The SRM fitted the results better for the water phase, consistent with previous studies

of integrative samplers. In contrast, the external resistance model (ERM) fits the sediment-phase data more accurately, as reflected by the values of the root mean squared.

In summary, the present study develops a framework that could be utilized for the estimation of porewater concentrations at contaminated sites.

## Conclusion

In the present study, a derivative of the POCIS sampling device combined with a mass transport model was developed, to provide an estimate of PFAS porewater concentrations in saturated soils and sediments. The results of these experiments demonstrated the feasibility of the passive sampling device to accumulate PFAS in soil-water matrices in accordance with an external transport theory.

## Limitations

Certain measurements such as physico-chemical characteristics of the PFAS contaminant, resin, and sediments, which can be measured in the laboratory may introduce uncertainty in the results due to variations in sampling and analysis methods, or spatial heterogeneity of the sampled sediment. Additionally, the presence of other contaminants can interfere as well. The calibration parameters, such as the sampling rate and the effective sampling volume, may vary depending on the specific conditions at the site, such as the flow rate and the chemical properties of the contaminants. Thus, the accuracy of the estimates may also be limited by the uncertainty in the calibration values and measured parameters. To reduce these uncertainties, additional measurements or calibration under different conditions may need to be conducted.

Still, the approach of this study may be useful to environmental regulators and other stakeholders involved in environmental remediation processes.

## References

- [1] Qi, Y. et al. (2022). The role of dissolved organic matter during Per- and Poly-fluorinated Substance (PFAS) adsorption, degradation, and plant uptake: A review. *Journal of Hazardous Materials*. DOI: 10.1016/j.jhazmat.2022.129139.
- [2] Kot, A. et al. (2000). Passive sampling for long-term monitoring of organic pollutants in water. *TrAC Trends in Analytical Chemistry*. DOI: 10.1016/S0165-9936(99)00223-X.
- [3] Bicanova, J. et al. (2021). A graphene-based hydrogel monolith with tailored surface chemistry for PFAS passive sampling. *Environmental Science: Nano*. DOI: 10.1039/D1EN00517K.
- [4] Morin, N. et al. (2012). Chemical calibration, performance, validation and applications of the polar organic chemical integrative sampler (POCIS) in aquatic environments. *TrAC Trends in Analytical Chemistry*. DOI: 10.1016/j.trac.2012.01.007.
- [5] Kaserzon, S.L. et al. (2014). Characterisation and comparison of the uptake of ionizable and polar pesticides, pharmaceuticals and personal care products by POCIS and Chemcatchers. *Environ. Sci.: Processes Impacts*. DOI: 10.1039/C4E-M00392F.
- [6] Hoogsteen, M.J.J. et al. (2015). Estimating soil organic carbon through loss on ignition: effects of ignition conditions and structural water loss. *European Journal of Soil Science*. DOI: 10.1111/ejss.12224.
- [7] Hindle, Ralphe, H., Kathy (2020). EPA Method 533 for Analysis of Per/Polyfluoroalkyl Substances in Drinking Water Using Agilent 6470 Triple Quadrupole LC/MS.
- [8] Washington, J.W. et al. (2008). Analysis of perfluorinated carboxylic acids in soils II: Optimization of chromatography and extraction. *Journal of Chromatography A*. DOI: 10.1016/j.chroma.2007.12.042.

# A geospatial and binomial logistic regression model to prioritize sampling for per- and polyfluorinated alkyl substances in public water systems

Adapted from Ojha, S. et al. 2022

Per- and polyfluoroalkyl substances (PFAS) are examples of complex, pervasive compounds, often globally contaminating environmental systems, such as drinking water [1]. They are receiving increasing attention due to adverse health effects, such as cancer and neurodevelopmental effects [2]. Due to this, the United States Environmental Protection Agency (USEPA) has recognized them as contaminants of emerging concern [3]. Possible routes of human exposure include air and diet, which includes drinking water. This study aimed to develop a statistical screening model to help prioritize public water systems (PWS) sampling sites, locate industries highly likely to utilize PFAS in their processes and predict whether PFAS are likely to be detected in a particular PWS.

## Screening model development

Drinking water can be exposed to PFAS through various pathways (Fig. 1). To assist in prioritizing PWS sampling locations, a binomial logistic regression model was developed, capable of predicting whether PFAS are likely to be detected in a certain location. Two hypotheses are crucial: H1 assumes that the number and quantity of releases into the atmosphere and water would increase the likelihood of PWS contamination, and H2 assumes that the distance between PWS and the release source would decrease the likelihood of PWS contamination.

## Mapping potential hot spots for priority sampling

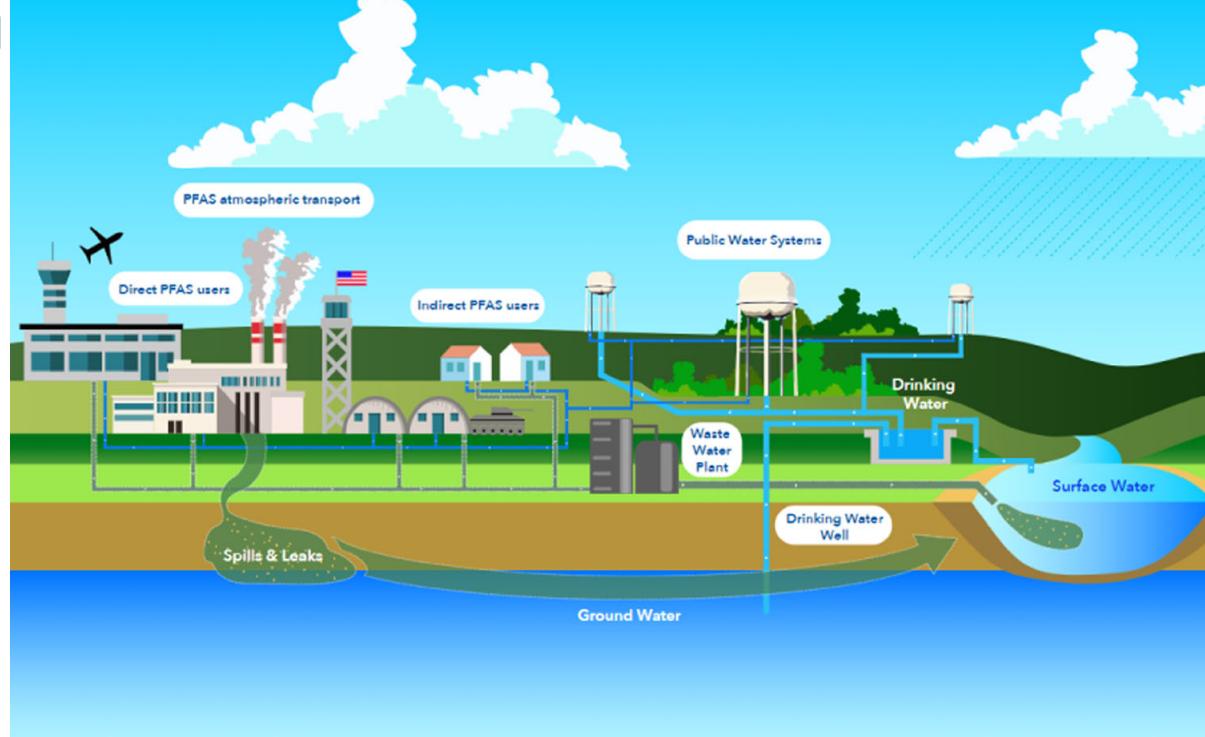
Potential PFAS direct users include metal plating facilities, paper manufacturing facilities, textile manufacturing facilities, electronic manufacturing facilities, and

facilities known to be contaminated with chlorinated volatile organic compounds (Table 1).

Specific scores were assigned to geographical sites of interest that indicated their potential to be PFAS hotspots (Fig. 2). The heatmap density was manipulated with the help of the Kernel density process.

## Screening Model Application

The state of Kentucky does not currently have specific guidelines for any PFAS compounds, and PFAS policy formulation for drinking water regulations is in the early stages. The screening approach presented in this study is a tool to augment existing information for the decision-makers, helping them prioritize sampling locations, and assess drinking water exposure risks during policy implementation, despite uncertainty regarding PFAS users and PFAS sources.



**Figure 1: Conceptual model for per- and polyfluorinated alkyl substances (PFAS) entering drinking water systems.** Note that the sewer system shown in this figure is intended to represent various scenarios, including storm, wastewater, and combined sewers. Direct PFAS users intentionally use PFAS as part of their operations. Examples of direct users include military operations, airports, sites that conduct fire training operations using PFAS-containing firefighting foams, and chemical manufacturing industries that produce or use PFAS in their processes. Indirect PFAS users include residences, commercial businesses, and offices that do not use PFAS intentionally but use PFAS-containing consumer materials.

### PFAS sampling and results in Kentucky

In Kentucky, 434 PWS provide drinking water for more than 95% of Kentuckians. The majority of Kentucky PWS (71% or 307 systems) use surface water (SW), while 29% (127 systems) rely on groundwater (GW) as their drinking water source (EPA, 2019). One or more PFAS were detected in 41 of the 81 samples taken from these PWS. Results also show that one or more PFAS were detected in 66% of sampled surface water systems, while PFAS were detected in only

22% of the sampled groundwater systems. KDEP sampled and analyzed PWS for eight PFAS, including perfluorobutane sulfonate, hexafluoropropylene oxide dimer acid (also referred to as Gen X), perfluoroheptanoic acid, perfluorohexane sulfonate, ammonium 4,8-dioxa-3Hperfluorononanoate, PFOA, PFOS, and perfluorononanoic acid.

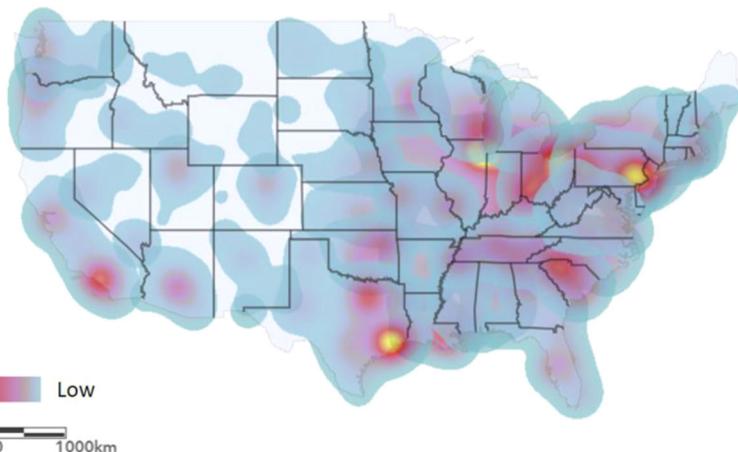
### Modeling the outcomes from the Kentucky case study

For GW, the regression model predicted cor-

rectly for 24 of 28 water systems with an 86% accuracy. For SW, the model predicted correctly for 33 of 47 water systems with a 70% accuracy (Table 2). Overall, 57 out of 75 water systems (77%) were predicted correctly by the model (within the acceptable range of 70%). When the TRI for PFAS is available in other states, the model can easily be applied to other locations. Of the 359 PWS that have not been sampled by KDEP, the statistical screening model recommends that 98 be sampled, and predicts that PFAS is likely to be detected in 143 PWS.

**Table 1: Potential direct PFAS users and assigned indicator scores for potential PFAS contamination.**

Risk score	Facility	Upper magnitude	Source
100	Department of Defense	10 000 µg/L (28 PFAS)	AFFF
	Landfill	1000 µg/L (13 PFAS)	Waste streams from landfills
	Chemical manufacturing Industries	1000 µg/L (11 PFAS)	PFAS or fluoropolymer manufacturer and user
75	Airport	100 µg/L (28 PFAS)	AFFF
	Fire training areas	100 µg/L (28 PFAS)	AFFF
	Petroleum refineries	10 µg/L (28 PFAS)	AFFF
50	Textiles	10 µg/L (13 PFAS)	Fluoropolymer coating
	Furniture	10 µg/L (13 PFAS)	Fluoropolymer coating
	Paper	10 µg/L (13 PFAS)	Fluoropolymer coating
25	Rubber and plastics	10 µg/L (13 PFAS)	Fluoropolymer coating
	Fire station	Not available	PFAS foam
	Fabricated metal	Not available	Fluoropolymer coating



**Figure 2: Example of screening model showing potential per- and polyfluorinated alkyl substances hotspots in the United States using Toxic Release Inventory data.**

## Results and Discussion

The study shows that the proposed screening approach is translatable to other states and countries where the input data are available. Given the distances from PWS, indicator score for each industry, and waste released from each industry from TRI, binomial regression modeling can be done using the “JMP pro 14” statistical model. Using the proposed formulation, the model will generate results regarding the water systems that may have a high probability of detection. PFAS releases to the environment could be controlled if industries stop using and producing PFAS, its precursors, and residuals. For instance, brands such as IKEA, H&M, Danish COOP, and ChemSec have stopped using the entire class of PFAS [4].

Given uncertainties related to emerging PFAS science and regulations, many people may be unaware of potential PFAS-related hazards. Communicating this model’s findings with various stakeholders is important to identify challenges, analyze opportunities, and develop risk-reducing strategies. Public and private stakeholders collaborating for risk management may produce more feasible and acceptable solutions for reducing PFAS use in manufacturing processes, as well as for performing cleanup efforts [4].

The results of the screening model, coupled with stakeholder engagement, can be used to im-

prove knowledge about the location of potential PFAS users and toxic chemicals discharged.

## Conclusion

This work provides a key contribution to developing a systematic approach for prioritizing PFAS sampling. Although these analyses used Kentucky PWS as a case study, the screening approach is translatable to other states and countries. Data is unclear for past chemical use for many industries, thus limiting the ability to identify the distribution and presence of PFAS at various sites.

## Limitations

Because this study uses publicly available sources, it only considers distances between PWS and direct user sites. The water path analysis of water systems and characteristics of water valves within the system have not been included in the model. Also, buying and selling of water are complex economically driven processes, and the developed screening approach is not able to account for these aspects. As KEPD analyzed for only eight of 9,000 possible PFAS, other PFAS that were not tested may be present. Although PFAS user sites such as industries and military installations are included in the model, other potential PFAS sites such as landfills are not. These limitations are necessary to maintain a simple, and broadly applicable screening approach; however, like all other models, there is a trade-off between simplicity and reality.

## References

- [1] Wallace, S. et al. (2022). On using DFT to construct an IR spectrum database for PFAS molecules. *Structural Chemistry*. DOI: 10.1007/s11224-021-01844-5.
- [2] Hagstrom, A.L. et al. (2021). Yale School of Public Health Symposium: An overview of the challenges and opportunities associated with per- and polyfluoroalkyl substances (PFAS). *Science of The Total Environment*. DOI: 10.1016/j.scitotenv.2021.146192.
- [3] Podder, A. et al. (2021). Per and poly-fluoroalkyl substances (PFAS) as a contaminant of emerging concern in surface water: A transboundary review of their occurrences and toxicity effects. *Journal of Hazardous Materials*. DOI: 10.1016/j.jhazmat.2021.126361.
- [4] Kwiatkowski, C.F. et al. (2020). Scientific Basis for Managing PFAS as a Chemical Class. *Environmental Science & Technology Letters*. DOI: 10.1021/acs.estlett.0c00255.

**Table 2: Screening results for groundwater (GW), surface water (SW), and combined.**

	Sample size	Sample-Y Model-Y	Sample-Y Model-N	Sample-N Model-Y	Sample-N Model-N	Accuracy	True precision	False precision
Combined	75	32	5	13	23	0.76	0.86	0.83
GW only	28	2	4	0	22	0.86	0.33	0.85
SW only	47	30	1	13	3	0.70	0.97	0.75

# PFAS

# “Forever Chemicals”

## Per- and Polyfluoroalkyl Substances

PFAS are a family of more than 4,700 chemical molecules which are persistent, non-stick, chemical and heat-resistant and have waterproof characteristics. EPA database have more than 12,000 PFAS with confirmed structure.

Europe has a broader PFAS definition than US EPA. Since they persist in the environment, they have been found in the air, water, sediment, soil, and even in rain. Globally, one study showed that PFAS is found in Antarctica and Himalaya. The same stable chemical bonds that make them useful, also make them resistant to degradation.

Due to their unique chemical properties, PFAS were used in different industries and daily consumer goods like cosmetics, drinking water, firefighting foam, food packaging, textiles, cookware, automobiles and much more. After release from industrial plants, PFAS eventually enter water bodies and oceans, where they do not dissolve but are released into the atmosphere via aerosols. Rainfall brings the chemicals back to the surface, so they continue to pose a threat to the environment decades after their original release.

Despite the fact that the world's largest producers of PFAS discontinued certain products, production of alternate fluoroochemicals is ongoing, maintaining PFAS contamination in the environment.

shampoo  
stain-resistant products  
paints  
photography  
pesticides  
firefighting foams  
fast food packaging  
cosmetics non-stick cookware  
cannabis  
drinking water pharmaceuticals  
beverages medical devices

## Concerns about PFAS

### Effects on human health

- Development of kidney and testicular cancer
- Liver damage
- Elevate cholesterol levels
- Weaken immune function
- Decrease fertility or increase high blood pressure in pregnant women
- Interfere with the body's natural hormones

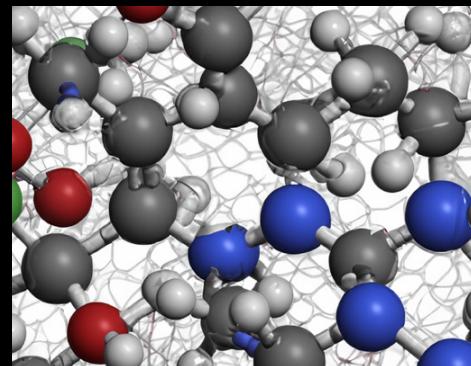
### Effects on environment

- Bioaccumulation
- Contamination of groundwater and drinking water
- Harmful effects on reproduction, development and the immune system of animals



## PFAS as “Forever Chemicals”

PFAS have stable carbon-fluorine bonds, which are the strongest covalent bonds in chemistry, along with varying carbon chain lengths. These chemical bonds take a lot of energy to break, which makes them extremely durable or stable to degradation in the environment and even in the human body. Currently, the FDA assesses food products for six PFAS (PFOA, PFOS, PFNA, PFHxS, HFPO-DA, GenX and PFBS) contaminants from the environmental that may pose a human health concern.



## Regulations



### International

The Stockholm Convention, in force since 2004, is a global treaty aiming to protect the environment and human health from the effects of Persistent Organic Pollutants (POPs).

A list of chemicals is classified into Annexes A-B-C:

- Completely prohibited (A)
- Not completely banned (B)
- Unintentionally produced (C).

### United States of America

The Environmental Protection Agency (EPA) plans to take specific actions and commits to bolder new policies to safeguard public health, protect the environment, and hold polluters accountable.

In the EPA's fifth Unregulated Contaminant Monitoring Rule (UCMR 5), the agency established minimum reporting levels (MRLs) for the UCMR 5 contaminants, including 29 PFAS chemicals.

### Europa

PFASs are among the new parameters introduced as part of the recasting of Directive (EU) 2020/2184 of 16 December 2020 on the quality of water intended for human consumption. Twenty PFASs are targeted and a quality limit (0.10 µg/L) has been set for the sum of these 20 compounds in drinking water.

REACH Regulation was introduced in 2006 to regulate the production and use of chemical substances. PFOA, PFOS, GenX, PFBS... are, for example, classified as Substances of Very High Concern SVHC.

## Sample Preparation for PFAS Determination

Sartorius provides a range of solutions for your sample preparation:

- Materials and supplies used in environmental sampling must be free of interference below a 1/3 of Minimum Reporting Level (MRL)
- Accurate and time saving workflows for robust and reproducible results

A non exhaustive review of regulations and standards to date: EPA 533, EPA 537.1, EPA 8327, EPA1633, ISO25101, ISO21675, ASTM E3302. The number of regulations may evolve with a raised global awareness and continued improvement of detection limits.

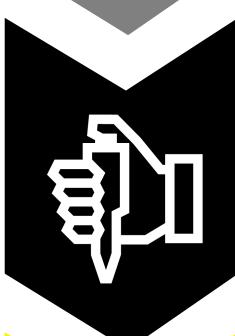
## Workflow

**Step 1: Preparation of solvents**

Ultrapure water conforming to Type 1 (or LC-MS grade) which is demonstrated to not contain contaminants at concentration sufficient to interfere with the analysis.

**Step 2: Preparation of standards**

Calculation of standards or laboratory control samples in defined concentrations with high precision Cubis® II balances and guided preparation with the Q-App software.

**Step 3: Pipetting**

To detect small amounts of residual contaminants, it is important to use every last microliter of sample. Tacta® and Picus® pipettes ensure reliable data from samples, duplicates and surrogate spiking solutions.

**Step 4: Filtration**

Filtration devices for clarification and prefiltration and sterile filtration. Prepare your sample in a first clarification step with Minisart® syringe filters to remove particles, rule out interference in the best possible way during detection and prevent blockage of your chromatography column.

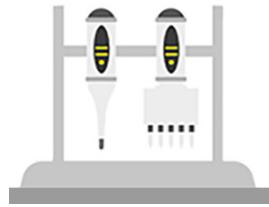
## Solutions



**Arium® Mini Lab Water Systems**



**Cubis® II Ultramicro, micro, analytical, and precision balances**



**Tacta® and Picus® Pipettes**



**Minisart® Syringe Filters**

## Tips for PFAS sampling



### Do's

- Wear cotton clothing or well-laundered synthetic fabrics
- Use nitrile gloves without powder
- Ensure sampling equipment and supplies, including caps, are PFAS free
- Use pesticide-free or higher purity reagents and solvents
- Use pipettes that are free of target analyte with disposable polypropylene or polyethylene tips



### Don't's

- Wear water-repellent, waterproof, staub-resistant, fire-repellant clothes
- Put makeup, cosmetics, hand cream, moisturers, sunblocker, insect repellents, which include PFAS
- Use plastic clipboards, waterproof logbooks
- Bring packaged food/drinks
- Use aluminum foil labels, permanent markers, sticky notes
- Use chemical ice

Learn more about how Sartorius solutions can be used in environmental testing labs: [www.sartorius.com/environmental-testing](http://www.sartorius.com/environmental-testing)



### References

1. <https://stormwater.wef.org/2022/08/scientists-contend-pfas-in-rainfall-represents-global-crisis/>  
Perfluoroalkyl chemicals (PFAS) - ECHA (europa.eu)
2. PFASs: chemicals in the spotlight | Anses - Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail PFAS Strategic Roadmap: EPA's Commitments to Action 2021-2024 | US EPA
3. <https://daa.com/sampling-and-analysis-of-pfas/>
4. <https://pfas-1.itrcweb.org/11-sampling-and-analytical-methods>
5. <https://echa.europa.eu/hot-topics/perfluoroalkyl-chemicals-pfas>
6. <https://www.anses.fr/en/content/pfass-chemicals-spotlight>
7. <https://www.epa.gov/sdwa/questions-and-answers-drinking-water-health-advisories-pfoa-pfos-genx-chemicals-and-pfb>

## Further Readings and Resources



## Application-Oriented and Flexible to Meet the Highest Demands

### Arium® Pro Ultrapure Water System with Smart Station

Arium® Pro Ultrapure Water Systems make lab results accurate, error-free and reproducible. Whether it's high performance liquid chromatography (HPLC), liquid chromatography-mass spectrometry (LC/MS), molecular biology, or any other critical analytical techniques, Arium® Pro systems deliver consistent water quality that meets or exceeds ASTM Type I standards. Combine them with Arium® Smart Station for flexible remote dispensing to simplify your lab work.

### Simplifying Progress



Learn More

# SARTORIUS