The SFSE management guideline for PFAS : Contamination sources, Environmental Behavior, Investigations, Risk Assessments and Treatments

Le Guide de Gestion SFSE pour les PFAS : Sources de contamination, comportement environnemental, diagnostics de pollution, évaluations des risques et traitements

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1. Context

The SFSE: Société Francophone de Santé et Environnement (Association of Health and Environment of the French speaking Hemisphere as in Belgium, Canada, France, Luxembourg, Switzerland, African Countries, etc.), created in France in 2008, aims to be the place where knowledge, know-how and let-know can be met on the topic of Environmental Health. At the crossroads of fields as Toxicology, Epidemiology, Expology, Environmental Chemistry, Medicine, Human and Social Sciences, Regulations and Management, Environmental Health cannot be ensured without a Global Approach.

The PFAS show properties of high temperature resistance, chemical stability and waterproofing power are assets for industries and are explained by the strong and stable carbon-fluorine bond. PFAS are used in fire-fighting foams but are also found in everyday products: plasticized paper, food packaging (grease resistant films), various waterproofed clothes and textiles (against rain or dirt), sports equipment, surfactants (allows the emulsion of organic liquids with water), photolithography tools (anti- reflection coating), semiconductors (surface protection), varnishes, paints, adhesives, medical equipment, beauty and hygiene products (shampoo, sun cream). The whole population uses these products on a daily basis and is exposed to PFAS, which is becoming a public health issue.

PFAS production started in the 1940s, mainly by 8 international industries (in alphabetical order): Arkema, Asahi, BASF Corporation, Clariant, Daikin, DuPont, 3M/Dyneon and Solvay/Solexis (ITRC, 2022). Until 2000, the US Company 3 M was the world's largest manufacturer. At the beginning DuPont invented the PFAS chemicals (Poly & Perfluoro Alkyl Substances) in form of Teflon polymers, but 3M became its most important producer. In 2001, a first PFAS pollution scandal occurred in Parkersburg /USA, after discovery of PFAS monomers in drinking water of tens of thousands of people near a DuPont plant. As early as 2004, Per and Poly Fluoro Alkyl Substances (PFAS) were measured in the environment in Scandinavia (Kärrman A., 2019). Since then, environmental pollution linked to PFAS and revealed to the general public in Europe (in Germany in 2014, in Belgium in 2021, in France and in Italy in 2022. In beginning 2023 thousands of FAS contaminated sites were published in Europe, as in France, Germany, Belgium, etc. (cf. Fig.1 - 3).

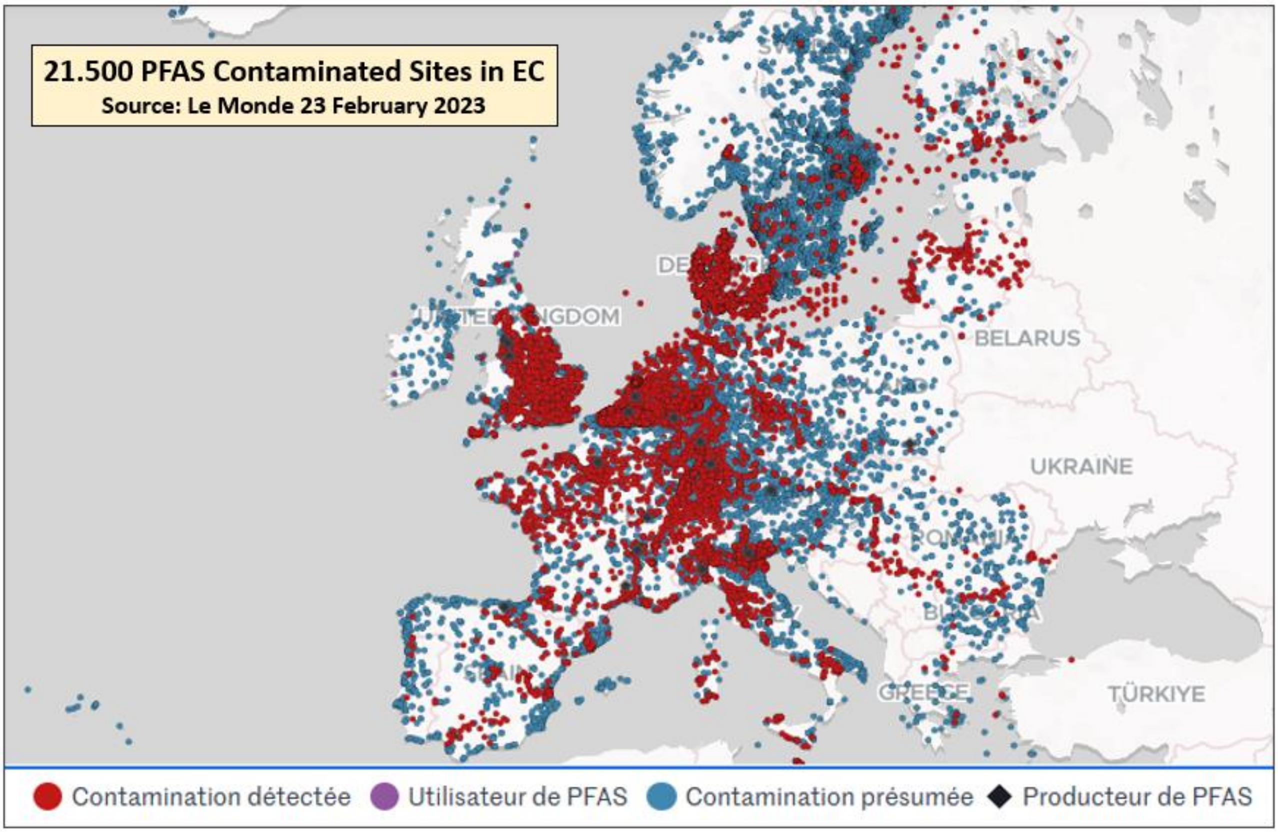

Fig. 1: In total 21.500 PFAS (potential) contaminated Sites in EC are accounted (Source: « Forever Pollution Project », Le Monde 23 February 2023)

All these events have led to an awareness of the impact of this pollution in Environment and impact to Public Health. Thousands of scientific works and publications on PFAS' toxicology, environmental behavior, epidemiology etc. Many scientific publications deal with PFAS but there are still major uncertainties due to scattered data on their behavior or toxicity, as we know in beginning 2023 about a large number of 9 000 – 12 000 existing individual PFAS compounds. In this context of uncertainties and research needs, the Management of an Environmental and Public Health crisis related to PFAS will be complex for the next years.

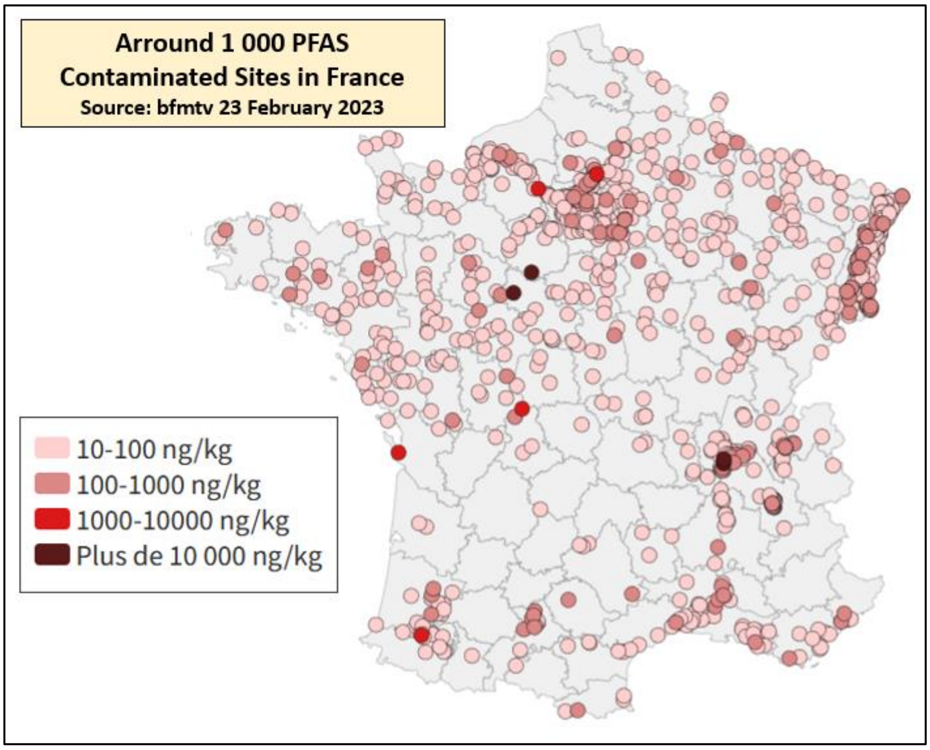

Fig. 2: Around 1 000 PFAS contaminated Sites in France are accounted (Source: bfmtv 23 February 2023)

As a result, PFAS are expected to be present in the environment, in order of importance (ITRC, 2022, Merly C., 2020):

- on fire-fighting training areas (airports, military bases, fire-fighting training sites, oil refineries) where fire-fighting foams (also called AFFF for Aqueous Film-Forming Foam) containing PFAS are used;
- in the factories where they are produced;
- in the industrial processes in which they are used: textiles and leather, paper/cardboard, metallization and galvanization (anti-corrosion action, used to limit workers' exposure to chromium VI aerosols), cable manufacturing, surfactant manufacturing, photolitho-graphy, semiconductors, aeronautics (hydraulic fluids) as well as fire-fighting foam manufacturers ;
- in waste water treatment plants and WWTP sludge used as fertilizer on agricultural land;
- in waste storage facilities or landfills and in their leachate.

Where appropriate, adding PFAS to the list of pollutants to be analyzed in Environmental Samples as soil or groundwater, drinking water or foodstuff is a reflex to be adopted after the historical review of activities, without forgetting the precursors (Poly fluorinated PFAS).

In Europe, the following PFAS production sites indicated high contamination for the local population: in France (Arkema in Lyon), Belgium (3M in Zwijndrecht), Italy (Solvay in Spinetta Marengo), Germany (Flughafen Düsseldorf, NATO Site Bitburg, Agriculture site Rastadt) etc. .

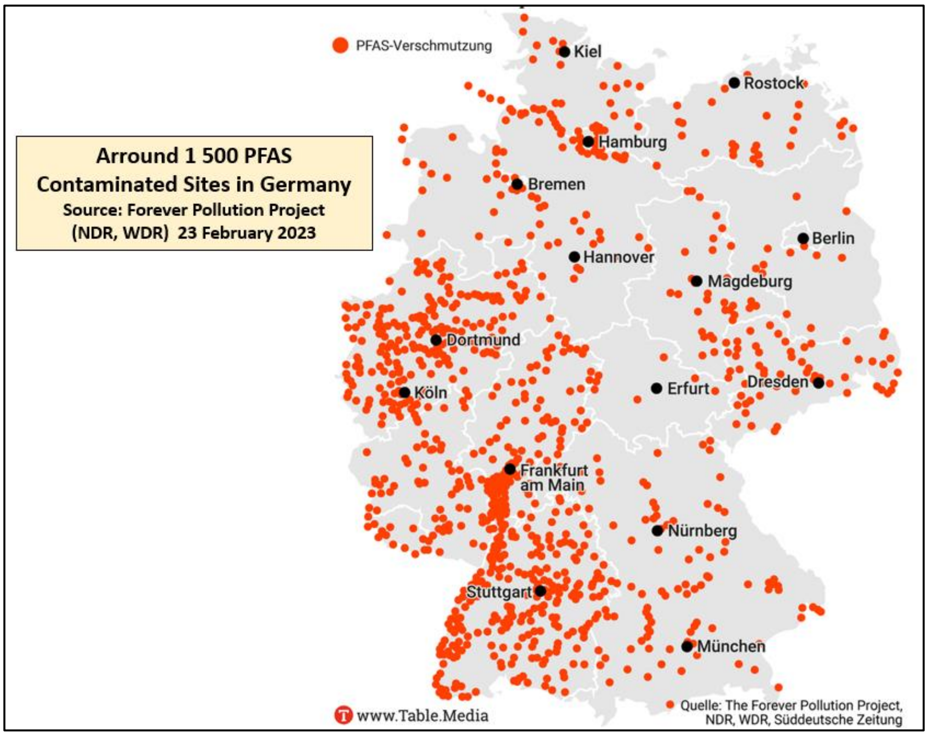

Fig. 3: Around 1 500 PFAS contaminated Sites in Germany are accounted (Source: Forever Pollution Project (NDR, WDR) 23 February 2023)

2. Environmental chemistry: PFOS and PFOA, the tree that hides the forest:

PFAS are compounds containing a chain of hydrophobic carbon and fluorine atoms [CnF2n+1-R] with a hydrophilic functional group at its end, such as a sulphonate (SO^{3-}) or carboxylate (CO^{2-}). They can be present in both ionised and non-ionised forms. Carcinogenic PFOA (Perfluoro- Octanonic-Acid) and PFOS (Perfluoro-Octanonic-Sulfone) are classified as banned POP (Persistent Organic Pollutants by the Stockholm Convention).

Due to their high water solubility and low volatility, most of PFAS are measured mainly in groundwater (rather long chains) and surface water (rather short chains). In the environment (pH between 5 and 9), PFAS are normally present in anionic form, thus explaining their low sorption to soils and sediments (which are negatively charged) and their high solubility in water. Some PFAS, as for ex. Sulfo-betaines as 6:2-FT(S)AB (= Capstone B) or 6:2-FTS (= H4-PFOS), are much more soluble under even only slight alkaline conditions (F. Karg 2022). A very important point is, that poly-fluorinated PFAS (called Precursors) are biotransformed to stable per-fluorinated PFAS. Further biodegradation was not proved up today.

Due to their hydrophilic & hydrophobic character, PFAS tend to accumulate at the water/air interface for surface waters. Their tendency to accumulate at the top of a groundwater table is a current topic of research. With a dispersion potential in groundwater equivalent or even higher than that of benzene and trichloroethene, PFAS are measured over long distances, even at the North Pole. Thus, the sampling strategy should include sampling points far downstream of the source.

Data on saturation vapor pressure (very different depending on the ionised or non-ionised form), Henry's law constant (H) and organic carbon/water partition coefficient (Koc) available in the literature. Some PFAS, as the Fluorotelomer alcohols (FTOH) are volatile.

Physical-chemical data, for ex. mainly for PFOS and PFOA, are very variable and often only exist for the acid form (and not for the salts). In order to better estimate the behavior of PFAS, data related to the appropriate form should be selected and on-site measurement of the adsorption coefficient based on the soil organic carbon content (Koc) is recommended.

Particular care should be taken when collecting PFAS, avoiding the use of materials containing "fluorine" as Teflon, etc. to avoid false positive analysis results. Analytical laboratories encounter difficulties in analyzing PFAS: only about 40 compounds can be quantified normally. Best laboratories could analyze about 500 PFAS compounds, with limits of quantification sometimes higher than the regulatory values and suspicions of interference, increasing the difficulties of interpretation. To compensate for these uncertainties, it is recommended to increase the number of blank and replicate analyses.

3. Toxicology and Health Risk Assessment:

As some PFAS decompose into perfluorinated acids which are more toxic and do not degrade, the precursors should also be analyzed.

Risk assessment: about 40 compounds (only) well known for their effects on human health and for which knowledge is evolving

The risk assessment of PFAS for human health and the environment is complex: it cannot consider the mixing effect of these 9 000 – 12 000 compounds because there are not 9 000 Toxicological Reference Values (TRV). Human toxicity data are principally available for : PFOS, PFOA but also for PFHxA, PFDA and PFNA.

Major toxicological effects are summarized in the following Table (US-EPA: 2021):

	# of Carbons	Liver	Develop-mental	Repro-ductive	Immune	Hema-tologic	Thyroid	Neuro-behavioral	Tumors
Perfluoroalkyl Carboxylates									
PFBA	4	■	■	■	□	■	■	□	□
PFPeA	5	□	□	□	□	□	□	□	□
PFHxA	6	■	■	■	□	■	■	□	□ (Negative)
PFHpA	7	■	□	□	□	□	□	□	□
PFOA	8	■	■	■	■	■	■	■	■
PFNA	9	■	■	■	■	■	■	□	□
PFDA	10	■	■	■	■	■	■	■	□
PFUnA	11	■	■	□	■	□	□	□	□
PFDoA	12	■	■	■	■	■	□	■	□
Perfluoroalkyl Sulfonates									
PFBS	4	■	■	■	■	■	■	□	□
PFHxS	6	■	■	□	□	■	■	■	□
PFOS	8	■	■	■	■	■	■	■	■
Per- & Polyfluoroalkyl Ether Replacements									
ADONA	6	■	■	□	□	■	□	□	□
HFPO-DA GenX	6	■	■	■	■	■	■	□	■

■ Effect reported in one or more laboratory animal study
□ Effect was evaluated but not found, or effect has not been evaluated

The main routes of exposure are ingestion of contaminated drinking water (tap water) or contaminated food. In 2020, EFSA assessed the exposure of the European population to PFAS through food (EFSA, 2020).

Based on 67,839 samples analysed in 16 countries (of which 33,000 analysed in fish), the main exposure to PFAS comes from fish consumption (in particular carp, eel, roach, perch and sardine) followed by fruit and eggs.

The TRV evolve every year with a drastic decrease in the maximum permissible dose for PFOS and PFOA, divided by a factor of 10 in 10 years. Regarding the mixture effect, the RIVM (RIVM, 2018) proposes to use Relative Potency Factors (RPF), according W. Bil (2021) for 12 compounds, based on liver toxicity effects. EFSA (EFSA, 2020) proposes a different 'exposure indicator' approach.

Despite the to improve the health situation by producing shorter-chain PFAS, the results of toxicological studies do not yet provide reassurance that the toxic effects of these alternatives will be reduced.

4. SFSE's PFAS Management Guideline Fact Sheets:

In order to help the authorities, industries, consultancy firms, etc. concerned by this PFAS Pollution Management issues, the SFSE has decided to summarize in a pragmatic manner the available information and to draw up a practical Guideline with Thematic Sheets made available to as many concerned people as possible, , as for ex.:

1. **Fact Sheet 1:** Generalities, identity and Chemistry of PFAS,
   Fiche 1 : Note chapeau : Connaissances générales; identité et chimie des PFAS,
2. **Fact Sheet 2:** Regulations regulatory context of PFAS,
   Fiche 2 : Cadre réglementaire & juridique des PFAS,
3. **Fact Sheet 3:** Contamination Sources of PFAS,
   Fiche 3 : Sources de contamination des PFAS,
4. **Fact Sheet 4:** Environmental behavior and biotransformation of PFAS,
   Fiche 4 : Devenir dans l'environnement et biotransformation des PFAS,
5. **Fact Sheet 5:** Sampling Procedures (soil, groundwater, surface water, soil vapor, ambient air, Human Bio-Monitoring),
   Fiche 5 : Méthodes de prélèvements (sols, eaux souterraines, eaux de surface, gaz du sol, air ambiant, Human Bio-Monitoring),
6. **Fact Sheet 6:** Analysis Methods (soils, groundwater, surface water and others),
   Fiche 6 : Méthodes d'analyses (sols/eaux souterraines/eaux de surface et autres),
7. **Fact Sheet 7:** Chemical Background and Recommendations for definition of chemical backgrounds (data banks),
   Fiche 7 : Bruit de fond et recommandations pour la détermination du bruit de fond (base de données),
8. **Fact Sheet 8:** Environmental Behavior – Physical & chemical Parameters (data banks),
   Fiche 8 : Comportement dans l'environnement – Paramètres physico-chimiques (base des données),

9a. **Fact Sheet 9a:** Toxicity – Toxicological Reference Values,
   Fiche 9a : Toxicité - Valeurs Toxicologiques de Référence (VTR),

9b. **Fact Sheet 9b**: Health Risk Assessments,
   Fiche 9b : Evaluation des Risques Sanitaires (ERS),

10. **Fact Sheet 10:** Consideration of Toxic Effects in case of PFAS Mixtures,
    Fiche 10 : Considération de l'effet toxique de mélange des PFAS,
11. **Fact Sheet 11:** Exposure and Human Bio Monitoring Data (HBM),
    Fiche 11 : Expositions et Données de bio-monitoring humain (HBM),
12. **Fact Sheet 12:** Soil Remediation for PFAS Contaminations,
    Fiche 12 : Méthodes d'assainissement - dépollution des sols,
13. **Fact Sheet 13:** Groundwater Treatments for PFAS Contaminations,
    Fiche 13 : Méthodes d'assainissement - dépollution des eaux souterraines,
14. **Fact Sheet 14:** Soil Vapor and Ambient Air Treatments for PFAS Contaminations,
    Fiche 14 : Méthodes d'assainissement des gaz du sol et de l'air ambiant.

These PFAS SFSE-Fact Sheets will be regularly up-dated and will be made available on https://www.sfse.org/accueil

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