THE Water Research FOUNDATION

Per- and Polyfluoroalkyl Substances

THE CHALLENGE

Per- and polyfluoroalkyl substances (PFAS), also commonly referred to as perfluorinated chemicals or PFCs, are a group of anthropogenic chemicals with past and current uses in industrial processes and consumer products. These chemicals are used in firefighting foams, coating for food packaging, ScotchGard™, and Teflon™, among other products. PFAS are highly resistant to chemical decomposition since the carbon-fluorine bond they contain is so strong. They are also soluble in water and can enter source waters through industrial releases, discharges from wastewater treatment plants, storm-water runoff, release of firefighting foams, and land application of contaminated biosolids. PFAS have been detected in surface, ground, tap, and bottled waters; wastewater and industrial influents and effluents; and rivers, lakes, and tributaries.

In May 2016, the U.S. Environmental Protection Agency (EPA) established drinking water health advisory (HA) levels for perfluorooctane sulfonate (PFOS) and perfluo-rooctanoic acid (PFOA) of 0.07 µg/L based on lifetime exposure concerns for sensitive sub-populations. In June 2022, these HAs were reduced to 0.004 ng/L and 0.02 ng/L, respectively, and two new HAs were established for Gen-X chemicals (10 ng/L) and perfluoro-butanesulfonic acid (PFBS) (2000 ng/L). In February 2021, EPA formally announced its intent to regulate two specific chemicals, PFOA and PFOS, and to include 29 PFAS in the Fifth Unregulated Contaminant Monitoring Rule (UCMR5). UCMR5 monitoring began in 2023 and will continue through 2025. In October 2021, EPA announced a new PFAS Strategic Roadmap with three aims: increase research, restrict PFAS releases to the environment, and accelerate cleanup.

On April 10, 2024, EPA released its final PFAS National Primary Drinking Water Regulation. Years of research led EPA to determine that regulation of six specific PFAS in drinking water will prevent thousands of deaths and tens of thousands of serious illnesses, including cancer and developmental effects.

Under the final rule, utilities will have three years from promulgation to complete initial monitoring. Starting three years after promulgation, utilities must begin compliance monitoring and include the results in their Consumer Confidence Reports as well as issue public notification for monitoring and testing violations. Starting five years after rule promulgation, utilities must comply with all maximum contaminant levels (MCLs) and provide public notification for MCL violations.

THE RESEARCH

WRF has been performing research on compounds of emerging concern for over 50 years. In 2015, WRF expanded this research to include the emerging issue of PFAS, with several projects ongoing to investigate occurrence, detection, treatment, media regeneration, destructive technologies, and waste stream disposal.

Treatment and Mitigation

Because early research showed that conventional treatment strategies (i.e., coagulation, sedimentation,

TABLE 1. FINAL PFAS REGULATORY LEVELS RELEASED BY EPA

Chemical	Max Contaminant Level Goal	Max Contaminant Level
Perfluorooctanoic Acid (PFOA)	0 ppt	4.0 ppt
Perfluorooctanesulfonic Acid (PFOS)	0 ppt	4.0 ppt
Perfluorohexanesulfonic Acid (PFHxS)	10 ppt	10 ppt
Perfluorononanoic Acid (PFNA)	10 ppt	10 ppt
Hexafluoropropylene Dimer Acid (HFPO-DA) and Its Ammonium Salt (Gen-X Chemicals)	10 ppt	10 ppt
Perfluorobutanesulfonic Acid (PFBS), PFHxS, PFNA, and HFPO-DA and Their Salts	Hazard Index of 1*	Hazard Index of 1*

*Hazard Index (HI) of 1 accounts for additive impacts from two or more chemical mixtures:

$$\text{HI MCL} = \frac{[\text{HFPO - DA}_{\text{water}}\ \text{ppt}]}{[10\text{ppt}]} + \frac{[\text{PFBS}_{\text{water}}\ \text{ppt}]}{[2000\text{ppt}]} + \frac{[\text{PFNA}_{\text{water}}\ \text{ppt}]}{[10\text{ppt}]} + \frac{[\text{PFHxS}_{\text{water}}\ \text{ppt}]}{[10\text{ppt}]} = 1$$

filtration, chlor[am]ination) do not effectively remove PFAS from drinking water, WRF has been leading the way on research into cutting-edge processes to treat and remove these substances. Published in 2015, *Removal of Perfluoroalkyl Substances by PAC Adsorption and Anion Exchange* (4344) found that anion exchange processes showed promise for long-chain PFAS removal if resins are regenerated to periodically restore the PFAS removal capacity. An alternative for PFAS removal could be a hybrid adsorption/anion exchange approach, in which more strongly adsorbing PFAS are removed by activated carbon, and the more weakly adsorbing PFAS are removed subsequently by anion exchange.

While there are similarities and differences in toxicological effects among long-chain and short-chain PFAS, the longer-chain PFAS are more persistent in the environment and have the potential to degrade. Granular activated carbon (GAC), superfine PAC, and anion exchange (AIX) are less effective at removing shorter chain PFAS. *Treatment Mitigation Strategies for Poly- and Perfluorinated Chemicals* (4322), published in 2016, evaluated the ability of various full-scale treatment techniques to remove PFAS from contaminated raw water or potable reuse sources.

The project looked at 15 full-scale water treatment systems throughout the United States, including two potable reuse treatment systems, for attenuation of PFAS. These systems included a wide range of full-scale treatment techniques, including conventional and advanced technologies, such as ferric and alum coagulation, granular/micro-/ultrafiltration, aeration, oxidation, disinfection, GAC, AIX, reverse osmosis (RO), nanofiltration (NF), dissolved air flotation, and river bank filtration. This study further evaluated GAC and NF at the bench-scale for the removal of a suite of perfluorocarboxylic acids (PFCAs) and perfluorosulfonic acids (PFSAs). The project team found that GAC and AIX can remove many PFAS but are less effective at removing shorter chain PFASs. The most effective treatment technologies appeared to be NF and RO.

RO is a costly treatment method, and disposal or treatment of the membrane concentrate stream is a consideration for both NF and RO. Full-scale AIX and GAC column treatments were more effective at removing long-chain PFAS and PFSAs than PFCAs. GAC rapid small-scale column tests demonstrated that natural organic matter (NOM) competition can affect the ability of GAC to adsorb PFCAs and PFSAs. This suggests that GAC may be more effective towards groundwaters that have less NOM than surface waters.

Published in 2020, *Concept Development of Chemical Treatment Strategy for PFOS-Contaminated Water* (U2R16/4877) investigated advanced oxidation integrated with chemical reduction to decompose PFOS. The strategy was implemented by using zerovalent iron (Fe, ZVI) nanoparticles conjugated with common oxidants. Synergistic removal of PFOS was achieved by the integrated system, compared to oxidants or ZVI alone. Unexpectedly, identifiable reaction intermediates targeted were not detected, and thus exact mechanisms for explaining the observed PFOS removal was not clear. Many possible scenarios occurring in the integrated system were proposed, including adsorption of PFOS onto ZVI, complexation of PFOS with Fe, and transformation of PFOS to ill-defined or other intermediates.

Formation and Occurrence

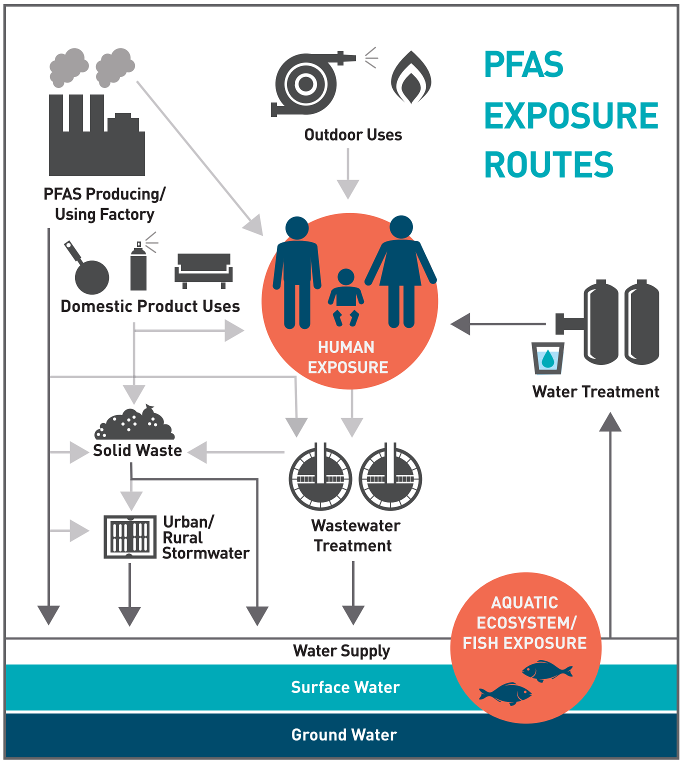
The most effective routes to mitigate PFAS are restricting its use in future products to essential use only, followed by proper disposal of existing products. While industry and consumers must shoulder the brunt of this responsibility, water utilities recognize that they can also control the formation of additional PFAS through their treatment and waste disposal practices.

Ozone treatment can mitigate human and environmental impacts associated with trace organic contaminants, making it a promising treatment alternative for reuse applications. However, the formation of ozone by-products, including PFAS, could be a barrier to the widespread use of ozone. The 2015 WRF report, *Formation of*

Nitrosamines and Perfluoroalkyl Acids During Ozonation in Water Reuse Applications (Reuse-11-08/1693), found that some PFAS, including perfluoropentanoic acid, perfluorohexanoic acid (PFHxA), PFOA, and perfluorobutane sulfonic acid, were formed after ozonation of secondary treated wastewaters. PFHxA was most frequently formed. Control strategies, such as full nitrification during secondary biological treatment, optimized ozone dosing, or certain post-treatment technologies can be implemented to potentially mitigate the formation of these contaminants. In some instances, secondary biological treatment resulted in increased PFAS concentrations.

Published in 2022, *Assessing Poly- and Perfluoroalkyl Substance Release from Finished Biosolids* (5042) used bench-scale leaching tests of biosolids collected from water resource recovery facilities (WRRFs) that use differing post-digestion treatment processes. This research assessed PFAS release from finished biosolids; specifically, the release was examined as a function of PFAS loading in the finished biosolids, the post-digestion processing of the biosolids, and the age of the biosolids. This project may be the first to examine the impacts of both biosolids processing and biosolids aging on PFAS release, and provides a unique data set, as well as insights into the mechanisms that control PFAS leaching.

Because PFAS are used in a wide variety of consumer care products, which are typically washed down drains, they are being found in wastewater treatment plant influent and effluent. During wastewater treatment, polyfluoroalkyl compounds (often called precursors) can degrade into perfluoroalkyl compounds. However, due to their chemical nature, these compounds are not efficiently removed during conventional wastewater and sludge treatment processes. Thus, the release of treated effluent as well as land application of biosolids provides an opportunity for the re-release of PFAS into receiving environments. *Occurrence of PFAS Compounds in U.S. Wastewater Treatment Plants* (5031), published in 2024, evaluated PFAS at 38 WRRFs and found widespread and elevated concentrations of PFAS precursors, highlighting the need to identify and manage these PFAS in WRRFs. Furthermore, the potential accumulation and concentration of hydrophobic precursors in concentrated streams such as scums/foams, dewatering flows, and solids may be an important consideration in management strategies. An additional project focused on these concerns, *Investigation of Alternative Management Strategies to Prevent PFAS from Entering Drinking Water Supplies and Wastewater* (5082), is ongoing.



Communication

While PFAS have been a growing concern for many years, EPA's recent activity, as well as increasing state-level regulatory actions, will bring PFAS to the attention of an even broader audience. Utilities' clear and open communications with the public on this health risk are vitally important to building and maintaining trust with consumers in their efforts to provide safe drinking water. To address these needs, in 2022 WRF published *PFAS One Water Risk Communication Messaging for Water Sector Professionals* (5124). This project developed two PFAS communication toolkits, the first of which includes guidance and communication tools about PFAS results from sampling related to the EPA's Fifth Unregulated Contaminant Monitoring Rule. The second toolkit is specific to One-Water-focused messaging about minimizing exposure to PFAS.

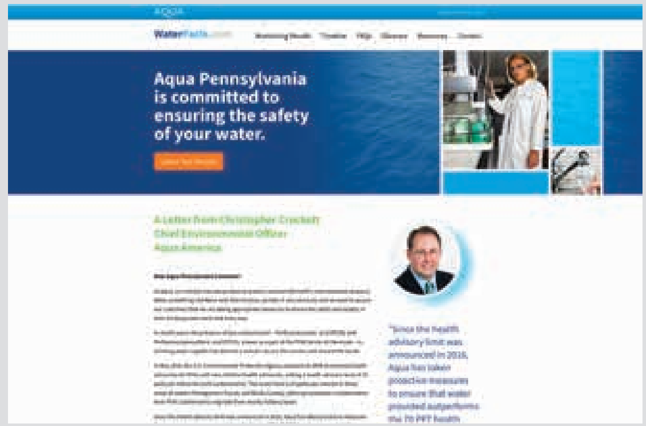
WHAT'S NEXT?

In early 2018, WRF was awarded funding from the U.S. Department of Defense (DoD) to conduct the research project *Evaluation and Life Cycle Comparison of Ex-Situ Treatment Technologies for Poly- and Perfluoroalkyl Substances in Groundwater*. This project will develop a framework for assessing PFAS treatment techniques from a life-cycle cost and assessment perspective.

SOLUTIONS IN THE FIELD: Aqua Pennsylvania

Aqua Pennsylvania (Aqua PA), an Aqua America subsidiary, serves more than 1.4M residents in 32 counties across Pennsylvania. In 2017, EPA released data on water samples collected in and around Aqua PA's service area. Although none of Aqua PA's sources had PFAS levels above EPA's Health Advisory level, several sites contained low levels of PFOA and PFOS. A chief source of these compounds was thought to be Willow Grove Naval Air Station in Montgomery County, which ceased flight operations in 2011.

In the wake of these findings, Aqua PA responded swiftly by taking selected wells offline and retrofitting them with GAC treatment. Aqua PA also began piloting anion exchange at one of the affected wells. Aqua PA hosted a series of public meetings and briefings for local elected officials. In addition, Aqua prioritized customer outreach and education, primarily by creating a website called waterfacts.com, which communicates information on PFAS and shares results of ongoing PFAS monitoring. The site includes a glossary, FAQs, and links to other helpful resources from EPA.



A 2018 WRF webcast shared Aqua PA's response to PFAS, including the launch of their WaterFacts website.

On May 31, 2018, WRF hosted a webcast titled "PFAS in Water: Background, Treatment, and Utility Perspective," which was attended by over 800 live viewers from around the world. In this interactive forum, Aqua PA shared their PFAS response and risk communication experiences with hundreds of other utility officials who might be facing similar challenges.

Funded in 2018, *Investigation of Treatment Alternatives for Short-Chain PFAS* (4913) will aid water treatment professionals in selecting the most cost-effective and sustainable treatment options for short-chain PFAS removal. The guidance manual will consider the effects of background water matrices and uncertainties involved with scaling up from bench-scale performance data to field-scale design.

Recognizing the role of municipal wastewater effluent as a potential pass-through source of PFAS into the aquatic environment has driven a need for more investigation of residuals management strategies. In 2022, WRF funded *State of the Science and Regulatory Acceptability for PFAS Residual Management Options* (5170) to develop an operational toolkit with a set of techniques and tools for PFAS disposal.

A suite of projects is also underway to provide more insight into thermal approaches to destroy and remove PFAS. *Understanding Pyrolysis for PFAS Removal* (5107) will study the performance and feasibility of a full-scale thermal drying and pyrolysis facility to remove PFAS while processing municipal sludge. *Studying the Fate of PFAS through Sewage Sludge Incinerators* (5111) will provide more insight on whether PFAS can be fully mineralized by sewage sludge incinerators, and whether such an approach generates products of incomplete combustion. Finally, *Understanding the Value Proposition for Thermal Processes to Mitigate PFAS in Biosolids* (5211) will establish mass balances for PFAS in biosolids across torrefaction, pyrolysis, and gasification effluent products, which will support the development of a life-cycle assessment tool to help decision makers with biosolids planning.

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