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## Per- and polyfluoroalkyl substances (PFASs) in drinking water: current state of the science

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### Abstract

Perfluoroalkyl and polyfluoroalkyl substances (PFASs) are ubiquitous emerging contaminants that have been used in many applications since the 1950s. They have been detected in many drinking water sources, sometimes at  $\mu\text{g/L}$  level in water impacted by point sources. Following growing concerns on adverse ecological and human health effects, in the early 2000s several countries established regulations on the PFASs of most concern. Fluorinated alternatives were consequently developed by manufacturers, resulting in the release of novel PFASs that have recently been detected in water resources. Like legacy PFASs, most of them are recalcitrant to conventional drinking water treatments. Governments face the challenge of defining guideline values for water often containing a mixture of several PFASs with little conclusive toxicological and epidemiological evidence. Around 3,000 PFASs have been available on the global market, so the other key challenge is to identify the main ones in contaminated water resources, and to detect novel PFASs quicker than was the case for legacy PFASs.

### Keywords

Per- and polyfluoroalkyl substances (PFASs); drinking water treatment; human exposure; point sources; guideline values

### Introduction

Perfluoroalkyl and polyfluoroalkyl substances (PFASs) are a large group of persistent anthropogenic molecules containing the perfluoroalkyl moiety  $\text{C}_n\text{F}_{2n+1}$  [1\*\*,2\*]. Perfluoroalkyl substances contain just a functional group (e.g.  $\text{COOH}$ ,  $\text{SO}_3\text{H}$ ) directly linked to the  $\text{C}_n\text{F}_{2n+1}$  moiety. Polyfluoroalkyl substances contain the  $\text{C}_n\text{F}_{2n+1}$  moiety, a functional group and at least one C-H bond in their chemical formula (e.g.  $\text{C}_n\text{F}_{2n+1}\text{C}_2\text{H}_4\text{SO}_3\text{H}$ ,  $\text{C}_n\text{F}_{2n+1}\text{SO}_2\text{NHC}_2\text{H}_4\text{OH}$ ). The difference in their behavior in the environment is huge, because perfluoroalkyl substances are extremely persistent, whereas polyfluoroalkyl substances have been shown to degrade into perfluoroalkyl substances under both biotic and abiotic conditions [1\*\*].

Since the 1950s, PFASs have been used in a wide range of industrial and domestic applications, such as processing aids for fluoropolymer manufacture, surfactants in specific firefighting foams, and constituents of side-chain-fluorinated polymers for water- and grease-proof textiles and food containers [1\*\*,3,4]. As a consequence of their widespread use and extreme resistance to

environmental degradation mechanisms, PFASs have been universally detected in many environmental compartments, including remote locations far from human settlements [1\*\*,5\*]. In the early 2000s, growing concerns about the ecological effects and human health impact of long-chained PFASs (with 7 or more perfluorinated carbons) have led to a drastic decline in their production and their progressive replacement by fluorinated alternatives with shorter chains, considered less bio-accumulative but unfortunately more mobile [1\*\*,6]. Consequently, the phasing out and restricted use of long-chained PFASs will not lower the PFAS burden in the environment, but just result in different composition profiles being found in the environment.

### **Sources and occurrence in raw water**

Of all PFASs, perfluoroalkyl carboxylic acids (PFCAs,  $C_nF_{2n+1}COOH$ ) and perfluoroalkane sulfonic acids (PFSAs,  $C_nF_{2n+1}SO_3H$ ) have been the most studied for various reasons, including the fact that i) they are highly persistent, ii) they have been directly released into the environment, and iii) they are the ultimate metabolites of many PFASs [1\*\*]. In drinking water sources from non-industrial areas, PFCAs and PFSAs can be detected at the lower ng/L range due to transport over long distances and diffuse sources related to domestic applications [7-9]. However, the highest PFAS concentrations have been recorded near firefighter training areas [8-14], industrial sites making or using PFASs [11,15-21], landfill sites [22], and wastewater treatment plants [7,11] (Fig. 1).

Recent studies have emphasized that the analysis of PFCA and PFSA alone is insufficient to assess an environmental PFAS contamination from point sources. Besides legacy PFCAs and PFSAs, different emerging PFASs have thus recently been identified in the aquatic environment [5\*], including drinking water sources (Table 1). However, probably at least 3,000 PFASs have been available on the global market [2\*]. As it is impossible to individually identify and quantify all of them, novel analytic approaches such as the total precursor assay [23] or the total organic fluorine measurement [24] have been developed. They all aim to highlight the presence of unidentified PFASs in samples, but the interpretation of findings remains problematic in risk assessment terms [9].

Table 1: Emerging PFASs recently detected in drinking water sources and tap water

Name	Acronym	Formula	Concentration range (ng/L)		Reference
			Drinking water sources	Tap water	
Trifluoroacetic acid	TFA	$CF_3COOH$	<30-17,000	<30-11,000	J Janda, et al. [25]
Perfluoro-2-propoxypropanoic acid	PFPrOPrA (GenX)	$C_6HF_{11}O_3$	55-4,560	n.a.	M Sun, et al. [17*]
			n.a.	<0.2-11	WA Gebbink, et al. [18*]
Polyfluoroalkyl carboxylic acids		$C_nH_nF_nO_2$	n.a.	< 1 <sup>a</sup>	WA Gebbink, et al. [18*]
Polyfluoroalkyl sulfonic acids		$C_4H_2F_8SO_3$	n.a.	~ 1 <sup>a</sup>	
Mono-ether perfluoroalkyl carboxylic acids	moPFECAs	$C_nHF_{2n+1}O_3$	Detected but not quantified <sup>b</sup>		M Sun, et al. [17*]
Multi-ether	muPFECAs	$C_nHF_{2n-1}O_n$	Detected but not		

perfluoroalkyl carboxylic acids			quantified <sup>b</sup>		
6:2 Fluorotelomer sulfonic acid	6:2 FTSA	C <sub>8</sub> H <sub>4</sub> F <sub>13</sub> SO <sub>3</sub>	0.32-11.4	n.a.	C Wei, et al. [7]
			<4-66	<4-16	X Dauchy, et al. [10], V Boiteux, et al. [16]
6:2 Fluorotelomer sulfonamide alkylbetaine	6:2 FTAB	C <sub>15</sub> H <sub>20</sub> F <sub>13</sub> N <sub>2</sub> SO <sub>4</sub>	<25-84	<25-32	
Chlorinated perfluoroalkyl ether sulfonate	6:2 Cl-PFAES (F-53B)	C <sub>8</sub> ClF <sub>16</sub> SO <sub>4</sub>	0.17-2.63	n.a.	C Wei, et al. [7]

<sup>a</sup> Estimated concentrations based on structurally similar standards

<sup>b</sup> 1 moPFECA and 2 muPFECAs exhibited peak areas 2-113 times greater than PFPrOPrA (GenX)

### **Removal efficiency of water treatments and PFAS concentrations in tap water**

Several different PFASs are often found together in raw water samples due to the PFAS mixtures used in certain applications, fluorinated impurities contained in products and by-products of environmental transformation [15]. Water treatment technologies therefore have to remove a suite of PFASs with different and specific molecular properties (hydrophobic perfluorinated carbon tail of variable length linked to an anionic, neutral, cationic or zwitterionic functional group).

Traditional treatment technologies (i.e. coagulation, flocculation, sedimentation, sand filtration, biofiltration or UV irradiation) have been shown to be inefficient at removing PFASs [26] (Fig. 1). Granular activated carbon (GAC) filtration can be effective for long-chained PFCAs and PFSAs when the GAC is new. Its removal efficiency depends on the contact time and water quality (competitive effects of ions and dissolved organic carbon) [26-28], and thus requires frequent replacement to avoid breakthrough [29,30]. The removal efficiency of powder activated carbon (PAC) is better than that of GAC because of its smaller particle size, resulting in a larger specific surface area and better accessibility to functional groups [26,30]. Anion exchange resins are more efficient than GAC in terms of total PFAS retention [27-30]. Furthermore, unlike GAC, some of them have the advantage of being easy to regenerate in situ [29]. High-pressure membranes like nanofiltration and reverse osmosis can remove a wide range of PFASs [16,30], but the disposal of highly contaminated eluates/concentrates produced during resin regeneration or treatments using high-pressure membranes remains a crucial issue. PFCAs and PFSAs are both resistant to chlorination and ozonation [15-17\*]. Furthermore, an increase in PFCA concentrations has been observed after ozonation, suggesting the transformation of PFASs containing C-H bonds (e.g. 6:2 FTAS or 6:2 FTAB) into PFCAs [16,17\*,26,31].

Most studies have focused on PFCA and PFSA removal, whereas other PFASs can be present in drinking water sources impacted by point sources. The preliminary data available suggest that the efficient removal of new PFASs can be challenging for conventional drinking water treatments. GAC systems are thus inadequate for the efficient removal of 13 recently discovered PFASs [32]. Negligible removal by a treatment process including coagulation, ozonation, biofiltration and disinfection was observed for PFPrOPrA (GenX) and other perfluoroalkyl mono- and multi-ether carboxylic acids [17\*]. In the Netherlands, the drinking water treatment plants investigated were not able to completely remove PFPrOPrA or 2 polyfluoroalkyl carboxylic acids [18\*]. In a batch experiment, PAC achieved > 50% removal of 2 perfluoroalkyl multi-ether carboxylic acids, but < 40% for other perfluoroalkyl ether carboxylic acids [17\*] tested.

### **Current regulations and guidance values**

The discovery of many different PFASs in raw and drinking water has led several European countries and the U.S. to establish regulatory advisory levels or guidelines [33] that could not be exhaustively cited in this review. Since toxicological data on many PFASs are sparse, most of these provincial and national authorities set regulatory guidelines for perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS). Thus, in 2016, the U.S. Environmental Protection Agency established a lifetime health advisory level at 70 ng/L for the sum of PFOA and PFOS in drinking water. The German Drinking Water Commission recently revised its risk assessment for PFASs, including short-chained PFASs [34].

The Danish Environmental Protection Agency and the National Food Agency of Sweden had an innovative and pragmatic approach in establishing guidance values for the sum of several PFASs frequently found in drinking water. Above these values, PFAS concentrations could pose a health risk and should therefore be reduced and consumers must be advised not to drink the water until these concentrations have been reduced. In Sweden, for instance, a drinking water action level of 90 ng/L has been established for the sum of 3 PFSAs, 7 PFCAs and 6:2 FTSA [33].

In Sweden [13,33], France [10], Germany [6], Italy [35], and the U.S. [14], drinking water sources have been closed down or advanced treatments implemented to lower PFAS concentrations in tap water, either because the guidance values were exceeded or because the precautionary principle was applied in the absence of toxicological knowledge on the PFASs detected.

### **Effects of exposure to contaminated drinking water**

Human exposure to PFASs can occur through contact with consumer products, ingestion or inhalation of house dust particles, or drinking water. However, food—especially seafood and freshwater fish—seems to be the dominant exposure source for the general population [36]. Risk assessment is complicated because the exposure involves many different PFASs, and even more complicated in the case of water tainted by emerging PFASs such as GenX or 6:2 FTAB [37]. Often, only direct exposure to perfluoroalkyl acids (PFAAs), i.e. PFCAs and PFSAs, is taken into account. The uncertainty on the contribution of each of the multiple exposure sources may explain why different PFAA concentrations have been proposed as a limit above which the relative importance of drinking water in overall exposure may be considered significant. Contaminated water can indirectly contribute to human exposure (Fig. 1). Thus, in areas with a history of PFAS-contaminated drinking water, it has been shown that short-chained PFASs can be readily transferred to vegetables via watering [6,38] (Fig. 1).

After drinking tainted water, the human serum levels of some PFAAs in the exposed population have been found to be above those of the general population [13,14,19,20,33,39,40]. A probable link between these higher serum levels of PFAAs and adverse health effects has been mentioned in a series of studies investigating the health effects of PFOA exposure among residents living in six contaminated water districts (the average PFOA concentration was 3.5 µg/L in the most contaminated water district) [41].

### **Conclusions**

Due to their widespread use since the 1950s, their release into the environment and extreme persistency, PFASs have been frequently detected in the raw water of many countries. Conventional drinking water treatments are unable to entirely remove them. In the vicinity of sites heavily impacted by PFAS releases, sometimes remediation simply entailed closing down the water source, with important socioeconomic consequences. Furthermore, the per- and polyfluorinated alternatives to regulated PFASs developed by manufacturers have also recently been detected in water. These novel PFASs are also persistent and recalcitrant to removal from water by conventional treatments, so further research is needed to develop effective water treatments. It is difficult to include novel PFASs in drinking water guidelines since toxicological data for most of these chemicals are still inadequate. At this point in time, regulations based on the precautionary principle and/or chemical properties such as persistency and mobility are the only way to reduce the use and release of such chemicals. It is quite likely that new PFASs will be discovered and detected in the next few years. Although the main PFAS point sources (e.g. manufacturing facilities and firefighter training areas) have now been located and surveyed, this is not the case for landfills where industrial waste containing PFASs was dumped from the '60s to the '80s, a period when waste disposal requirements were not as stringent as now. It is likely that some of these sites will be found out by chance during routine monitoring. It can be challenging to accurately locate a point source, as many other different sources (e.g. biosolid applications, or the textile, paper, electronic and semiconductor industries) can release PFASs into the environment. PFAS contamination of water resources is often irreversible, and condemns important water supplies for many years. Like in other areas (such as the fight against doping in sport), scientific knowledge and regulations do not progress at the same pace as the market.

## References

Papers of particular interest, published within the period of review, have been highlighted as:

\* of special interest

\*\*of outstanding interest

1. Buck RC, Franklin J, Berger U, Conder JM, Cousins IT, de Voogt P, Jensen AA, Kannan K, Mabury SA, van Leeuwen SP: **Perfluoroalkyl and polyfluoroalkyl substances in the environment: terminology, classification, and origins.** *Integrated environmental assessment and management* 2011, **7**:513-541.
2. Wang Z, DeWitt JC, Higgins CP, Cousins IT: **A Never-Ending Story of Per- and Polyfluoroalkyl Substances (PFASs)?** *Environmental Science & Technology* 2017.
3. Prevedouros K, Cousins IT, Buck RC, Korzeniowski SH: **Sources, Fate and Transport of Perfluorocarboxylates.** *Environmental Science & Technology* 2006, **40**:32-44.
4. Kissa E: *Fluorinated Surfactants and Repellents*, vol 97. New York: Marcel Dekker, Inc.; 2001.
5. Xiao F: **Emerging poly- and perfluoroalkyl substances in the aquatic environment: A review of current literature.** *Water Research* 2017, **124**:482-495.
6. Brendel S, Fetter É, Staude C, Vierke L, Biegel-Engler A: **Short-chain perfluoroalkyl acids: environmental concerns and a regulatory strategy under REACH.** *Environmental Sciences Europe* 2018, **30**:9.
7. Wei C, Wang Q, Song X, Chen X, Fan R, Ding D, Liu Y: **Distribution, source identification and health risk assessment of PFASs and two PFOS alternatives in groundwater from non-industrial areas.** *Ecotoxicology and Environmental Safety* 2018, **152**:141-150.
8. Guelfo JL, Adamson DT: **Evaluation of a national data set for insights into sources, composition, and concentrations of per- and polyfluoroalkyl substances (PFASs) in U.S. drinking water.** *Environmental Pollution* 2018, **236**:505-513.

9. Banzhaf S, Filipovic M, Lewis J, Sparrenbom CJ, Barthel R: **A review of contamination of surface-, ground-, and drinking water in Sweden by perfluoroalkyl and polyfluoroalkyl substances (PFASs).** *Ambio* 2017, **46**:335-346.
10. Dauchy X, Boiteux V, Bach C, Rosin C, Munoz J-F: **Per- and polyfluoroalkyl substances in firefighting foam concentrates and water samples collected near sites impacted by the use of these foams.** *Chemosphere* 2017, **183**:53-61.
11. Hu XC, Andrews DQ, Lindstrom AB, Bruton TA, Schaidler LA, Grandjean P, Lohmann R, Carignan CC, Blum A, Balan SA, et al.: **Detection of Poly- and Perfluoroalkyl Substances (PFASs) in U.S. Drinking Water Linked to Industrial Sites, Military Fire Training Areas, and Wastewater Treatment Plants.** *Environmental Science & Technology Letters* 2016, **3**:344-350.
12. Boiteux V, Bach C, Sagres V, Hemard J, Colin A, Rosin C, Munoz J-F, Dauchy X: **Analysis of 29 per- and polyfluorinated compounds in water, sediment, soil and sludge by liquid chromatography–tandem mass spectrometry.** *International Journal of Environmental Analytical Chemistry* 2016, **96**:705-728.
13. Stubleski J, Salihovic S, Lind PM, Lind L, Dunder L, McCleaf P, Eurén K, Ahrens L, Svartengren M, van Bavel B, et al.: **The effect of drinking water contaminated with perfluoroalkyl substances on a 10-year longitudinal trend of plasma levels in an elderly Uppsala cohort.** *Environmental Research* 2017, **159**:95-102.
14. Daly ER, Chan BP, Talbot EA, Nassif J, Bean C, Cavallo SJ, Metcalf E, Simone K, Woolf AD: **Per- and polyfluoroalkyl substance (PFAS) exposure assessment in a community exposed to contaminated drinking water, New Hampshire, 2015.** *International Journal of Hygiene and Environmental Health* 2018.
15. Bach C, Dauchy X, Boiteux V, Colin A, Hemard J, Sagres V, Rosin C, Munoz JF: **The impact of two fluoropolymer manufacturing facilities on downstream contamination of a river and drinking water resources with per- and polyfluoroalkyl substances.** *Environ Sci Pollut Res Int* 2017, **24**:4916-4925.
16. Boiteux V, Dauchy X, Bach C, Colin A, Hemard J, Sagres V, Rosin C, Munoz JF: **Concentrations and patterns of perfluoroalkyl and polyfluoroalkyl substances in a river and three drinking water treatment plants near and far from a major production source.** *Science of the Total Environment* 2017, **583**:393-400.
17. Sun M, Arevalo E, Strynar M, Lindstrom A, Richardson M, Kearns B, Pickett A, Smith C, Knappe DRU: **Legacy and Emerging Perfluoroalkyl Substances Are Important Drinking Water Contaminants in the Cape Fear River Watershed of North Carolina.** *Environmental Science & Technology Letters* 2016, **3**:415-419.
18. Gebbink WA, van Asseldonk L, van Leeuwen SPJ: **Presence of Emerging Per- and Polyfluoroalkyl Substances (PFASs) in River and Drinking Water near a Fluorochemical Production Plant in the Netherlands.** *Environmental Science & Technology* 2017, **51**:11057-11065.
19. Herrick RL, Buckholz J, Biro FM, Calafat AM, Ye X, Xie C, Pinney SM: **Polyfluoroalkyl substance exposure in the Mid-Ohio River Valley, 1991–2012.** *Environmental Pollution* 2017, **228**:50-60.
20. Ingelido AM, Abballe A, Gemma S, Dellatte E, Iacovella N, De Angelis G, Zampaglioni F, Marra V, Miniero R, Valentini S, et al.: **Biomonitoring of perfluorinated compounds in adults exposed to contaminated drinking water in the Veneto Region, Italy.** *Environment International* 2018, **110**:149-159.
21. Tan K-Y, Lu G-H, Piao H-T, Chen S, Jiao X-C, Gai N, Yamazaki E, Yamashita N, Pan J, Yang Y-L: **Current Contamination Status of Perfluoroalkyl Substances in Tapwater from 17 Cities in the Eastern China and Their Correlations with Surface Waters.** *Bulletin of Environmental Contamination and Toxicology* 2017, **99**:224-231.
22. Yan H, Cousins IT, Zhang C, Zhou Q: **Perfluoroalkyl acids in municipal landfill leachates from China: Occurrence, fate during leachate treatment and potential impact on groundwater.** *Science of the Total Environment* 2015, **524-525**:23-31.

23. Houtz EF, Sedlak DL: **Oxidative conversion as a means of detecting precursors to perfluoroalkyl acids in urban runoff.** *Environmental Science and Technology* 2012, **46**:9342-9349.
24. Wagner A, Raue B, Brauch HJ, Worch E, Lange FT: **Determination of adsorbable organic fluorine from aqueous environmental samples by adsorption to polystyrene-divinylbenzene based activated carbon and combustion ion chromatography.** *Journal of Chromatography A* 2013, **1295**:82-89.
25. Janda J, Nödler K, Brauch H-J, Zwiener C, Lange FT: **Robust trace analysis of polar (C2-C8) perfluorinated carboxylic acids by liquid chromatography-tandem mass spectrometry: method development and application to surface water, groundwater and drinking water.** *Environmental Science and Pollution Research* 2018.
26. Pan C-G, Liu Y-S, Ying G-G: **Perfluoroalkyl substances (PFASs) in wastewater treatment plants and drinking water treatment plants: Removal efficiency and exposure risk.** *Water Research* 2016, **106**:562-570.
27. McCleaf P, Englund S, Östlund A, Lindegren K, Wiberg K, Ahrens L: **Removal efficiency of multiple poly- and perfluoroalkyl substances (PFASs) in drinking water using granular activated carbon (GAC) and anion exchange (AE) column tests.** *Water Research* 2017, **120**:77-87.
28. Kothawala DN, Köhler SJ, Östlund A, Wiberg K, Ahrens L: **Influence of dissolved organic matter concentration and composition on the removal efficiency of perfluoroalkyl substances (PFASs) during drinking water treatment.** *Water Research* 2017, **121**:320-328.
29. Zaggia A, Conte L, Falletti L, Fant M, Chiorboli A: **Use of strong anion exchange resins for the removal of perfluoroalkylated substances from contaminated drinking water in batch and continuous pilot plants.** *Water Research* 2016, **91**:137-146.
30. Merino N, Qu Y, Deeb RA, Hawley EL, Hoffmann MR, Mahendra S: **Degradation and Removal Methods for Perfluoroalkyl and Polyfluoroalkyl Substances in Water.** *Environmental Engineering Science* 2016, **33**:615-649.
31. Anumol T, Dagnino S, Vandervort DR, Snyder SA: **Transformation of Polyfluorinated compounds in natural waters by advanced oxidation processes.** *Chemosphere* 2016, **144**:1780-1787.
32. Xiao X, Ulrich BA, Chen B, Higgins CP: **Sorption of Poly- and Perfluoroalkyl Substances (PFASs) Relevant to Aqueous Film-Forming Foam (AFFF)-Impacted Groundwater by Biochars and Activated Carbon.** *Environmental Science & Technology* 2017, **51**:6342-6351.
33. Cousins IT, Vestergren R, Wang Z, Scheringer M, McLachlan MS: **The precautionary principle and chemicals management: The example of perfluoroalkyl acids in groundwater.** *Environment International* 2016, **94**:331-340.
34. Lilienthal H, Dieter HH, Hölzer J, Wilhelm M: **Recent experimental results of effects of perfluoroalkyl substances in laboratory animals – Relation to current regulations and guidance values.** *International Journal of Hygiene and Environmental Health* 2017, **220**:766-775.
35. World Health Organization; Keeping our water clean: the case of water contamination in the Veneto Region, Italy. 2017, 72, [http://www.euro.who.int/\\_\\_data/assets/pdf\\_file/0019/341074/pfas-report-20170606-h1330-print-isbn.pdf?ua=1](http://www.euro.who.int/__data/assets/pdf_file/0019/341074/pfas-report-20170606-h1330-print-isbn.pdf?ua=1)
36. Hansen S, Vestergren R, Herzke D, Melhus M, Evenset A, Hanssen L, Brustad M, Sandanger TM: **Exposure to per- and polyfluoroalkyl substances through the consumption of fish from lakes affected by aqueous film-forming foam emissions — A combined epidemiological and exposure modeling approach. The SAMINOR 2 Clinical Study.** *Environment International* 2016, **94**:272-282.
37. Rand AA, Mabury SA: **Is there a human health risk associated with indirect exposure to perfluoroalkyl carboxylates (PFCAs)?** *Toxicology* 2017, **375**:28-36.
38. Scher DP, Kelly JE, Huset CA, Barry KM, Hoffbeck RW, Yingling VL, Messing RB: **Occurrence of perfluoroalkyl substances (PFAS) in garden produce at homes with a history of PFAS-contaminated drinking water.** *Chemosphere* 2018, **196**:548-555.



39. Fromme H, Wöckner M, Roscher E, Völkel W: **ADONA and perfluoroalkylated substances in plasma samples of German blood donors living in South Germany.** *International Journal of Hygiene and Environmental Health* 2017, **220**:455-460.
40. Bao J, Liu L, Wang X, Jin Y-H, Dong G-H: **Human exposure to perfluoroalkyl substances near a fluorochemical industrial park in China.** *Environmental Science and Pollution Research* 2017, **24**:9194-9201.
41. C8 Science Panel; C8 Probable Link Reports. 2012,  
[http://www.c8sciencepanel.org/prob\\_link.html](http://www.c8sciencepanel.org/prob_link.html)

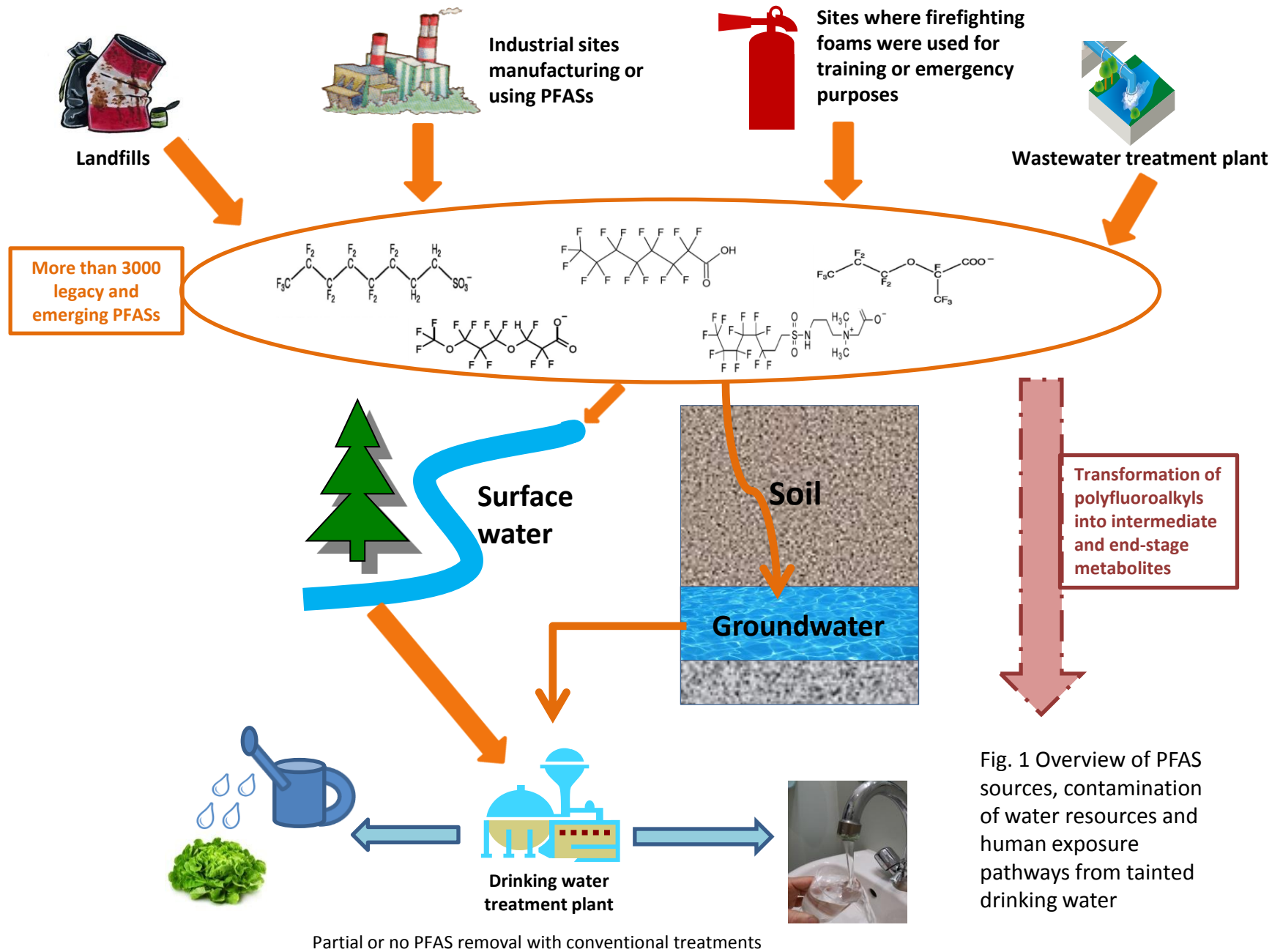


Fig. 1 Overview of PFAS sources, contamination of water resources and human exposure pathways from tainted drinking water