



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.

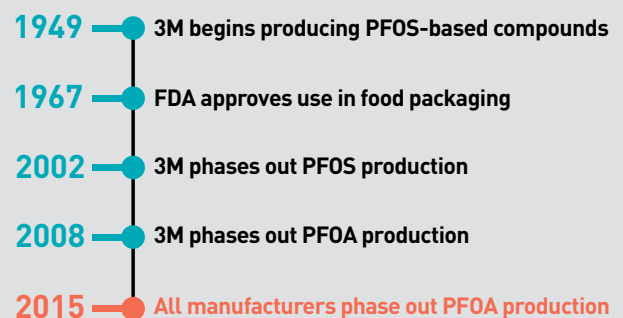
Chronic toxicology studies have only been conducted on perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA), but both compounds caused tumors in rats. In 2006, the U.S. Environmental Protection Agency (EPA) Science Advisory Board classified PFOA as a likely human carcinogen. There are not currently any federal regulations limiting PFAS in water, but EPA is considering whether to establish Maximum Contaminant Levels for PFAS in drinking water. In May 2016, EPA established drinking water health advisory (HA) levels for PFOS and PFOA of 0.07 µg/L based on lifetime exposure concerns for sensitive subpopulations.

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.

In October 2018, WRF hosted a congressional briefing on PFAS attended by over 60 congressional staffers and water sector leaders. Presentations were given on PFAS treatment, utility and state perspectives on PFAS, and the future of PFAS research. The variety of stakeholder perspectives contributed to a well-rounded view on the state-of-the-science on PFAS.

HISTORY OF PFAS PRODUCTION



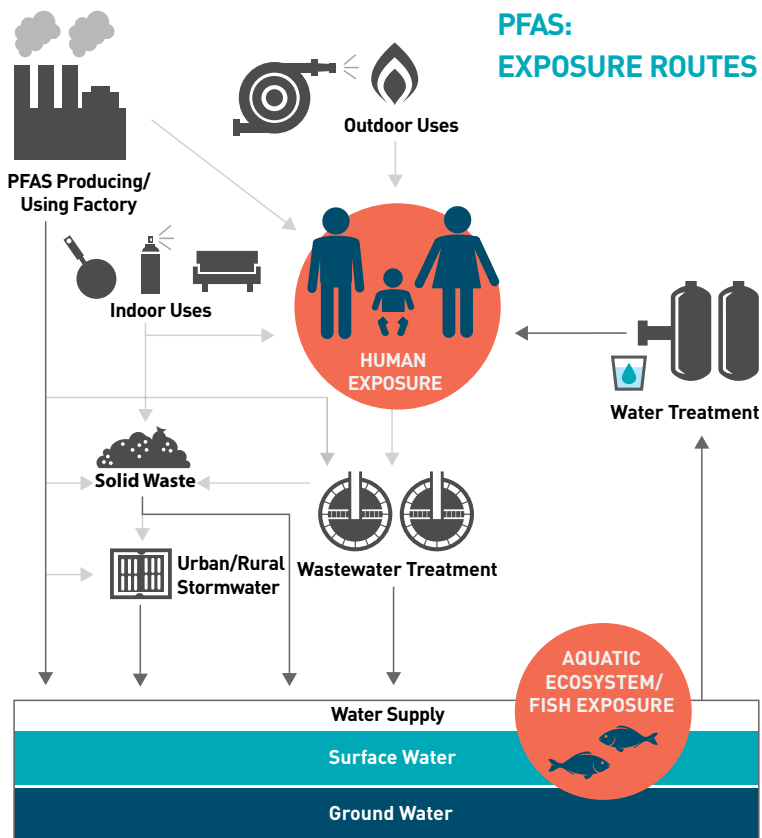
Treatment and Mitigation

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) assesses the effectiveness of innovative powdered activated carbon (PAC) adsorption and magnetic anion exchange processes for the removal of PFAS from drinking water sources. Apart from the more commonly studied PFOA and PFOS, the removal of eight additional PFCs that are frequently detected in water are also studied at environmentally relevant concentrations. Overall, the results of this research illustrate that PFAS are difficult to remove by superfine PAC adsorption and anion exchange. Anion exchange processes show greater promise for PFAS removal, if resins are regenerated in a manner that periodically restores the PFAS removal capacity. A possible alternative for PFAS removal could be a hybrid adsorption/anion exchange treatment approach, in which more strongly adsorbing PFAS are initially removed by activated carbon, and the more weakly adsorbing PFAS are removed subsequently by anion exchange. The hybrid approach may facilitate resin regeneration, which is more readily

accomplished if only PFAS that interact more weakly with the resin need to be removed.

While there are similarities and differences in toxicological effects among PFAS, in general, the longer-chain PFAS are more potent than the shorter-chain compounds. 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.

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), 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.



The Leaders Innovation Forum for Technology (LIFT) helps move water technology to the field quickly and efficiently. Recognizing that PFAS contamination is a challenge for more and more communities, in 2019, LIFT announced the launch of a PFAS Focus Group, which will investigate PFAS removal technologies and strategies from both a water quality and biosolids perspective.



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.

In addition to creating the framework, the project team will develop a treatment testing protocol and conduct laboratory-scale studies to evaluate the performance of various technologies for PFAS removal under different treatment scenarios. The results will be used to develop an Excel-based decision support tool to help DoD, utilities, and other practitioners select the most viable treatment technologies for different scenarios on a life-cycle cost and assessment basis by identifying advantages, disadvantages, limitations, and costs of the various technologies.

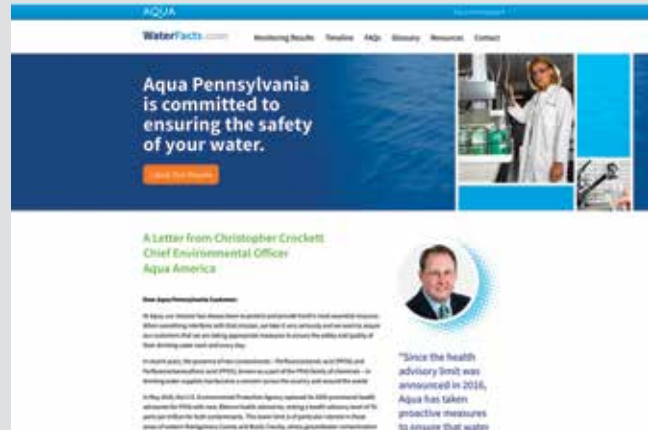
Another ongoing project, *Concept Development of Chemical Treatment Strategy for PFOS-Contaminated Water* (U2R16), will develop a practical high-efficiency chemical treatment strategy for PFOS. To decompose PFOS effectively, this research investigates advanced oxidation integrated with chemical reduction (AIR as a novel treatment strategy). The AIR strategy might have high potential to expedite the decomposition of PFOS via various chemical routes combining hydroxyl radical-oxidation, sulfate radical-oxidation, superoxide radical anion-reduction, and electrochemical defluorination. The strategy is implemented by using zerovalent iron (Fe, ZVI) nanoparticles conjugated with common oxidants (FECO as a tactical system). If the AIR strategy and the FECO system work for PFOS in this study, it could work for other problematic short-chain PFCs, significantly contributing to development



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 entitled "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.

of effective chemical treatment options for water contaminated with many persistent organic chemicals.

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 a potential source of PFAS in the aquatic environment. 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 the widespread land application of biosolids provides an opportunity for the re-release of PFAS into receiving environments. In 2019, WRF funded *Occurrence of PFAS Compounds in U.S. Wastewater Treatment Plants* (5031) to explore these implications.