



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 the strongest in organic chemistry. They are also soluble in water and can enter source waters through industrial releases, discharges from wastewater treatment plants, stormwater runoff, release of firefighting foams, and land application of contaminated biosolids. PFAS have been detected in surface, ground, tap, and bottled waters; wastewater influents and effluents; industrial waste influents and effluents; and rivers, lakes, and tributaries.

In May 2016, EPA established drinking water health advisory (HA) levels for perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) of 0.07 µg/L based on lifetime exposure concerns for sensitive subpopulations. In February 2021, the EPA formally announced its intent to include 29 PFAS in the fifth Unregulated Contaminant Monitoring Rule (UCMR5). In addition, EPA also indicated its intent to regulate two specific chemicals, PFOA and PFOS. Monitoring is set to begin in 2023.

THE RESEARCH

WRF has been performing research on compounds of emerging concern for over 50 years, helping utilities find treatment solutions for challenges like hexavalent chromium, volatile organic compounds, endocrine disrupting compounds, and pharmaceuticals and personal care products. In 2015, WRF expanded this research to include the emerging issue of PFAS, with several projects currently ongoing and planned over the next five years to investigate occurrence, detection, and treatment.

HISTORY OF PFAS PRODUCTION

- 1949 — 3M begins producing PFOS-based compounds
- 1967 — FDA approves use in food packaging
- 2002 — 3M phases out PFOS production
- 2008 — 3M phases out PFOA production
- 2015 — All manufacturers phase out PFOA production

Treatment and Mitigation

Because early research showed that conventional treatment strategies (i.e., coagulation, sedimentation, 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](#)) assessed the effectiveness of powdered activated carbon (PAC) adsorption and magnetic anion exchange processes for the removal of PFAS from drinking water sources. Anion exchange processes showed

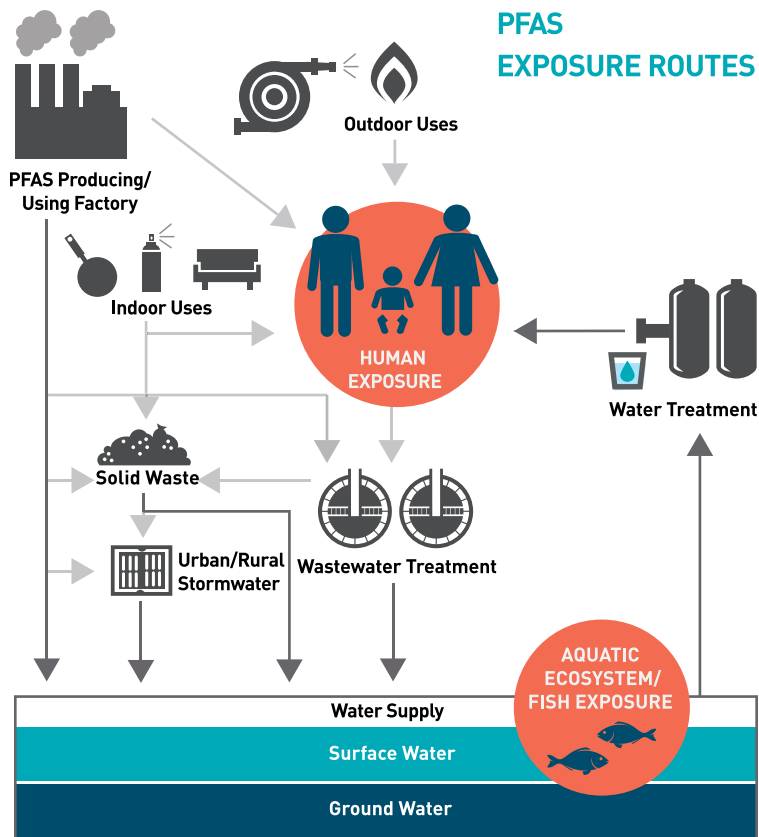
promise for long-chain PFAS removal, if resins are regenerated to periodically restore the PFAS removal capacity. An alternative for PFAS removal could be a hybrid adsorption/anion exchange approach, in which more strongly adsorbing PFAS are removed by activated carbon, and the more weakly adsorbing 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 powdered activated carbon, and anion exchange (AIX) can remove many PFAS but are less effective at removing shorter chain PFAS, although science on this topic is constantly changing. *Treatment Mitigation Strategies for Poly- and Perfluorinated Chemicals (4322)*, published in 2016, evaluates the ability of a wide spectrum of full-scale water treatment techniques to remove PFAS from contaminated raw water or potable reuse sources.

The project looks 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, anion exchange (AIX), reverse osmosis (RO), nanofiltration (NF), dissolved air flotation, and river bank filtration. A low-level liquid-chromatography tandem mass-spectrometry method was used to measure a suite of 23 PFAS in source water, finished drinking water, or potable reuse product water, and at various steps along the treatment train. In addition, this study further evaluated two treatment technologies at bench-scale, GAC and nanofiltration (NF), for the removal of a suite of perfluoroalkyl carboxylic acids (PFCAs) and perfluoroalkane sulfonates (PFASs).

This study reinforces that full-scale conventional treatments, such as coagulation followed by physical separation processes, and chemical oxidation, aeration, and disinfection, are not effective in removing PFAS. NF/RO rejected almost all PFAS studied, but treatment should be further investigated and validated at pilot- and full-scale. 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 PFASs than PFCAs. GAC rapid small-scale column tests demonstrated that NOM competition can affect the ability of GAC to adsorb PFCAs and PFASs. Therefore, it is important to understand the type and quantity of NOM that could have an impact on the degree of PFAS removal.





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 complex 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 and other intermediates than were targeted. Additional PFCs with different structures should be examined to obtain insight into their chemical reactivity with the integrated system so that a fuller picture of what works and what does not, and if so, why and why not, can be developed.

Formation and Occurrence

Because preventing the formation of PFAS before they can become part of our water systems is one of the most effective mitigation strategies, WRF has also been exploring where and how these substances are formed and what can be done to offset the generation process.

Ozone treatment can mitigate human and environmental impacts associated with trace organic contaminants, making it a promising treatment alternative in water reuse applications, particularly potable reuse. However, the formation of ozone byproducts, 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](#)), evaluates PFAS occurrence, factors affecting formation, and potential mitigation strategies. The research explores the likelihood of PFAS formation after ozonation of treated wastewaters; evaluates the factors responsible for the formation of these byproducts; and recommends potential mitigation strategies.

Based on full- and pilot-scale system performance data and systematic bench-scale studies, 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. Depending on future regulatory determinations, these contaminants could

be of concern for potable reuse treatment systems that employ ozone. 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.



INNOVATION

The WRF Innovation Program embraces innovation to support healthy, sustainable communities, with efforts focused on moving water technology to the field quickly and efficiently. Recognizing that PFAS contamination is a challenge for many communities, WRF chose PFAS as a priority innovation topic for potential pilot projects. These pilot projects will evaluate promising PFAS destruction technologies and processes beyond the bench scale.



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, which will be structured based on input gathered during an expert workshop. This research will help fill knowledge gaps by evaluating traditional techniques and developing treatment technologies for PFAS.

Funded in 2018, *Investigation of Treatment Alternatives for Short-Chain PFAS* ([4913](#)) will develop a guidance manual to 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. In addition, a decision support tool will be created to aid water professionals in selecting effective treatment options for short-chain PFAS removal in their unique water matrices and appropriate bench-scale tests to compare sorbents, resins, or membranes.

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. And now, municipal wastewater effluents and biosolids are being viewed as potential pass-through sources of PFAS in the aquatic environment. During wastewater treatment, polyfluoroalkyl compounds



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.

(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 the widespread land application of biosolids provides an opportunity for the re-release of PFAS into receiving environments. Two projects are currently underway to explore these implications: *Occurrence of PFAS Compounds in U.S. Wastewater Treatment Plants* (5031) and *Investigation of Alternative Management Strategies to Prevent PFAS from Entering Drinking Water Supplies and Wastewater* (5082).

Funded in 2019, *Assessing Poly- and Perfluoroalkyl Substance Release from Finished Biosolids* (5042) will use bench-scale leaching tests of biosolids collected from WRRFs that use differing post-digestion treatment processes. This research will assess PFAS release from finished biosolids; specifically, the release will be 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 will provide a unique data set, as well as insights into the mechanisms that control PFAS leaching.

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 not only for drinking water utilities but also for water resource recovery facilities. 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 2021 WRF funded *PFAS One Water Risk Communication Messaging for Water Sector Professionals* (5124).