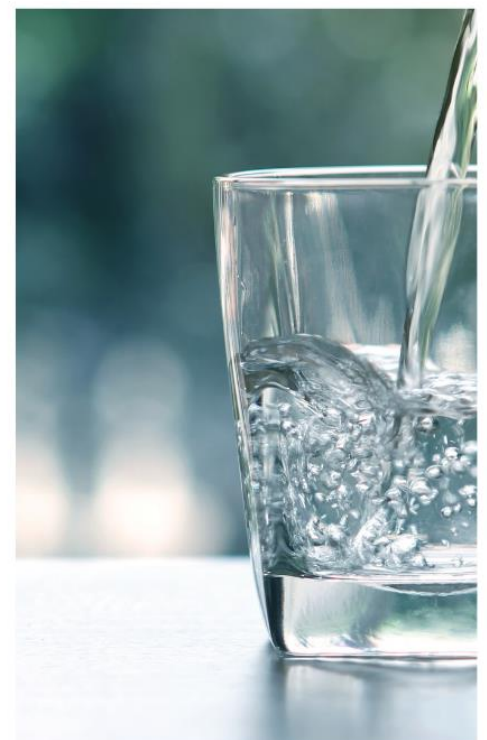


PFAS and drinking water

With case studies reported by EurEau members



Poly- and perfluoroalkyl substances (PFAS) are a diverse group of synthetic fluorinated compounds. Due to the unique surface active properties and very high chemical and thermal stability, these substances have been widely used in many applications in industries and in products that we use in our daily life.

The persistent nature of these substances means that they are very resistant to biodegradation and they are now ubiquitous in the environment, including – sometimes – water sources. Their widespread use in long-life domestic products, particularly carpets and furniture, means that it represents a major legacy issue to be managed.



Summary



Poly- and perfluoroalkyl substances (PFAS) are a diverse group of synthetic fluorinated compounds.

PFAS are a group of contaminants that have gained increased attention due to their potential to bio-accumulate, their environmental persistence, potential toxicity and, for many of them, high water solubility. They have been found in surface water, sediment, air, soil, sludge and ice caps globally, as well as in wildlife and humans. PFAS have also been detected in drinking water as a consequence of the contamination of groundwater or surface water and in the absence of limit values for these substances in water resources¹.

The text of the new Drinking Water Directive, once officially adopted, will regulate PFAS at the end of the pipe: there will be a parametric value for "Sum of PFAS" of 0,1 µg/l or for "PFAS Total" of 0,5 µg/l with which Member States will have to comply.

As things stand today this means that consumers will have to pay for extra treatment of water through their water bills, despite the wording of Art. 191.2 of the Treaty on the Functioning of the European Union, according to which the "*precautionary principle should be applied, preventive action should be taken and the environmental damage should, as a priority, be rectified at source, and the polluter should pay*"².

The affordability of water services will be jeopardised in the long term as we neglect the Polluter Pays Principle in favour of the Consumer Pays Principle.

This end-of-pipe approach is not in line with the EU Green Deal initiatives since extra drinking water treatment will lead to increased energy consumption, CO₂ emissions and complex management of treatment residues.

The following paper details the knowledge that drinking water operators have acquired on PFAS: what they are, why they are problematic for drinking water suppliers, if and how they can be removed from water by various treatments that would shift the problem from water to other media (carbon, concentrate, etc.), creating new challenges. Case studies reported by water operators from various EurEau countries are also gathered.

¹ EurEau position paper on "PFAS in the urban water cycle" <https://bit.ly/3itDKMk>.

² "Study on the feasibility of applying extended producer responsibility to micropollutants and microplastics emitted in the aquatic environment from products during their life cycle" Deloitte (2019) <https://bit.ly/3dQ7cc0>.



1. What are PFAS?

Poly- and perfluoroalkyl substances (PFAS) are a diverse group of synthetic fluorinated compounds. PFAS are aliphatic compounds, where all H atoms, except those in the functional groups, attached to all C (perfluoroalkyl) or to at least one C (polyfluoroalkyl) have been replaced by F atoms. Due to the unique surface active properties and very high chemical and thermal stability imparted by the C-F bonds, these substances have been widely used in many applications in industries and in products that we use in our daily life.



PFAS can bioaccumulate, are persistent and are potentially toxic.

In manufacturing, PFAS are favoured for their durability and well-functioning properties; they provide properties such as non-stick, water repellence and anti-grease to many types of products in domestic use, including skin creams and cosmetics, car and floor polish, rinse aid for dish washers, textile and fabric treatments, food packaging and microwave pop-corn bags, cupcake forms, frying pans, outdoor gear and shoes. They similarly have very many, and widespread, uses in industry, and notably in firefighting foam. The persistent nature of these

substances means that they are very resistant to biodegradation and they are now ubiquitous in the environment. Their widespread use in long-life domestic products, particularly carpets and furniture, means that it represents a major legacy issue to be managed.

Based on the Organisation for Economic Co-operation and Development (OECD, 2018) there are about 4,730 substances, known today, belonging to the big family of PFAS.

The molecules most studied and used in the different industrial sectors are PFOA (CAS no. 335-67-1) and PFOS (CAS no. 1763-23-1).

PFAS, as a group of environmental contaminants, have gained increased attention due to their potential to bio-accumulate, their environmental persistence, potential toxicity and high water solubility for many of them. PFAS have been found in surface water, sediment, air, soil, sludge and ice caps globally, as well as in wildlife and humans.

According to EFSA (2018)³ "Food contributed to 67–84% of the median total intake for PFOA and 88–99% for PFOS using different exposure factors such as the dust ingestion rate. Similarly, the median relative contribution from drinking water varied between 0.57% and 0.68% for PFOS, and 9.1% and 11% for PFOA".

Indeed PFAS have also been detected in drinking water as a consequence of the contamination of groundwater or surface water and in the absence of limit values for these substances to protect water resources.

³ EFSA Journal 2018; 16(12):5194, p. 42).



Key terminology

The family of compounds denoted by the acronym PFAS encompasses:

- ~ Perfluoroalkyl substances, which are defined as aliphatic substances for which all of the H atoms attached to C atoms have been replaced by F atoms, except those in the functional group. This usage is consistent with the definition of "perfluoro" and "perfluorinated". Based on the length of the fluorinated carbon chain, short and long chain PFASs can be distinguished. "Long chain" refers to:
 - ~ perfluorocarboxylic acids (PFCAs) with carbon chain lengths C8 (according to Buck et al. generally accepted) and higher, including perfluorooctanoic acid (PFOA);
 - ~ perfluoroalkane sulfonic acids (PFASs) with carbon chain lengths C6 and higher, including perfluorohexane sulfonic acid (PFHxS) and perfluorooctane sulfonic acid (PFOS); and
 - ~ precursors of these substances that may be produced or present in products.
- ~ Polyfluoroalkyl substances, defined as aliphatic substances, for which all H atoms attached to at least one (but not all) C atoms have been replaced by F atoms, in such a manner that they contain the perfluoroalkyl moiety C_nF_{2n+1} . Thus, whereas the general concept of "polyfluorination" embraces compounds containing "scattered" multiple F atoms, as well as "grouped" ones, we consider that only those polyfluorinated substances having at least one perfluoroalkyl moiety C_nF_{2n+1} belong to the PFAS family.

Polyfluoroalkyl substances have the potential to be transformed abiotically or biotically into perfluoroalkyl substances.

Many authors began using the acronym 'PFC' and defined it in many different ways. As a result, the meaning of the acronym PFC is unclear and not well defined. However, both PFCs and PFASs belong to the overall family of fluorinated chemicals and, hence, are too closely related to share a common acronym. The scientific community adopted the use of the term PFAS as an acronym for "perfluoroalkyl and polyfluoroalkyl substances" and the term PFCs (singular PFC) exclusively for "perfluorocarbons". PFCs are notionally derived from hydrocarbons by replacing all H atoms by F atoms, so that they contain only the element C and F, and functional groups are absent. (OECD, 2013; Buck et al., 2011).

1.1. Physicochemical properties

PFAS comprise both a water-soluble hydrophilic part, the functional group, and a water-insoluble hydrophobic part, the fluorinated carbon chain, which is either linear or branched (Bhatarai and Gramatica, 2010; Buck et al., 2011). As the chain length of the PFAS increases, the water solubility decreases (Bhatarai and Gramatica, 2010). PFAS comprise more than only perfluoroalkyl acids, e.g. zwitterionic surfactants in fire-fighting foams. In addition, the presence of a charged functional group affects the water solubility. Depending on the pH value in the surrounding matrix and the acid dissociation constant (pKa), PFAS with acidic properties may be present in a protonated or anionic form, or a mixture of both (Buck et al., 2011). In natural waters, all perfluoroalkylacids (PFAA) and also telomer acids are dissociated and appear in form of the corresponding anion.



In a sorption study, Ahrens et al. (2010) studied the distribution of PFAS in water, suspended particulate matter and sediment. Short-chain perfluorinated carbonic acids (PFCAs, $C < 7$) were exclusively detected in the dissolved phase, while long-chain PFCAs (C_{7-11}), PFOS, FOSA and perfluorohexane sulfonate (PFHxS) were detected both in the dissolved phase and bound to suspended particulate matter. Long-chain PFCAs ($C > 11$) and perfluorodecane sulfonate (PFDS) were exclusively detected in sediments (Ahrens et al., 2010). Similar results were observed in a study performed by Higgins and Luthy (2006), demonstrating increased $\log K_{oc}$ values with increased carbon chain length, i.e. higher sorption potential of longer chain PFAS than their short-chained equivalents.

1.2. Toxicity

The toxicity of PFAS, particularly PFOA and PFOS, has been extensively evaluated in humans and laboratory animals. However, comparison of the toxicity of PFAS across species is problematic due to differences in elimination half-lives, lack of adequate mechanism data, species differences in the mechanism of toxicity for some endpoints, and differences in the measurement of exposure levels between epidemiology and experimental studies. Substantial differences in the rate of elimination of PFAS exist across species, e.g. for PFOA, the estimated elimination half-life ranges from 8 years in humans to 1.9 hours in female rats. The mechanism of toxicity of PFAS has not been fully elucidated. Although a large number of epidemiology studies have examined the potential of perfluoroalkyl compounds to induce adverse health effects, most of the studies are cross-sectional in design and do not establish causality. Based on a number of factors including the consistency of findings across studies, the available epidemiological studies suggest associations between human exposure to PFAS and several health outcomes:

- ~ pregnancy-induced hypertension/pre-eclampsia (PFOA, PFOS)
- ~ liver damage, as evidenced by increases in serum enzymes and decreases in serum bilirubin levels (PFOA, PFOS, PFHxS)
- ~ increases in serum lipids, particularly total cholesterol and low-density lipoprotein (LDL) cholesterol (PFOA, PFOS, PFNA, PFDeA)
- ~ increased risk of thyroid disease (PFOA, PFOS)
- ~ decreased antibody response to vaccines (PFOA, PFOS, PFHxS, PFDeA)
- ~ increased risk of asthma diagnosis (PFOA)
- ~ increased risk of decreased fertility (PFOA, PFOS)
- ~ small (< 20 g or 0.7 ounces per 1 ng/mL increase in blood PFAS level) decreases in birth weight (PFOA, PFOS).

The International Agency for Research on Cancer (IARC 2017) concluded that PFOA is possibly carcinogenic to humans (Group 2B) and EPA (201 6e, 201 6f) concluded that there was suggestive evidence of the carcinogenic potential of PFOA and PFOS in humans. Increases in testicular and kidney cancer have been observed in highly exposed humans (ATSDR, 2018).

1.3. Regulation

Since 2000 long-chain PFCA, perfluorinated sulfonic acids (PFSAs) and their potential



precursors (Buck et al. 2011), have attracted attention as global contaminants. Long-chain PFAS are problematic because they are highly persistent (Frömel and Knepper, 2010; Parsons et al., 2008), bioaccumulative (Conder et al., 2008), and have been detected ubiquitously in soil, water and air (Rayne and Forest, 2009), biota (Giesy et al., 2001), food items (Clarke and Smith, 2011) and humans (Vestergren and Cousins, 2009). As a result, perfluorooctane sulfonate (PFOS) and related substances based on perfluorooctane sulfonyl fluoride (POSF) were listed under Annex B (restriction of production and use) of the Stockholm Convention in 2009. In 2012, C₁₁-C₁₄ PFCAs were identified as vPvB chemicals (very persistent and very bio-accumulative), and were included in the Candidate List of Substances of Very High Concern under the European chemicals regulation, REACH (ECHA, 2013a). In 2013, also perfluorooctanoic acid (PFOA) and ammonium perfluorooctane (APFO) were listed in the Candidate List of Substances of Very High Concern ECHA (2013).

Since 2013, PFOS and its derivatives have been reported as priority substances under Directive 2013/39/EU of the European Parliament and of the Council of 12 August 2013 amending Directives 2000/60/EC and 2008/105/EC as regards priority substances in the field of water policy.

In May of 2016, the US EPA released lifetime Health Advisories of 0.07 µg/l for PFOA and PFOS (individually or combined) for exposure from drinking water.

The new Drinking Water Directive (2020) establishes a new 'group limit' value for 'Total PFAS' of 0.5 µg/L or the limit for the 'Sum of 20 PFAS' of 0.1 µg/L in drinking water.

In June 2019, the European Council of Ministers (EC, 2019) highlighted the widespread occurrence of PFAS in the environment, products and people, and called for an action plan to eliminate all non-essential uses of PFAS (Cousins et al., 2019).

In the December 2019 Environment Council meeting, The Netherlands announced the preparation of a restriction dossier under REACH for the whole PFAS family concerning all uses and products except where essential. The competent authorities in Denmark, Germany, Sweden and Norway, together with the ECHA (European Chemicals Agency) have indicated their willingness to cooperate. In view of this restriction, Member States

The new Drinking Water Directive (2020) establishes a new 'group limit' value for total PFAS in drinking water.

and stakeholders are invited to share information relevant to such restriction proposal, including information related to health or environment problems caused by PFAS or costs incurred to avoid or remediate them. At the Environment Council meeting, Italy, Austria and France backed the initiative of the Dutch government.



2. Best available techniques for removal of PFAS in Drinking Water Production

PFAS should not be allowed to reach the aquatic environment. However, in the absence of effective control-at-source measures, PFAS are released to the environment through multiple pathways and, locally, may reach drinking water resources. Due to their persistency, concentrations are likely to increase for the years to come and drinking water suppliers will have to be obliged to resort to costly extra-treatment measures to comply with the limits values set in the new Drinking Water Directive (2020).

Different treatment options have been examined to reduce the levels of PFAS in drinking water. Quiñones and Snyder (2009) studied the removal of PFAS (e.g. PFOS, PFOA and PFHxS) using different treatment trains in full-scale water treatment systems, including filtration, ozonation, coagulation/flocculation, and chlorination processes. The study indicated that all tested combinations of treatment processes were ineffective, with no or low reduction in PFAS levels (Quiñones and Snyder, 2009). Similar results can be seen in a study performed by Appleman et al. (2014), and the authors additionally highlight the use of other treatment options, such as reverse osmosis, activated carbon and anion exchange (AE), which have been shown to decrease the PFAS levels in drinking water (Appleman et al., 2014).

2.1. Activated Carbon

Activated carbon is commonly used to adsorb contaminants found in water. It is used to remove synthetic organic chemicals, natural organic compounds, and other compounds affecting taste and odour in drinking water treatment. Adsorption is a physical and chemical process of accumulating a substance at the interface between liquid and solids phases (USEPA, Treatability Database). Activated carbon, which is used in a granular or powdered form, is an effective adsorbent because it is highly porous and provides a large surface area on which contaminants may adsorb. Activated carbon is made from organic materials (e.g. coconut shell, coal, wood) that contain high amounts of carbon (Cummings et al, 2015).

Advantages:

- ~ it retains PFAS and other micropollutants (pesticides, solvents)
- ~ easily scalable (POE / POU, centralised systems, aqueducts)
- ~ it does not require particular technological devices.

Disadvantages:

- ~ considerable differences in abatement for the various types of coal (mineral, or 'plants' such as wood or coconut shells)
- ~ fast saturation (4-8 months) for short chain PFAS e.g. PFBA, but better performance for longer chains e.g. PFOA (13 months)
- ~ boosts prefiltration required
- ~ no indication of the saturation/exhaustion (periodic analyses required, they are difficult and costly)



- ~ impact on operating cost around 0.05 €/m³, excluding possible capital expenditures or/and GAC transportation cost.

2.2. Anion Exchange

Ion exchange involves the use of resins (i.e. very small plastic porous beads with charged functional groups) that are used to exchange undesirable ions with hydrogen cation or hydroxyl anion, to produce potable water. The rate of removal is dependent on the initial concentration of the contaminant, the concentration of competing ions, treatment design (i.e. flow rate, size of resin beads) and the nature of the ions within the beads (ITRC, 2008). Anion exchange has been studied for its ability to remove PFOA, PFNA and PFOS (Cummings et al, 2015).

Advantages

- ~ it retains PFAS and other pollutants (nitrates)
- ~ on-site re-generable material possible (more theoretical advantage than practical though, see disadvantages)
- ~ easy application on small (disposable), medium and large scale (regeneration) (POE / POU, centralised systems).

Disadvantage

- ~ Effective pre-treatment required (sand filtration)
- ~ no indication of exhaustion/saturation (periodic analyses required – they are difficult and costly)
- ~ limited regeneration (only partial regeneration from PFAS); regeneration after 30 min of resin exposure with 10% w/w NaCl almost completely recovered the PFAS adsorption capacity of MIEX
- ~ disposal of regenerating solutions is very problematic
- ~ removal of competitive ions (nitrates, sulphates).

2.3. Reverse Osmosis

Reverse Osmosis (RO) can remove many types of molecules and ions from solutions, and is used in both industrial processes and the production of potable water. For RO treatment of PFAS in drinking water, the result is that the concentrate (PFAS) is retained on the pressurised side of the membrane and the pure solvent (i.e. water) is allowed to pass to the other side.

Advantages

- ~ it retains all PFAS and other pollutants indifferently (pesticides, solvents, metals, ammonium ion, arsenic)
- ~ easy application on small and medium size scale (POE / POU, centralised systems)
- ~ not subject to saturation
- ~ easy clogging monitoring.

Disadvantage

- ~ high water consumption (around 15% of the treated flux)
- ~ strong pre-treatment required



- ~ mineral salts and oligo elements removed (re-mineralisation of drinking water required)
- ~ very expensive maintenance: EurEau estimates the cost for reverse osmosis, specifically, would raise the price of water treatment by between 0.5 and 1 €/m³ (resulting in an increase of the water bill for the average household of over € 100 per year)
- ~ difficult to handle/organise concentrate disposal
- ~ reverse osmosis **does not completely remove the short chain compounds** (e.g. C3)
- ~ **energy consumption** for low pressure reverse osmosis may be up to 1.0 kWh/m³
- ~ reverse osmosis plant with Ultrafiltration pre-treatment (UF/RO) requires 0.310-0.360 kWh/m³.

3. EurEau case-studies

The Veneto Region, Italy

In 2013, it became known that approximately 127,000 people in the Veneto Region of Italy were exposed to PFAS through their drinking water. The contamination had resulted primarily from the industrial emissions of a chemical plant in the area that produces these substances.

The first monitoring of PFAS in Italy started in 2006 through the European Project PERFORCE 2006 that discovered a high concentration of PFOA in the Po River. After this, other Italian projects started, including one project of the Environment Ministry CNR IRSA 2011 2013 that discovered a large-scale contamination of PFAS in the Veneto Region of Italy in 2013, directly affecting groundwater, surface water, drinking water and land in an area of over 200km². One of the sources of the contamination recognised by local authorities has been a fluorochemicals production plant (Miteni) that produced PFAAs since late sixties by electrochemical fluorination. The chemical company Miteni claims that production of PFOS and PFOA stopped in 2011, but their product catalogue still includes PFHxS and PHxSF. Monitoring data collected between 2013 and 2015 additionally identified the following specific long- and short-chain compounds: PFBA, PFPeA PFHxA, PFHpA, PFNA, PFDA, PFUnDA, PFDODA, PFBS, and PFHxS.

The highest concentration of the sum of PFAS was estimated to be 1214 ng/l in groundwater. One pathway of contamination was through waste water emitted from the chemical factory directly into a stream and the surrounding groundwater. The second pathway was from an industrial waste water treatment plant to a canal that drained into the surface waters of the Brenta river.

PFAS contamination was tackled by the Veneto Region with managers and administrators of regional health and national environment authorities.



In the absence of specific limits set for these pollutants by the current Drinking Water Directive 98/83/EC, local authorities established the following performance limits in:

- 0.09 µg/L for PFOA + PFOS, (reduced to 0.04 µg/L in the most contaminated municipalities),
- 0.03 µg/L for PFOS and 0.3 µg/L for the sum of all other PFAS.

One of the big water resources, affected by PFAS and used for drinking water production became a case study to apply the new approach of WSP (water safety plan) in collaboration with ISS (Istituto Superiore della Sanità).

Drinking water investments by Acque del Chiampo

From 2013 to 2018, Acque del Chiampo S.p.A. spent about €560,000 in activated carbon filtering materials and laboratory analysis, about €2,300,000 in the installation of activated carbon filters, water supply networks, laboratory equipment and the development of a UPLC-MS/MS method. This money was spent to remediate the most contaminated sites.

After three months of having discovered the PFAS contamination, the maximum PFOA and PFOS concentrations in drinking water had dropped well below the levels established by the National Institute of Health and local authorities.

For the other sources that are affected by PFAS, Acque del Chiampo is going to spend additional resources for the next years to 2023 with an investment programme of about €21,200,000 (project call PFAS to Zero).

Belgium

In Belgium, traces of PFAS have been found in some drinking water but below 0.1 µg/L, similar to pesticides for which traces are also found.

One study in the northern part of Belgium related to soil and shallow groundwater pollution with PFAS, focused on some sites identified at risk. High concentrations of PFAS in shallow groundwater were mostly found at sites having done or still doing firefighting exercises, as can be expected. These ground waters are not used for drinking water production.

Another study in the southern part of Belgium focused on groundwater monitoring under the WFD showing traces of PFAS well below 0.1 µg/L.

Detection depends on the analytical method used, and for PFAS a detection level as low as 1 ng/L (= 0.001 µg/L) or even lower can be reached, without necessarily implying a hazard for human health according to the health authorities' guidelines.

Some EurEau members (Belgium, France, Germany, Italy, the Netherlands, and Sweden) share their experience with PFAS in water resources.



France

Water resources and tap waters

The French health agency ANSES conducted a specific analysis in 2009 and 2010. The description of the study and the main results are found below.

2009 – Plan to sample 300 water resources with 3 samples in each of the 100 'départements' of the French territory (including overseas such as Guyana, Martinique, etc.): the main resource, one random and one chosen by the local health agency. Plan to sample 200 treated waters from the main production sites and random sites, and if PFAS were detected in the resources. **About 20% of the French population was covered by these analyses. Actually, 262 samples of resources were done. Only 66 samples contained at least one PFAS above the quantification limit.**

2010 – Sampling of the resources and treated water on 69 sites where PFAS were detected in raw waters. **At least one PFAS was above the quantification limit in 45 samples** (therefore, more or less from the 262 sites sampled on resources). However, the concentrations were very low: **almost all the PFAS were below 20 ng/l and the large majority below 10 ng/l**. The detailed results are presented in the table below ('souterraine' means 'underground').

Tableau VII : Nombre de résultats de contamination par classe de concentration pour chaque alkyl perfluoré faisant l'objet du présent avis et analysé dans les eaux traitées lors de la seconde campagne d'analyse du LHN (n = 69)

Sigles	Origine de l'eau	Classes de concentration (ng/L)					
		< 4	> 4 - < 10	> 10 - < 20	> 20 - < 30	> 30 - < 70	> 70
PFBS	surface	37	1	0	0	0	0
	souterraine	28	1	2	0	0	0
PFHxS	surface	34	3	1	0	0	0
	souterraine	21	8	2	0	0	0
PFOS	surface	30	6	2	0	0	0
	souterraine	20	8	2	1	0	0
PFBA	surface	36	2	0	0	0	0
	souterraine	26	4	1	0	0	0
PFPeA	surface	32	5	0	1	0	0
	souterraine	27	1	2	1	0	0
PFHxA	surface	26	10	0	0	1	1
	souterraine	24	2	3	2	0	0
PFHpA	surface	35	2	1	0	0	0
	souterraine	27	2	2	0	0	0
PFOA	surface	33	4	1	0	0	0
	souterraine	26	5	0	0	0	0

Other analysed PFAS not presented in the table:



PFNA: 1 sample "4 – 10 ng/l"; 1 sample "10 – 20 ng/l" and 1 sample "20 – 30 ng/l".

PFDA : no trace in the 69 samples.

Bottled waters

In addition, analysis were carried out in 2013 on 168 samples of bottled water (mineral / source / treated/ still / sparkling) from 150 different resources in 60 different 'departments' of the French territory. The main results are: 8 samples contained at least one PFAS above the quantification limits (localised in 3 *departments*). The graph below shows the molecules and concentrations of PFAS in these 8 samples.

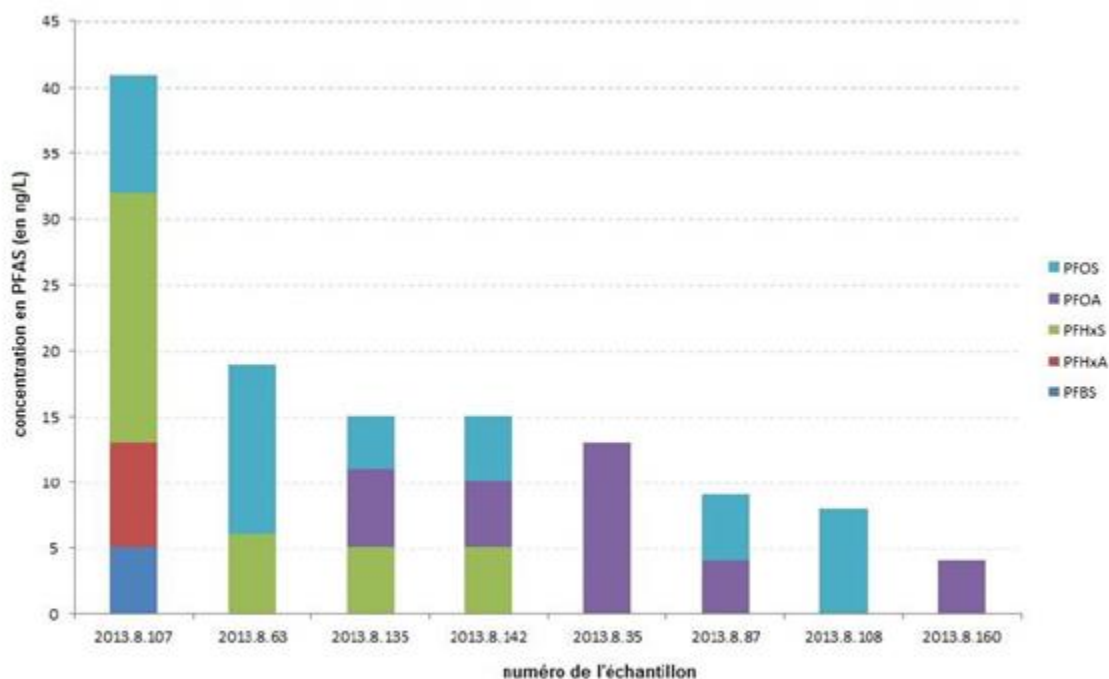


Figure 3 : Distribution des concentrations cumulées en PFAS pour les huit échantillons positifs de l'étude du LHN dans les eaux conditionnées (en ng/L)

Conclusion

These results give a quite complete vision of the situation for the different waters in France. **PFAS were found in about 25% of the water resources and 17% of the treated waters** (considering there is no PFAS in treated water if there is none in the raw water). **The concentrations of individual compounds in treated waters are below 20 ng/l (except rare cases). PFAS were also detected in about 5% of bottled waters.**

The Netherlands

In 2012, the PFAS manufacturer Dupont replaced long-chain PFOA production with the short-chain GenX at their Chemours plant in Dordrecht. While GenX may be less bioaccumulative than its long-chain analogue PFOA, it is more mobile, equally persistent,



and reports filed by Dupont with the USEPA indicated that the replacement chemical may cause some of the same health problems.

GenX from the chemical plant was discharged into the sewer system of the city of Dordrecht. As the waste water treatment plant was unable to remove it from waste water, it was released into the Lower Merwede River. From there it moved to rivers further downstream that act as the drinking water resource for a number of drinking water suppliers in the region. Due to GenX being highly persistent and mobile, neither river bank filtration nor drinking water treatment removed it from the raw water. Its discovery in drinking water provoked a public scandal. Given the chemicals properties and potential risks, Chemours was required to reduce GenX emissions from 6,400 kg/year to a maximum of 20 kg/year in 2020. The company invested in reducing emissions of GenX and organic fluorinated substances, by installing active carbon filters and other technical solutions. Chemours announces that it will even reduce their discharge to 2 kg/year in 2020.

During the research on the sources of PFOA/GenX contamination, it was found that handling (drying), use and disposal of material from the Chemours factory lead to a number of diffuse extra contamination sites affecting waste water treatment plants and drinking water.

Germany

In North Rhine-Westphalia, West-Germany, in May 2006, the application of an illegally contaminated so-called soil improver on agricultural land was detected and caused the release of large quantities of PFCs into the Möhne catchment area, a tributary to the Ruhr River. The Ruhr River, which confluences with the Rhine River, became highly contaminated mainly with PFOA and some other PFCs.

In Baden-Württemberg, South-Germany, in 2017, a major contamination of more than 640 hectares of agricultural crop land and its corresponding groundwater was noticed. This was caused by compost being laced with contaminated paper mud. Groundwater contamination also affected drinking water production. As a consequence, activated carbon filters had to be installed at local water utilities.

There are several contamination sites due to firefighting actions, in particular around airports.

Sweden

In Sweden, 2003, aqueous film-forming foams begun to comprise of a new type of PFAS. A 2013 groundwater quality survey detected high concentration of both long and short-chain PFAS in the Bredåkra delta (Ronneby). The source of the contamination was identified as the fire drill site located in the nearby military airport. Although the water source had a carbon filtering system to reduce the contamination of the drinking water, their effectiveness was hampered once they became saturated. To secure drinking water supply, new pipes were laid between 2013 and 2015 to provide Brantafors, one of the municipal waterworks, with uncontaminated water from the Karlsnäs area. The cost of changing the



water supply from Brantafors to Karlsnäs is roughly estimated to have cost Ronneby municipality €5.8 million. The additional annual cost for increased monitoring is calculated to be around €4,800. The Swedish Chemical Agency (KEMI) and the National Food Agency set up a national PFAS network which brings together a wide range of stakeholders to advance existing knowledge on the issue. A national monitoring exercise of PFAS in the environment compiled around 6,000 measurements of surface and groundwater. Significant water resources remain unusable, nonetheless, for an unforeseeable future due to PFAS contamination. This loss, however, has not been monetised.



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