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Experiences with control of PFAS in industries of the world: threshold settings, emission monitoring methods and campaigns

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Summary

The objective of this report is to gather information regarding air and water emissions control of PFAS in the world's industries with the aim of suggesting ways of regulating them. Given the large number of compounds involved, it is necessary to assess which parameters might be relevant, the feasibility in terms of metrology, and the levels that might be relevant. Thus, the report includes the analysis of existing Emission Limit Values (ELVs) and/or Environmental Quality Standards (EQSs), but also a state of the art of monitoring methods, progress of monitoring campaigns and substitutions possibilities.

This report is based on literature review, expertise from Ineris engineers and a benchmark study. Contacts for the benchmark refer to either national government, environmental agency, or technical institutes, including six European countries (Belgium, Italy, Netherlands, Spain, Sweden, France) and five non-European countries (Canada, Japan, Korea, USA, Switzerland). The benchmark was done by sending questionnaires to stakeholders or by performing interviews with Belgium and Japan.

At European level, there is currently no regulation regarding PFAS emissions to air; and only an EQS for PFOS in surface water.
For atmospheric emissions, only one country (The Netherlands) has reported ELVs for three PFAS; in November 2024, 289 additional PFAS have been included to their national list of substances of high concern, with ELV based on vapour pressure. In term of monitoring, methods begin to be developed and harmonised.

Regulation is more advanced with regard to PFAS in water, even though a lot of discussions are ongoing regarding the best way to regulate, in connection with the development of monitoring methods. Wastewater is up until now less investigated than ground- and surface water.

Regarding wastewater, Belgium (Flanders) has reported indicative ELVs for 42 individual compounds; there is no national ELV in force but ELVs have to be determined on a case-by-case basis during permitting for each industrial site, and updated regularly. In Italy, a draft law has been under preparation since 2021 to plan ELVs for 24 individual compounds, for the sum of these individual compounds, and also for a "Total PFAS" parameter; but the promulgation is not yet effective. US-EPA reports that ELVs may be set in permits.

Regarding groundwater, outside Europe, Canada has reported an indicative value for PFOS and Japan is planning values for PFOS and PFOA. In Italy, EQSs are in force for 5 individual compounds. In Sweden, indicative values are proposed to Water Authorities for 11 individual compounds; but a new approach is underway, based on the current discussion for drinking water at European level, that means for 24 individual compounds expressed in equivalent PFOA.

Regarding surface water, some European countries go further than the current European legislation, which concerns only PFOS. In Italy, at national level, EQSs are in force for 5 individual compounds; at the same time, at regional level of Piedmont region, EQSs are in force for 14 individual compounds and 2 groups (called "Other PFASs" molecules with 3-6 carbon atom chains or of 7 carbons atoms or more). In The Netherlands, EQSs are in force for 2 additional individual compounds and in Sweden, 13 compounds are on the list. Canada has an indicative value for PFOS, much higher than current European one. And Japan plans to set EQSs for PFOS and PFOA.

With the growing interest towards this family of thousands of individual compounds, the number of analytical methods available for water matrix increased rapidly during the past decade. 40 individual compounds can now be targeted and most of those methods are now applicable to wastewater. Twelve standardised methods for PFAS analysis in water, based on liquid chromatography coupled with tandem mass spectrometry (LC-MSMS), are listed in the report. Index methods are being

developed in parallel because targeted analysis will never be able to cover the whole PFAS family. There is a method relying on the quantification of Adsorbable Organic Fluorine (AOF), which is the most advanced in terms of harmonisation. Its major drawbacks are the non-specificity (other organic compounds containing fluorine are also included), the high limit of quantification and the potential interferences with other compounds. Other index methods, as TOP assay or non-target screening (NTS), exist but they are currently developed and used mainly for research purposes.
Regarding PFAS in air, several measurement methods are required to adapt both sampling and analysis to PFAS characteristics (volatile, semi-volatile, non-volatile, polar and non-polar forms…). Two American methods cover the measurement of 49 polar semi-volatile PFAS (OTM-45) and 30 non-polar volatile compounds (OTM-50). Development of European methods is based on American ones. There is currently no development of index methods in air.

To improve population protection, the number of individual compounds regulated or monitored is increasing, but the "substances approach" can be questioned due to the high number of compounds, by-products and degradation products; some other parameters such as "Sum of PFAS" or "Total PFAS" begin to appear in legislation. Each approach has its own limitation:

- Listing the individual compounds and calculating a sum is relevant only if adequate compounds have been considered. If not, thresholds are not useful to protect humans and environment. Moreover, the relative toxicity of each compound has to be taken into account through appropriate risk factors; that is why discussions are ongoing at EU level to calculate a response factor based on one compound (usually PFOA).
  For the "Sum of PFAS", reporting of measurements has to be defined precisely as well in order to get comparable results between sites, or to assess compliance with the ELV. It is necessary to define the way to report concentrations below the LoQ for all the sampled fractions and for the different compounds. The harmonisation for the determination of LoQs is also important.
- Setting thresholds for "Total PFAS" does not require the identification of the list of potential compounds but involves being able to measure and interpret this parameter. That is why numerous studies are ongoing to develop index methods, such as AOF, EOF or TOP assay. For the time being, the suitability of these methods is not proven, and they are not harmonised nor standardised.

At EU level, current discussions on PFAS threshold provisions in the Drinking Water Directive, Groundwater Directive, and Environmental Quality Standards Directive, should ensure a consistent approach between standards and monitoring, mainly for Total PFAS. Moreover, the decisions to be taken under the Water Framework Directive to establish EQSs will be fundamental to the harmonised establishment of ELVs. Furthermore, as part of the Sevilla process, BATs on PFAS have been introduced in the recently revised BREFs, but without any associated BAT-AELs. It may be possible to define BAT-AELs in future revisions.

Ongoing developments of methods for PFAS monitoring and of PFAS measurement campaigns (as done or on-going in several countries) will allow to have a better understanding of the situation and set new thresholds in the coming months or years.
Some projects in progress also suggests delving into risk assessment from groups of PFAS with a similar risk profile capitalising on information on exposure, hazard and the use of new risk assessment modelling methods (e.g. Promisces and Parc).

Regarding substitution, the regulatory initiatives currently underway are leading to an ever-increasing inventory of substitution possibilities. And this work suggests:

- that substitution is likely to be complicated in certain sectors, and will require major R&D efforts (medical sector, energy transition),
- that substitution possibilities exist for most applications.

1. Introduction and methodology

Per- and polyfluoroalkyl substances (PFAS) are a group of synthetic organofluorine chemical compounds that pose health and environmental concerns. According to OECD definition, PFAS are fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e., with a few noted exceptions, any chemical with at least a perfluorinated methyl group ($-CF_3$) or a perfluorinated methylene group ($-CF_2-$) is a PFAS. The noted exceptions refer to a carbon atom with a H/Cl/Br/I atom attached to it.
PFAS are not targeted specifically in most Best Available Techniques (BAT) conclusions developed in the Best Available Techniques Reference Documents (BREF) under the Industrial Emission Directive (IED). Only two BAT conclusions (textiles industries and waste treatment) involve BAT covering the monitoring of PFAS.
However, several industrial activities are known or suspected to emit PFAS during their manufacturing processes([1]), including chemical or surface treatment of metals.

The objective of this report is to gather information regarding air and water emissions control of PFAS in the world's industries with the aim of suggesting ways of regulating them. To do this, and given the large number of compounds involved, it is necessary to assess which parameters might be relevant, the feasibility in terms of metrology, and the levels that might be relevant. Thus, the survey includes the analysis of existing ELVs (Emission Limit Values) and/or EQSs (Environmental Quality Standards) at a global scale covering PFAS, their characteristics, but also a state of the art of monitoring methods and substitutions possibilities.

This report is based on literature review, expertise from Ineris engineers and a benchmark study. The latter covers current regulations, mainly existing ELVs/EQSs related to PFAS used in industry. The approaches followed by countries to set threshold values for individual PFAS, their sum or for total PFAS are also assessed. It includes desk research related to best practices on PFAS monitoring, as well as potential measurement campaigns and reporting.
Contacts for the benchmark study have been proposed by EEA and Ineris; they refer to either national government, environmental agency, or technical institutes. A detailed list is provided in Annex 1. European Member States have been selected during exchanges between EEA and Ineris: Belgium (Flanders), Italy, The Netherlands, Spain, Sweden and France were contacted in the framework of this benchmark. Several other countries, outside EU, were also contacted: Canada, Japan, Korea, USA and Switzerland.
The benchmark was done by sending questionnaires to stakeholders in the selected countries. Additional interviews were held with contacts from Belgium and Japan.
The questionnaire is divided into six sections: ELVs, EQSs, Monitoring, Measurement campaigns, Reporting and Status of compounds (for countries outside EU) (see Annex 2).

Findings from the benchmark study and state of regulatory knowledge were first used to describe the regulatory framework. Chapter 2 of the report sets forth an overview of the PFAS regulatory frameworks inside and outside the European Union. One of the aims of the report was to evaluate if EQSs and ELVs should be defined for total PFAS, individual PFAS or for sum of PFAS. To this end, the assessments conducted by the Joint Research Center (JRC) as part of the Water Framework Directive (WFD) and by European Food Safety Agency (EFSA) for Drinking water Directive have been considered. Moreover, materials from the POPs regulation which already bans or restricts several PFAS might be used. In addition, the ongoing PFAS Restriction dossier([2]) led by five Member States is a valuable source of information, both in terms of uses identification and risk management.

([1]) An overview of the uses of per- and polyfluoroalkyl substances (PFAS), Environmental Science: Processes & Impacts 22(12):2345-237, 2020
([2]) Registry of restriction intentions until outcome - ECHA

ELVs/EQSs setting is closely linked to monitoring capacities. Therefore Chapter 3 lists existing methods for monitoring aqueous and atmospheric emissions of PFAS. Their development level (already applied for monitoring or at the development stage), their application field (aqueous/atmospheric emissions, characterisation of individual PFAS or index for total PFAS), where applicable their performance if data is available (limits of quantification, assessment of uncertainties within the framework of interlaboratory comparison etc.), their strengths and limitations are specified.
To gain an overview regarding the PFAS situation in their region, several countries have conducted or are conducting monitoring campaigns. Thus Chapter 4 describes monitoring campaigns carried out in seven of the countries contacted. Some of these campaigns are focused on industrial wastewater providing a better insight of the PFAS contamination by industries.

Output of the benchmark study regarding ELVs and EQSs are gathered in an Excel table supplied with the report. Chapter 5 recaps the major outcomes, with associated values for air and water emissions.

In addition, regarding the industrial sectors where PFAS alternatives have already been identified, substitution will be preferred with the aim of reducing emissions to zero, instead of setting an ELV. Chapter 6 provides an overview as comprehensive as possible of available reports dealing with alternatives to PFAS in various industrial sectors (textiles, food containers, electronics, etc.).

Finally, several ongoing European projects such as PARC, PROMISCES, ZeroPM and NORMAN, dealing with chemicals management and assessment, tackle PFAS. Some work package or tasks are presented in Annex 3, in particular to discuss and suggest read-across approaches for PFAS not already covered by legislation on monitoring.

2. Regulatory framework

2.1 European Union

2.1.1 EU legislation

This section presents an overview of EU legislation (including provisions) for PFAS.

Water Framework Directive (WFD, 2000/60/EC) and Groundwater Directive (GWD, Directive 2006/118/EC)

The Water Framework Directive([3]) (WFD, Directive 2000/60/EC) is the primary legislation for water-related issues in the EU. It is supported by two so-called daughter directives on water quality for surface water and on the quality and quantity regarding groundwater.

The WFD sets in its Annex X the list of priority substances for which good surface water chemical status must be achieved in accordance with WFD Article 4 and Annex V point 1.4.3. The standards to meet to achieve good chemical status are set in the Environmental Quality Standards Directive (EQSD, Directive 2008/105/EC). The WFD also requires Member States to set and meet Environmental Quality Standards (EQSs) for substances of national concern, i.e. pollutants for which monitoring contributes to the assessment of ecological status. The list of priority substances and substances of national concern are regularly reviewed, and updated, if necessary, every 6 years. The last update (Directive 2013/39/EU) introduced new priority substances and adjusted the standards for certain existing substances.

Similarly, the list of pollutants and standards of EU-wide concern in Annex I to the Groundwater Directive([4]) (GWD, Directive 2006/118/EC) must be reviewed every 6 years as well. This list contributes to the assessment of chemical status in groundwater. The GWD also complements the WFD by including requirements that regards pollutant trends and quantitative status.

There are two classes of chemicals: priority substances listed in Annex X([5]) of the WFD (for which emissions need to be reduced progressively) and a subset of priority hazardous substances (for which emissions should also cease). Perfluorooctane sulfonic acid and its derivatives (PFOS) is the only PFAS currently listed in Annex X (it was introduced in 2013 in the WFD). EQSs are set in Annual Average (AA-EQS) and/or in Maximum Allowable Concentration (MAC-EQS) in µg/L for inland and other surface waters and in µg/kg of wet weight for biota (fish). An EQS for PFOS is also established for biota based on risk to human health from consuming fishery products.

In October 2022, the Commission adopted a proposal([6]) to revise the lists of pollutants in surface water and groundwater, including PFAS. One option is to add a sum of 24 individual PFAS substances([7]) to the Priority Substances list as a group with an EQS set for the «sum of» for surface water and groundwater. The EQS for PFAS in this proposal is expressed as PFOA-equivalent based on the relative potencies of the substances compared to PFOA. The Relative Potency Factor (RPF) is defined in the proposition for the whole of the EU for each substance. The RPF approach considers the contribution of each of the 24 PFAS to the total risk, taking account of its relative toxicity compared to PFOA by multiplying the concentration of each PFAS by its RPF. PFAS less potent than PFOA have an RPF lower than 1, otherwise the RPF is set higher than 1. An EQS value of 4.4 ng eq PFOA/l is currently being

([3]) Directive - 2000/60 - EN - Water Framework Directive - EUR-Lex
([4]) Directive - 2006/118 - EN - EUR-Lex
([5]) Water Framework Directive 2000-60, Annex X, Priority Substances - ECHA
([6]) Proposal amending Water Directives - European Commission
([7]) This refers to the following compounds: PFOA, PFOS, PFHxS, PFNA, PFBS, PFHxA, PFBA, PFPeA, PFPeS, PFDA, PFDoDA or PFDoA, PFUnDA or PFUnA, PFHpA, PFTrDA, PFHpS, PFDS, PFTeDA, PFHxDA, PFODA, HFPO-DA or GenX, ADONA, 6:2 FTOH, 8:2 FTOH, C6O4

considered. If the proposal is approved by the Council and the European Parliament, Member States will be required to implement measures to meet the quality standards for the additional pollutants.

Drinking Water Directive (DWD, 2020/2184)

Monitoring of PFAS in drinking water was introduced by European Directive (EU) 2020/2184([8]) of 16 December 2020 concerning the quality of water intended for human consumption. To date, a parametric value (set out in Part B of Annex I to the Directive) of 0.10 µg/L has been set for the sum of 20 PFAS([9]) in drinking water. Additionally, another parameter called "PFAS total" was introduced with a quality limit of 0.50 µg/L, intended to include all measurable PFAS in water.
Member States may decide to use either one or both parameters 'PFAS Total' or 'Sum of PFAS'. They must comply with their limit values by 12 January 2026.

Technical guidelines regarding analytical methods for monitoring of PFAS in water intended for human consumption (C/2024/4910)([10]) have been published in August 2024. "PFAS Total" means the totality of per- and polyfluoroalkyl substances; it is a typical sum parameter and all recommended methods can deliver useful results and a proxy for measuring it. In the guidelines, three methods, neither standardised nor harmonized, are recommended (see Chapter 3): Total oxidizable precursor assay (TOP assay), Combustion ion chromatography after extraction of fluorine (EOF-CIC) and Liquid chromatography high resolution mass spectrometry (LC-HRMS suspect and non-target analysis).
The 20 identified PFAS[6] to be analysed, as listed in this Directive, are important because several further other regulations follow this list.

Discrepancies between Drinking Water Directive and Water Framework Directive (and its daughter directives: Groundwater Directive and Environmental Quality Standards Directive):

Having noted discrepancies with regards to PFAS threshold provisions, the European Parliament adopted on 12 September 2023 an amendment([11]) seeking regulatory alignment with the aim to ensure a consistent approach between standards and monitoring methods across the EU, in particular regarding Total PFAS. The text has been amended with the following wording «*6a. By 12 January 2025, the Commission shall establish technical guidelines regarding methods of analysis for monitoring of per- and polyfluoroalkyl substances under the parameters 'PFAS Total'. The Commission is empowered to adopt delegated acts in accordance with Article 8a amending this Directive by setting a quality standard for 'PFAS total' and amend Annex I accordingly. The Commission shall adopt these delegated acts by 12 January 2026*.»
To date, this recommendation is still under debate in the context of the update of the Water Framework Directive and its daughter directives.

REACH

EU Regulation N° 1907/2006([12]) concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) includes in its article 57 provisions for the identification of Substances of Very High Concern (SVHC) which contain chemical substances fulfilling at least one criteria related to the following adverse effects in organisms/environments or properties: carcinogenic, mutagenic and toxic

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([8]) European Drinking Water Directive
([9]) This refers to the 20 following compounds: PFBA, PFPA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFTrDA, PFBS, PFPS, PFHxS, PFHpS, PFOS, PFNS, PFDS, Perfluoroundecane sulfonic acid, Perfluorododecane sulfonic acid and Perfluorotridecane sulfonic acid
([10]) European Commission, Technical guidelines regarding methods of analysis for monitoring PFAS in water for human consumption
([11]) Amendments adopted by the European Parliament on 12 September 2023 - EUR-Lex
([12]) Reach Regulation N°1907/2006 - EUR-Lex

for reproduction (CMRs); persistent, bioaccumulative and toxic (PBT) or very Persistent and very Bioaccumulative (vPvB).
These SVHC are placed on the candidate list for authorisation (Annex XIV). In addition, marketing and use restrictions apply to substances listed in Annex XVII of the regulation.
On 4 July 2020, restrictions on the use, import and production of PFOA, its salts and derivatives came into effect with thresholds specific to their applications (N° 2019/1021, N° 2020/784).
Perfluorocarboxylic acids (C9-14 PFCAs), their salts and related substances have been restricted in the EU/EEA since February 2023, following a decision by the European Commission.
Undecafluorohexanoic acid, as named by the Commission (or Perfluorohexanoic acid PFHxA), its salts and related substances, will face restrictions in the EU/EEA starting in April 2026. This decision([13]) by the European Commission, taken in September 2024, is based on a proposal from the German authorities (2019), with ECHA's scientific committees adopting their opinion on it in 2021.

In June 2019, January 2020 and January 2023, three groups of PFAS were identified as SVHCs. These groups are:

- 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propionic acid, its salts and its acyl halides (HFPO-DA), a short-chain PFAS substitute for PFOA in fluoropolymer production. Its ammonium salt is commonly known as GenX;
- perfluorobutane sulfonic acid (PFBS) and its salts, a replacement of PFOS;
- perfluoroheptanoic acid (PFHpA) and its salts.

The approach to regulate authorisations/restrictions has evolved and is now addressed by substance group rather than individual PFAS by PFAS.
The national authorities of Germany, Denmark, the Netherlands, Norway and Sweden are proposing a restriction covering a wide range of PFAS uses – in support of the statements made at the Environment Council in December 2019. They submitted their proposal to ECHA in January 2023, and ECHA's scientific committees are now evaluating it([14]).

Best Available Techniques Reference Documents (BREFs) – Industrial emissions Directive (IED)

BREFs are developed for specific industrial activities in the scope of Directive 2010/75/EU (industrial emissions Directive, IED([15])) through information exchange among EU Member States, relevant industries, non-governmental organisations, and the Commission, as mandated by Article 13(1) of the IED on Industrial Emissions (now amended by EU Directive 2024/1785([16])).
For each specific sector, the BREF document outlines the applied techniques, current emissions and consumption levels, techniques to be considered for determining the best available techniques and the associated binding emission levels.
For the time being, the BAT conclusions containing BAT covering PFAS are those relating to metal surface treatment (STM), the textile industry (TXT) and waste treatment (WT).
The BREF STM([17]), published in 2006, sets out generic BATs for the use of PFOS.
In the TXT BAT conclusions([18]), BAT8 defines monitoring requirements for PFAS in wastewater. In this BAT8, PFAS water emissions should be monitored at least once every 3 months and according to CEN standards (which do not exist yet). If there were no EN standards then BAT is to apply ISO or national

([13]) Commission restricts use of a sub-group of PFAS chemicals
([14]) Next steps for PFAS restriction proposal - ECHA, March 2024
([15]) Directive EU - 2010/75 - EUR-Lex
([16]) Directive EU - 2024/1785 - EUR-Lex
([17]) BREF Surface Treatment of Metals and Plastics, August 2006
([18]) COMMISSION IMPLEMENTING DECISION (EU) 2022/2508 of 9 December 2022 establishing the best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions, for the textiles industry

or international rules that guarantee the obtention of data with the same quality. It is stated: «The monitoring only applies when the substance(s)/parameter(s) (including groups of substances or individual substances in a group of substances) concerned is identified as relevant in the wastewater stream, based on the inventory of inputs and outputs mentioned in BAT 2.»
The actual TXT BREF([19]), section 3.4.14 includes two ISO standards:

- «ISO 21675 - Water quality — Determination of perfluoroalkyl and polyfluoroalkyl substances (PFAS) in water — Method using solid phase extraction and liquid chromatography-tandem mass spectrometry (LC-MS/MS)»
- «ISO 25101 - Water quality — Determination of perfluorooctanesulfonate (PFOS) and perfluorooctanoate (PFOA) — Method for unfiltered samples using solid phase extraction and liquid chromatography/mass spectrometry».

Table 3.6 «Perfluorocarbons emissions to water» of the TXT BREF also mentions measurement techniques such as:

- DIN 38407-42 in Germany for PFOS, PFOA and PFHxA,
- CEN/TS15968 in Italy (Determination of extractable perfluorooctanesulphonate (PFOS) in coated and impregnated solid articles, liquids and firefighting foams, withdrawn in November 2023),
- WAC/IV/A/025 in Belgium for PFOS, PFOA, PFHxA, PFHpA.

In WT BAT([20]) conclusions, BAT7 tackles monitoring emissions to water. In this BAT7, PFOS and PFOA emissions in water should be monitored at least once every 6 months and according to EN standards. It is specified: "The monitoring only applies when the substance concerned is identified as relevant in the wastewater inventory mentioned in BAT 3". As in TXT BAT, if EN standards are not available, BAT is to use ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality.
There are currently no BATs for PFAS in atmospheric emissions.

Reporting under the Industrial emissions Portal Regulation

The industrial emissions Portal Regulation (Regulation 2024/1244([21])) which replaces the E-PRTR Regulation (166/2006) and enters into force in 2028 is a Regulation where industrial activities, mostly in the scope of the IED are required to report their emissions, waste and pollutant transfers and other information. Annex I includes the list of activities in the scope and annex II has the list of pollutants and thresholds above which emissions need to be reported in annual load (normally kg per year).

In this Regulation there are three new pollutants in annex II, two of which are PFAS:

- Perfluorooctanoic acid (PFOA) and its salts with a threshold of 1kg per year for air, water and soil emissions.
- Perfluorohexane-1-sulfonic acid (PFHxS) and its salts with the same threshold as PFOA above.

Article 13(a) of the Regulation also establishes that the Commission, assisted by the EEA and in consultation with Member States, should draw up and periodically update guidance supporting the implementation of this Regulation, addressing among other things:

> Reporting procedures, with particular attention to be paid to provisions that were not part of Regulation (EC) No 166/2006 and sectors that were not covered by that Regulation, including technical guidelines regarding **methods facilitating analysis for monitoring of PFAS, such as detection limits, parametric values and frequency of sampling**.

([19]) BREF for Textiles Industry, December 2022
([20]) COMMISSION IMPLEMENTING DECISION (EU) 2018/1147 of 10 August 2018 establishing best available techniques (BAT) conclusions for waste treatment, under Directive 2010/75/EU of the European Parliament and of the Council
([21]) https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202401244

The new Regulation offers the possibility to update annex II and its thresholds via delegated acts. This means that more PFAS could be added to the scope in the future.

2.1.2 National regulations in EU Member States

This information was gathered through interviews and questionnaires and covers the way PFAS are regulated in surface waters and industrial discharges.
Where thresholds exist, they are given in paragraph 5 and in the attached summary table.

Belgium (Flanders)

Regarding permitting of industrial installations, general binding rules are defined in Flemish Regulations on Environmental Permitting called VLAREM (in particular Part 4. General Environmental Conditions for Classified Establishments). In general, permits are granted by local competent authorities, except for incineration that are decided by national authorities. Relevant advisory bodies do support competent authorities. In permits, ELVs are associated with deadlines and objectives.

For air emissions, the Flemish administration is still working to draft ELVs for PFAS to be used in permits. There are no general binding rules so far.
For air, Flanders focuses on the Air Quality Directive 2024/2881([22]); and no PFAS EQS is set for air.

For water emissions, ELVs for PFAS are established in permits. Indeed, the discharging of industrial wastewater and cooling water refer to VLAREM, Part 4, Section 4.2.3. The discharging of industrial wastewater containing one or more hazardous substances([23]); hazardous substances cannot be emitted without a permit –meaning that, for PFAS, ELVs are needed in permits if the substances are emitted above the limit of quantification (LoQ) of the measurement methodology. LoQ to consider are defined in Article 4, Annex 4.2.5.4, Titel II of VLAREM([24]). Not all PFAS are hazardous regarding CLP classification, but during discussions with industries, they are now all considered as hazardous.
PFAS ELVs for water emissions are permitted for a limited time (e.g. 2 years) – within this timeframe the operator must tackle the source of the problem (substitution…) or apply for a new permit and motivate why PFAS are still present in the industrial wastewater. Some examples of permits have been received and give different specific ELVs for each plant. There is an obligation for companies to carry out technical-economic study to reduce/substitute PFAS; industries have transition periods (linked with a maximum duration of permits of 2 years). The goal is for emissions to be below the LoQ of the measurement methodology. On global level and long-term view, the aim is to eliminate PFAS.

ELVs are currently only given for individual compounds, not for total PFAS and for PFAS that can be measured using the Flemish measurement methodology, described in section 3.

Regarding EQS for surface and transitional water, PFOS EQS from the Water Framework Directive is implemented via attachment 2.3.1 of VLAREM II ([25]) and no other PFAS is added.

Italy

In Italy the issue of PFAS is a current one with pollution observed in several regions of the country. And it is not yet regulated from a legislative point of view.
The Italian Parliament is currently discussing the introduction of limits on wastewater discharge (Draft Law N°. 2392([26]) "Urgent measures for the reduction of pollution from poly and perfluoroalkyl

([22]) Directive - EU - 2024/2881 - EN - EUR-Lex
([23]) VLAREM, Discharge of industrial wastewater containing one or more hazardous substances
([24]) VLAREM, Annex 4.2.5.2, Titel II
([25]) VLAREM, Basic environmental quality standards for surface water
([26]) Draft Law No. 2392, Italy

substances (PFAS) and for the improvement of the quality of water intended for human consumption"). At the moment, this regulation has not yet been approved.

In the meantime, the Piedmont Region, while awaiting the national regulation, approved a regional law, LR 25/2021(([27]) which, in article 74, regulates the discharge of perfluoroalkyl substances and, in the annex A, defines "Emission limit values (ELVs) for PFAS in discharges to surface waters (µg/L)". In this law, the Region has deemed, applying the precautionary principle, to use for PFOS as a limit value for wastewater, the AA-EQS Inland Surface Water in Directive 2008/105/EC of the European Parliament. To implement the Regional Law, the subsequent decree n° 60-5220 of 14 June 2022 provided operational instructions on the application of article 74 of Regional Law 25/2021, which established limit values for the discharge of PFAS into surface waters throughout the regional territory.

According to our understanding, there are two additional regulations mentioned in the SNPA guideline n° 305/2019, which are active; confirmation has been asked to Italian contacts:

- Legislative Decree N° 172 of October 13, 2015 (Implementation of Directive 2013/39/EU amending Directive 2000/60/EC as regards priority substances in the field of water policy):
  In table 1/B, AA-EQS for Inland surface waters and other surface waters are specified for PFBA, PFPeA, PFHxA, PFBS and PFOA in addition to PFOS.
- Decree July 6, 2016 (Transposition of Commission Directive 2014/80/EU of June 20, 2014 amending Annex II to Directive 2006/118/EC of the European Parliament and of the Council on the protection of groundwater against pollution and deterioration):
  In table "Tabella 3 — Valori soglia da considerare per la valutazione dello stato chimico delle acque sotterranee", EQSs are specified for groundwater (PFPeA, PFHxA, PFBS, PFOA, PFOS) and for surface water (PFOA, PFOS).

The Netherlands

The Dutch policy on substances([28]) provides a special approach for substances that meet the criteria of REACH article 57f([29]). These are included on a national list of substances of high concern (in Dutch: Zeer Zorgwekkende Stoffen, abbreviated as ZZS). Note that the ZZS-list is broader than the Annex XIV REACH. E.g., CMR substances fall under the national substances of high concern because they meet the criteria of REACH Article 57f, even when they are not assigned as SVHC.
For ZZS, industries should investigate the options of a source-oriented approach, by e.g. substitution or optimising/adapting processes. Any remaining emissions should be minimised according to best available techniques, and authorities have the option to request additional measures (BAT+).
Authorities judge the resulting immission([30]) against environmental immission limits.

Regarding emissions to air, ELVs in the Netherlands exist for three classes of industrial chemicals([31]). Assignment to a class depends on hazard characteristics of the chemical in question and on physico-chemical characteristics. Stringent ELVs are set for ZZS, thus also to some individual PFAS (PFOS, PFOA and HFPO-DA) described in Annex III of the Besluit activiteiten leefomgeving([32]). As from November 2024, the whole group of PFAS is declared ZZS([33]), following the decision of OSPAR to include PFAS as defined by OECD([34]) to the List of Chemicals for Priority Action (LCPA). Since LCPA-chemicals are ZZS

([27]) Regional Law 25/2021, Piedmont Region, Italy
([28]) Living Environment Activities Decree, Netherlands
([29]) Regulation - 1907/2006 - EN - REACH - EUR-Lex (europa.eu)
([30]) Emission is the quantity of pollutant emitted by the source, whereas immission is the quantity of pollutant in the environment, resulting from the emission.
([31]) Substances of very high concern and air, Information Point, Netherlands
([32]) Living Environment Activities Decree, Annex III Dust Classes, Netherlands
([33]) Problematiek rondom stikstof en PFAS | Tweede Kamer der Staten-Generaal
([34]) Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances, OECD, July 2021

by definition([35]), these PFAS are included in the ZZS-list on RIVM's website([36]) and Annex III will have to be updated.

Immission limits in local air should be met, which represent the concentration in air at which no unacceptable effects for humans are anticipated upon lifetime exposure. Such immission limits have not been set for PFAS.

Regarding emissions to water, similar to air, chemicals are assigned to one of four different categories based on hazard characteristics. The category reflects the level of the required decontamination effort for discharges based on the properties of substances. ZZS fall in the Z-category for which highest decontamination efforts are required, meaning that higher financial investments can be asked from industry.

Remaining discharges after minimisation are judged against water quality standards using a mixing zone approach.

At present, officially set EQSs in surface water for PFAS are limited to PFOS([37]), PFOA([38]) and HFPO-DA([39]) (also called GenX). Revised risk limits for PFAS have been proposed by RIVM (RIVM-briefrapport 2022-0074([40])); they represent the concentration in surface water which is protective for lifetime consumption of fish by humans based on health-based limit value derived by European Food Safety Authority([41]) (EFSA) in 2020. Proposed values by RIVM refer to total PFAS using the Relative Potency Factor-approach, and consider bioaccumulation potential relative to PFOA. However, the values as proposed by RIVM are not implemented as officially set national EQS. It is expected that European-wide EQS for PFAS will set under the WFD as proposed by the Commission.

Apart from European-wide EQSs, additional EQS may be set on national level when needed for e.g., discharge permitting. If no EQS is available, the local authority can approach RIVM for advice on risk limits and decide on using the risk limits for permitting, even when it's not formally set as EQS. In general, it is the intention that environmental risk limits as derived by RIVM are formalised, but this depends on policy.

Spain

Spain indicated that only (or mainly) distributors of PFAS are present on the territory, not producers. There is not additional regulation above EU regulation.

France

An interministerial action plan on PFAS([42]), published in April 2024, integrates and replaces the Ministry of Ecological Transition and Territorial Cohesion's 2023-2027 actions plan, published in January 2023, on the same subject.

This plan is organised around five main lines of action:

- Develop methods for measuring emissions, environmental contamination and impregnation of humans and other living organisms;

([35]) Identificatie Zeer Zorgwekkende Stoffen | Risico's van stoffen (rivm.nl)
([36]) Total list of Substances of Very High Concern, RIVM
([37]) Decree on the quality of the living environement, Annex III (environmental values for the good chemical status of surface water body), Netherlands
([38]) PFOA information, RIVM
([39]) HFPO-DA information, RIVM
([40]) Risk limits for PFAS in surface water. Translation of EFSA's health-based limit value to concentrations in water, RIVM, 2022
([41]) PFAS in food: EFSA assesses risks and sets tolerable intake | EFSA
([42]) Interministerial action plan on PFAS, April 2024, France

- Develop robust exposure assessment scenarios for organisms (humans and other living organisms), taking into account the multiple routes (ingestion, inhalation, skin contact) and sources of exposure to ubiquitous PFAS pollutants;
- Strengthen emission monitoring systems;
- Reduce the risks associated with exposure to PFAS; innovate by involving economic players and supporting research;
- Improve information for the public, to take better action.

No specific EQSs or ELVs are currently defined at national level, ELVs are specified on a case-by-case basis in permits for relevant activities (for example for PFAS producers). The results of the ongoing monitoring campaign in industrial waste waters (see 4.3 France) might enable the definition of the ELVs/monitoring requirements.

Sweden

PFAS- pollution affects many actors in the Swedish society, and therefore, several different authorities are involved in handling the variety of PFAS related issues., depending on the context. In 2014, an informal network was formed, nowadays consisting of 14 different authorities, sharing information on PFAS. The role relating to PFAS, of three of those authorities are briefly described below.

The Swedish EPA is responsible for environmental issues regarding e.g. emissions from industries, contaminated soil/groundwater, legislation on the professional use of chemicals and is also one of several authorities that are responsible for environmental monitoring of PFAS and other environmental pollutants. An overview of the PFAS-work is provided at the Swedish EPA's website([43]).
The Swedish Chemicals Agency (KEMI Kemikalieinspektionen) is responsible for the rules on PFAS that apply to how the substances are used and their introduction on the market. Their website([44]) supplies information on e.g. sectors and activities that use (or have used) PFAS.
The Swedish Food Agency assesses the risks of PFAS in drinking water and food and develops limit values and requirements for chemicals to which drinking water producers are bound. The Swedish Food Agency also provides recommendations on how the risks should be managed. These recommendations target drinking water producers, local enforcement authorities and small drinking water producers for private use. Their website([45]) provides e.g. recommendations and information to consumers on drinking water and food.

In Sweden, there are no general regulations on PFAS emission for specific sectors and there are only a few examples of installations with permits that regulate PFAS through emission limit values and/or monitoring. In general, all activities, are obliged to comply with the indicative EQSs as implemented in the Swedish framework law, the Environmental Code. Hence, every actor/activity should monitor their emissions and apply measurements necessary to comply with the indicative EQSs. In Sweden, compliance of the environmental and chemicals legislation is controlled mainly by local and regional enforcement agencies, i.e. the municipal environmental boards and the county administrative boards respectively.

In Sweden, there are drinking and ground water quality standards as a part of the implementation of the EU drinking water and ground water directives, as well as limit values for certain foodstuffs implemented through commission regulation (EU) 2022/2388. Also, there are national limit values of PFAS in soil, and as for the quality standards the limit value in soil is not related to ELV in media (eg. Air/water) emitted from operators, but having the objective of ensuring safe remediation of PFAS-

([43]) Information on PFAS issues, Swedish Environmental Protection Agency
([44]) Information on PFAS, Swedish Chemicals Agency
([45]) PFAS and other environmental toxins in drinking water and food - control, Swedish Food Agency

contaminated soil. A table([46]) established by Swedish authorities in February 2024 summarizes limit values for different matrices. To provide a broad and easy-to-understand guide to introduce the PFAS issue to non-experts, KEMI published an overview of knowledge on PFAS([47]) in 2022.

Some of the historically most important sectors, where high levels have been identified, are firefighting equipment sites, airports/airfields and landfills. There are some examples of specific emissions monitoring requirements in permits at facility-level in these sectors. In addition, few landfills have ELVs, or at least provisional ELVs for PFAS in some form. For example, there are some facilities discharging to REVAQ-certified WWTP (private actor) that have PFAS water ELVs. In 2022, the EPA, together with regional authorities in Sweden produced guidance on PFAS in landfills([48]). Some municipalities, for pragmatic reasons, use the Swedish EQS for surface water (health based in relation to drinking water) as an ELV when for example discharging contaminated water collected from firefighting operations.

Another relevant sector is combustion and/or incineration plants. A report on PFAS emission during incineration([49]), primarily looking at PFAS in ashes and condensate after the flue gas condenser has been published in 2021 by IVL Swedish Environmental Research Institute. Research on the incineration of mixed municipal waste at Umeå University is ongoing; their latest publication is about the issue of Emission of Per- and Polyfluoroalkyl Substances from a Waste-to-Energy (WtE) Plant([50]): their results demonstrate that some PFAS are not fully degraded by the high temperatures during WtE conversion and can be emitted from the plant via ash, gypsum, treated process water, and flue gas. More information on this issue will be available in the near future.

A recently added sector, in relation to PFAS-emissions in Sweden, is the production and recycling of lithium-ion batteries. PFAS have been identified in this sector as a potential chemical risk (Section 1.1 of the 2023 annual report of the Toxicological Councils([51])). Production and recycling facilities of lithium-ion batteries and facilities handling this type of waste downstream will most likely have ELVs on PFAS in their permits.

2.2 Outside EU

2.2.1 Stockholm convention

The Stockholm Convention on Persistent Organic Pollutants (POPs) is a global environmental treaty aimed at protecting human health and the environment from chemicals that remain in the environment for long periods and are transported far from their production site to pristine areas. In the European Union, Regulation N° 850/2004 on POPs implemented the Stockholm Convention([52]) regarding their use, reduction, elimination and related actions. PFAS are not addressed as a chemical family.

([46]) Limit values and guidance values for PFAS, February 2024, Sweden
([47]) PM-3-22-Overview-of-knowledge-on-PFAS, Swedish Chemicals Agency
([48]) PFAS in landfills, Administrator support with focus on PFAS in leachate, 2022, Sweden
([49]) PFAS in waste residuals from Swedish incineration plants, 2021, IVL Swedish Environmental Research Institute
([50]) Emission of Per- and Polyfluoroalkyl Substances from a Waste-to-Energy Plant–Occurrence in Ashes, Treated Process Water, and First Observation in Flue Gas, 2023, Department of Chemistry Umea University
([51]) Toxicological Council Annual Report 2023, Toxicological Council, Sweden
([52]) Stockholm Convention on Persistent Organic Pollutants, Overview (pops.int)

However, since 2009, perfluorooctane sulfonic acid and its derivatives (PFOS) have been included in Stockholm Convention on POPs to eliminate their use; some purposes are still acceptable([53](and specific exemptions in accordance with part III of Annex B([54]).
The Stockholm Convention also regulates the global elimination of perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds. PFOA([55]) has been banned and listed in Annex A, since 4 July 2020. An updated indicative list of substances covered by the listing of PFOA, its salts and PFOA-related compounds has been reviewed in October 2024([56]).
In June 2022, the Stockholm Convention parties decided to include perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds in the treaty. The Commission added the substance group in the EU's POPs Regulation in Annex A in May 2023 and the regulation entered into force on 28 August 2023. An updated indicative list of substances covered by the listing of PFHxS, its salts and PFHxS-related compounds has been reviewed in October 2024([57]).
Long-chain perfluorinated carboxylic acids (C9-21 PFASs) are being considered for inclusion in the Stockholm Convention and consequent global elimination. During its 20th meeting in October 2024, the POP Review Committee took the Decision to recommend that the Conference of Parties (COP) consider listing long-chain perfluorocarboxylic acids (PFCAs) and related compounds in Annex A (elimination) to the Convention, with specific exemptions. An indicative list of long-chain perfluorocarboxylic acids, their salts, and related compounds has been published([58]).

2.2.2 National regulations outside the EU

This information was gathered through countries interviews and questionnaires.

Switzerland

The PFAS-related chemicals legislation([59]) in Switzerland is largely harmonised with that of the EU, particularly Ordinance on the Reduction of Risks relating to the Use of Certain Particularly Dangerous Substances, Preparations and Articles([60]).
As part of a political initiative, it is being examined whether the newly proposed quality standards for surface water bodies and groundwater within the WFD, EQSD and GWD that are expected to come into force in 2025 should be incorporated into the Swiss Water Protection Ordinance.

Switzerland is currently working on the state of the art for the elimination of PFAS from collected landfill leachate and pumped groundwater from remediation sites. It is also working on establishing the procedure for deriving ELVs in individual cases for these types of industrial wastewater. General ELVs are not discussed.

Canada

Environment and Climate Change Canada (ECCC), the lead federal department for a wide range of environmental issues, develops environmental quality guidelines via two different mechanisms. One mechanism is in-house by ECCC as Federal Environmental Quality Guidelines([61]) (FEQGs) while the

([53]) Stockholm Convention on Persistent Organic Pollutants, PFOS (pops.int)
([54]) Stockholm Convention on Persistent Organic Pollutants, Chemicals listed in Annex B (pops.int)
([55]) Decision SC-9/12 in Stockholm Convention for PFOA
([56]) Updated indicative list of substances covered by the listing of perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds, UNEP/POPs/POPRC.20/INF/12
([57]) Updated indicative list of substances covered by the listing of perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds, UNEP/POPS/POPRC.20/INF/13
([58]) Proposal to list long-chain perfluorocarboxylic acids, UNEP/POPS/POPRC.20/INF/17
([59]) Per- and polyfluoroalkyl substances (PFASs) (admin.ch)
([60]) SR 814.81 - Ordinance of 18 May 2005 on the Reduction of Risks | Fedlex (admin.ch)
([61]) Federal Environmental Quality Guidelines (FEQGs) - Canada.ca

second mechanism is as part of the Canadian Council of Ministers of the Environment([62]) (CCME) where ECCC may lead or contribute to the development of Canadian Environmental Quality Guidelines (CEQGs) with other Canadian jurisdictions (i.e., provinces and territories). Environmental quality guidelines are developed for several media, including surface water, groundwater, soil, sediments, wildlife diet, fish tissues and bird eggs.

These guidelines are science-based thresholds for environmental protection and their use is voluntary unless prescribed in permits or other regulatory tools. They are either preventative guidelines (i.e., water, sediment, fish tissue, bird egg, wildlife diet) that represent an environmental concentration below which there is a low likelihood of direct adverse effects in biota, or remedial guidelines (soil and groundwater) which represent a concentration that maintains important ecological functions that support activities associated with identified land use. Surface water guidelines are intended to be applied to the ambient environment and not intended to be applied directly to effluents or leachates, though they can be taken into consideration when developing regulatory measures.

ECCC (in-house or via the CCME) developed environmental quality guidelines for PFOS([63]) and or is developing guidelines for PFOA([64]), that were determined to meet the definition of toxic under the Canadian Environmental Protection Act (CEPA) by the Government of Canada. For PFOS, FEQGs([65]) for surface water, fish tissue, wildlife diet and bird egg, and CEQGs([66]) for soil and groundwater were developed. Currently, surface water, soil and groundwater CEQGs are under development for PFOA via the CCME while FEQGs for other media (wildlife diet, bird egg) are under consideration.

In the future, guidelines may be developed for other PFAS identified as meeting the definition of toxic under CEPA.

Japan

Although there are no EQSs for water, as “items requiring monitoring of water quality”, monitoring of the substances in public water bodies and groundwater is conducted in cooperation with local governments. A provisional target value (50 ng/l) has been set for sum of PFOS and PFOA as “items requiring monitoring of water quality”, and experts are currently discussing how to handle them.
No effluent standards have been set.

In Japan, the “Act on the Regulation of Manufacture and Evaluation of Chemical Substances (CSCL)” prohibited in principle the manufacture and import of PFOS in 2010 and PFOA in 2021. The manufacture and import of PFHxS was also prohibited in principle in February 2024. In June of the same year, the import of products containing these substances will be prohibited.

Korea

Permissible emission levels for some substances and facilities are defined by “Clean Air Conservation Act and Water Environment Conservation Act”. Fluoride compounds are relevant, but not PFAS.

([62]) Canadian Environmental Quality Guidelines (CEQGs), Canadian Council of Ministers of the Environment (ccme.ca)
([63]) Perfluorooctane sulfonate (PFOS), information sheet - Canada.ca
([64]) Perfluorooctanoic Acid (PFOA), its salts, and its precursors - information sheet - Canada.ca
([65]) Canadian Environmental Protection Act, 1999 Federal Environmental Quality Guidelines Perfluorooctane Sulfonate (PFOS) - Canada.ca
([66]) Canadian Soil and Groundwater Quality Guidelines for the Protection of Environmental and Human Health: Perfluorooctane Sulfonate (PFOS) (ccme.ca)

United States of America

The protection of surface water quality from the impacts of discharges from publicly owned treatment works (POTWs) and industrial wastewater treatment works is based on the establishment of effluent limits for pollutants in the discharges from those facilities. The effluent limits are enforced through National Pollution Discharge Elimination System (NPDES) permits. Those effluent limits are developed by establishing technology-based (TBELs) and water quality-based (WQBELs) effluent limits for a specific pollutant and using the most restrictive value of the two for the final effluent limit in the permit.

Effluent limits are also informed by effluent limit guidelines (ELGs) that are national wastewater discharge standards developed by US EPA on an industry-by-industry basis. These are technology-based regulations that are intended to represent the greatest pollution reductions that are economically achievable for an industry. The standards for direct dischargers are incorporated into NPDES permits issued by states and US EPA regional offices and permits or other control mechanisms for indirect dischargers.

At the present time, there are no US EPA-established ELGs for PFAS. US EPA outlined an approach for establishing ELGs for selected PFAS in its PFAS Strategic Roadmap([67]). This includes regulations promulgated to establish drinking water standards for some PFAS, work under development to propose discharge limits of PFAS from certain industrial sources, and other research to derive toxicity values and environmental and human health assessments.

One key action for Office of Water is to restrict PFAS discharges from industrial sources through a multi-faceted Effluent Limitations Guidelines program to proactively establish national technology-based regulatory limits, including progress on the nine industrial categories in the proposed PFAS Action Act of 2021. The agency released its Effluent Guidelines Program Plan 15([68]) in 2023.

Currently, only North Carolina has an NPDES permit with TBELs for PFAS. These TBELs were established using Best Professional Judgment, the process used when ELGs are not available. Minnesota has adopted an NPDES permit([69]) with WQBELs for PFOS.

([67]) PFAS Strategic Roadmap: EPA's Commitments to Action 2021-2024 | US EPA
([68]) Current Effluent Guidelines Program Plan | US EPA
([69]) Permit for Brainerd Wastewater Treatment Facility, Updated May 2024, Minnesota Pollution Control Agency

3. Monitoring methods

Existing methods for monitoring aqueous and atmospheric emissions of PFAS are presented below. Their level of development (already applied for monitoring or at the development stage), their field of application (aqueous/atmospheric emissions, characterization of individual PFAS or index of a sum of PFAS), where applicable their performance (limits of quantification, assessment of uncertainties within the framework of interlaboratory comparison etc.), their strengths and limitations have been specified.

The development of analytical methods is the subject of numerous national and governmental initiatives, as well as standardization (at different stages: national/EU/ISO) and research projects such as PARC or NORMAN described in Annex 3.

Monitoring PFAS raises several issues related to implementation and performance of measurement methods, whether in water or air matrix, which are also described in this section.

3.1 Water

Existing standardised methods for PFAS analysis, applicable to water are summarised in Table 1. The first method has been reported in early 2010's with only two compounds in the scope of the method: PFOA and PFOS. With the growing interest towards this family of thousands of individual compounds, the number of methods available in different part of the world increased rapidly during the past decade. With the growing number of methods, the number of compounds targeted by each of them also increased with up to 40 individual compounds in recent methods and most of those methods are now applicable to a large spectrum of water type, including wastewater.

Two types of sample preparation methods are reported in standardised methods:

1) **Dilution of the water sample by methanol**. This method is almost considered as a direct injection of the sample, with no pre-treatment required. This method has the advantage of being rapid, avoiding additional extraction, purification or concentration steps, with the inherent risks of contamination and losses. It also requires only a small sample volume but requires more sensitive, latest-generation analytical equipment to be able to reach the limit of quantification or detection imposed in the latest regulations. A major drawback of this method is that there is little to no information concerning the particulate phase on which certain PFAS (particularly those with the longest chains) might be adsorbed. Furthermore, the absence of a purification step can rapidly lead to a deterioration of the analytical performance due to fouling of the source, especially for wastewater samples.

2) **Solid-phase extraction (SPE) of the water sample**. This method often reports the use of a weak anion exchange phase (WAX type) without a pre-filtration step. It is thus assumed that PFAS adsorbed on the particulate phase would be extracted by the solvent used to elute the cartridge, which is, in most case alkaline methanol. A drawback with this method is that it requires a greater number of sample preparation steps which, in addition to being time-consuming in terms of sample volume and solvents, can also be sources of contamination and loss of PFAS by adsorption during the various processing stages. In particular, in order to reduce the operational cost and improve the reproducibility, SPE is often carried out on automatic devices for other types of compounds but is not recommended for PFAS as the automat's component (tubing, seals…) are often made of PTFE which is also a drawback.

Both methods generally describe a method for water without distinguishing the dissolved and particulate phase. It is however assumed in many cases that the particulate phase is taken into account up until a defined Total Suspended Solids (TSS) threshold that is describe in the scope of the methods.

In France, a method has been proposed with a special step to describe the extraction of the particulate phase prior to the extraction of the dissolved phase([70]). This method is applicable to surface water, for 7 PFAS, with a limit of quantification between 1 and 2 ng/l.

Regardless of the sample preparation method applied by the laboratory, the subsequent analysis is always performed by liquid chromatography coupled with tandem mass spectrometry (LC-MSMS) with a chromatographic separation carried out on an apolar column. This method has been implemented a long time ago and is still robust. Over the years, some slight changes have been made simply to enhance the separation of the increasing number of individual PFAS targeted and the separation of the PFAS contained in the samples regarding the interferences coming from the analytical devices. One of the ongoing problems is the separation and reliable quantification of branched PFAS in opposition to their linear form, such as branched and linear PFOS or branched and linear PFOA. Most of the listed methods report the lack of corresponding analytical standards for the branched PFAS and advise to either only report the linear form or quantify the total (branched and linear homologues) with respect to the linear analytical standard.

([70]) Datasheet for raw water analysis method, Aquaref

Table 1 Standardised or recommended methods for PFAS analysis in water

Available method	Year of publication	Emitting country / body	Number of PFAS concerned	Scope	Information on performances
ISO 25101	2009	ISO	2	Non-filtered water (potable, surface or groundwater)	LoQ = 2-10 ng/l International interlaboratory trial was performed in 2007
ISO 21675	2019	ISO	30	Non-filtered water (potable, surface or groundwater with SM < 2 g/L)	LoQ ≥ 0.2 ng/l Interlaboratory trial was carried out in 2017
DIN 38407-42	2011	DIN / Germany	10	Potable, surface, ground and wastewater	LoQ = 10-25 ng/l Performance tested in an interlaboratory trial carried out in 2010
US EPA 8327	2021	US EPA	24	Surface, ground and wastewater	N.A
US EPA 533	2019	US EPA	25	Potable water	LoQ = 1-16 ng/l
US EPA 537	2020	US EPA	18	Potable water	MDL = 0.5-3 ng/l LoQ = 0.5-6 ng/l
ASTM D7979	2020	ASTM / USA	21	Surface, ground and wastewater	MDL = 0.7-106.8 ng/l LoQ = 5-100 ng/l
WAC/IV/A/025	2022	WAC / Belgium	30	Potable, surface, ground and wastewater	LoQ = 10-50 ng/l
NF EN 17892	2024	AFNOR / France	30	Potable water. Possible for surface, ground or wastewater if validation of method is proven in the same conditions	Interlaboratory trial held in 2023
US EPA 1633	2024	US EPA	40	Aqueous samples, solids, biosolids, and biota tissues	MDL = 0.3-9.5 ng/l LoQ = 1-100 ng/l
WAC/IV/A/026	2024	WAC / Belgium	7	Potable, surface, ground and wastewater	N.A
ES 10363.1a	2021	Korea	27	Surface water	MDL = 5 ng/l

MDL: Method Detection Limit / LoQ : Limit of Quantification or Lowest concentration minimum reporting limit
Note: The MDL and LoQ in US methods are calculated statistically while they are analysed in French methods. No details are given in Korean and Belgian methods.

Apart from the targeted standardised methods listed in Table 1, index methods are being developed in parallel because targeted analysis will never be able to cover the whole PFAS family. An index method is generally a matching method: one parameter (e.g. AOF) is analysed to estimate another parameter (PFAS).
Among index methods, methods relying on the quantification of Adsorbable Organic Fluorine (AOF) is the most advanced in terms of harmonisation. In this method organic compounds containing fluorine are adsorbed on an activated carbon cartridge followed by its combustion. The product of this combustion is then bubbled in water which is then analysed by ion-chromatography to determine the concentration of fluorine. This method is already described in a German standardised method (DIN 38409-59), a Belgian procedure (WAC/IV/B/013), a US Method (US EPA 1621) and is currently being examined at the European level (ISO/WD 18127:2022) and hope to be applicable to potable, surface, ground and wastewater alike. The major drawbacks of this method are that it is not totally specific of the PFAS family so other organic compounds containing fluorine are also included and the limit of quantification is in the range of 2µg/L which is higher than the values required in the monitoring programs and regulations. Also, some studies report potential interferences coming from inorganic fluorine (when the activated carbon is not properly washed), from high concentrations of chlorine that can interfere during the ionic chromatography separation, or from TSS or Total Organic Carbon (TOC) that influence the adsorption of organic molecules that contains fluorine onto the cartridge.

Other index methods exist but are not as advanced as AOF methods in terms of harmonisation. One of them is the TOP assay which relies on an alkaline oxidation of the sample and subsequent quantification of usual PFCA. By comparison of the concentration of PFCA before and after oxidation, an estimate of the presence of so-called PFAS precursors can be made. As a complementary tool, non-target screening (NTS) by high-resolution mass spectrometry can be carried out to try to identify those precursors and express the diversity of individual PFAS compounds in the samples. Although the first is quantitative, it can not clearly identify the type of initial compounds present in the sample. On the contrary, the second method is able to identify the PFAS but is only qualitative. In both cases, those methods are currently developed and used mainly at the research levels. Some collaborative trials concerning the TOP assay are currently being discussed at the European level, specifically within the scope of the PARC project. Concerning NTS, a collaborative trial for suspect screening of PFAS in passive sampler was held at the end of 2023 by NORMAN and, depending on the results of this first trial, two more are expected in the years to come to cover the preparation part and the whole NTS strategy.

3.2 Air

3.2.1 Developed standards for the measurement of PFAS in atmospheric emissions

United States

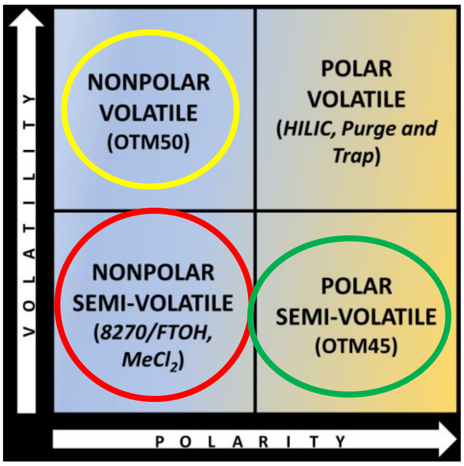
The Air Emission Measurement Center (EMC) of the US EPA publishes methods as OTMs ("Other Test Methods"). The OTM status means that the method is not yet approved for regulation by the U.S.-EPA, but it was reviewed by the EMC and found to be relevant for emissions monitoring. OTM can be updated based on feedback data.

The PFAS family covers a significant number of compounds. In the case of atmospheric emissions, several measurement methods are required to adapt both sampling and analysis to their characteristics: PFAS can have volatile, semi-volatile, non-volatile, polar and non-polar forms, etc.
3 OTM methods were planned for PFAS (see Figure 1).

Today two of the methods have been published: OTM-45 and OTM-50. The publication of these methods by the EMC aims to promote a harmonization of PFAS measurements, emitted from stationary sources, based on best practices available at the time of their publication on the US EPA website. Standards describing OTM(71) can be downloaded from the US EPA website. A Frequently Asked Questions (FAQ) document is also available and may be interesting to consult for additional information on the implementation of these methods.

The third one (OTM-55) is being developed as part of the work of the Office of Research and Development (ORD) and the Office of Air Quality Planning and Standards (OAQPS) of the US EPA.

Figure 1 American methods developed or under development for the measurement of PFAS

<table>
<tr>
<td>OTM-50
Method published in 2024
On-site sampling by canister + laboratory analysis
C1-C8 compounds</td>
<td rowspan="2">
</td>
<td></td>
</tr>
<tr>
<td>OTM-55
Method under development
Approach based on a compendium of 3 methods, for sampling, extraction and analysis
Targets in particular fluorotelomer alcohols (FTOHs) and products of incomplete combustion/destruction (ICP/PID)</td>
<td>OTM-45
Method published in 2021
Sampling with a device with multiple trapping stages + laboratory analysis
C4 [3] compounds</td>
</tr>
</table>

European Union

To date, several European countries have begun work on developing standards for measuring PFAS in emissions to the atmosphere. This is the case in Flanders (Belgium) and France in particular.
VITO (Flemish Institute for Technological Research and Reference Laboratory) published in 2023 the first version of a standard: LUC/VI/003, which is to be added to the compendium of methods to be applied within the framework of certain Flemish regulations for air measurement and analysis.
Within AFNOR (French Association for Standardisation), a French standard will be published at the end of 2024: XP X 43-126.
Germany is also currently working on the subject.
The development of a European standard for the measurement of PFAS in atmospheric emissions has been identified as a new priority topic by the Technical Committee 264 "Air Quality" of the European Commission for Standardisation (CEN). As a first step, a new European working group has been set up within CEN/TC 264, to review PFAS methods for both ambient air and emissions to the atmosphere from stationary sources. This group will provide an opportunity to share national work on the sampling and analysis of PFAS in emissions of industrial facilities and in ambient air. This will provide a base of information when the European regulatory authorities request to draw up standards.

(71) [EMC Other Test Methods | US EPA]

3.2.2 Principle of measurement methods

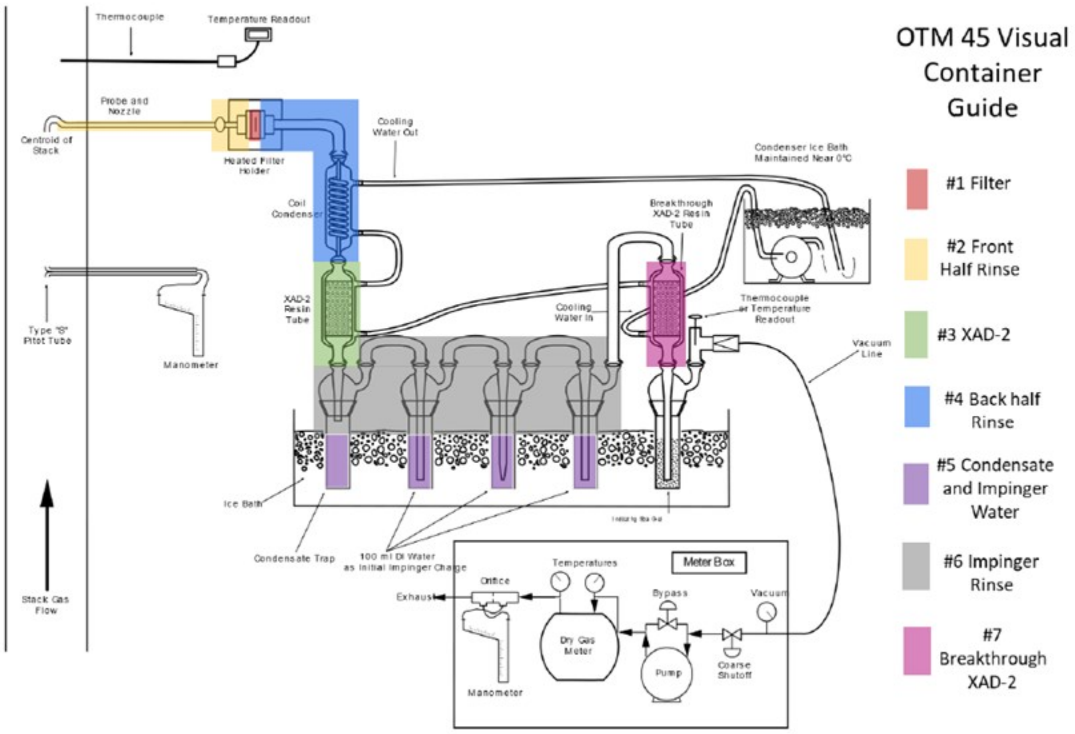
OTM-45 "Measurement of Selected Per- and Polyfluorinated Alkyl Substances from Stationary Sources"

The OTM-45 method is adapted to the measurement of polar semi-volatile PFAS (boiling point > 100°C). Published in 2021 and revised in January 2024, it is the first reference published and therefore the most proven, in the United States but also when measurements have been implemented in other countries.

The scope of application covers 49 compounds.

The principle of the method is based on representative sampling of the gaseous effluent using a sampling device. This sampling device includes several successive trapping supports that trap PFAS in particulate and gaseous forms**:** filter, adsorbent resin, absorption solutions; an additional resin at the end of the sampling device is used to check the trapping efficiency (see Figure 2).

Figure 2 Sampling Train in OTM-45 method



A minimum sampling volume of $3m^3$ is recommended in order to achieve sufficiently low limits of quantification (LoQ) with regard to potential concentrations. It may be necessary to adapt the sampling time according to the concentration in the effluent or according to the limit value to which the measurement is to be compared. For example, it may be necessary to reduce the volume sampled in order to avoid dilution of the sample before analysis in the case of a "high" concentration; an increase of duration and therefore of the sampled volume may be required to lower the LoQ if the concentration is low or if the measurement is compared to a low threshold.

The filter, adsorbent resins, condensates, absorption solutions and rinsing solutions are recovered at the end of the sampling step for analysis, in the form of 7 samples. After extractions, some samples are combined which leads to 4 analysed fractions.

The extracts are analysed by LC-MS/MS (Liquid Chromatography coupled to tandem Mass Spectrometry) and MRM (Multiple Reaction Monitoring) detection.

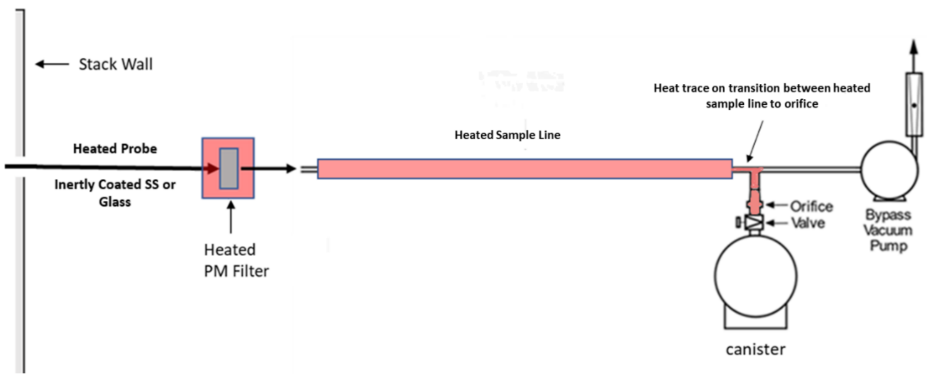
The results provide:
- The mass concentration for each fraction analysed, of each individual target PFAS,
- The total mass concentration of each individual target PFAS,
- If required, the mass concentration of the sum of the target PFAS.

OTM-50 "Sampling and Analysis of Volatile Fluorinated Compounds from Stationary Sources Using Passivated Stainless-Steel Canisters"

The OTM-50 method, published at the beginning of 2024, is dedicated to non-polar volatile compounds (boiling point ≤ 100°C). Being more recent, it has been less implemented than the OTM-45.

The scope of application covers 30 compounds.
The principle of the method is also based on representative sampling of the gaseous effluent using a sampling device, and analysis of the samples in the laboratory.
The gas sample is taken in a canister (vacuum container in which the gas to be characterised is aspirated) at a regulated flow rate (cf. Figure 3). The recommended sampling flow rate allows for sampling over a period of 1 hour. Upstream of the canister, a heated filter traps the particles. If the effluent is wet or acidic, absorbers are also added to prevent condensation in the canister and to remove compounds that may interfere with the analysis. In case of a high concentration outside the range of analysis, a second canister can be added; a lower sampling rate is applied to only partially fill the canister and then allow a dilution of the sample.
The gas sampled from the canister is then analysed by GC/MS (gas chromatography/ mass spectrometry).
The results provide:
- The total mass concentration of each individual target PFAS,
- If required, the mass concentration of the sum of the target PFAS.

Figure 3 Direct sampling system in OTM-50



OTM-55 (under development)

The OTM-55 method targets nonpolar semi-volatile compounds to meet the need for measurement of fluorotelomer alcohols and incomplete combustion/destruction compounds.
The sampling device should be identical to this described in OTM-45 for polar semi-volatile compounds. But work on the extraction step of the trapped compounds on the trapping media is required to allow the use of a single equipment to take both polar and nonpolar semi-volatile compounds.

Flemish Method LUC/VI/003 and French Standard XP X 43-126

Both standards developed in Flanders and France are based on OTM-45.

The OTM-45 method was tested and implemented between 2021 and 2023 by VITO, as part of a study to characterise PFAS emissions to the atmosphere from different industries, commissioned by the Flemish government. REX of these measurement campaigns led VITO make some adaptations (e.g. addition of a rinsing step, simplification of final site blank).
For the French reference system, laboratory REX was also used.

So, in both cases, additional or slightly different provisions have been introduced, in particular to improve or optimize quality controls, in order to reduce the cost while ensuring a level of requirement that meets the precautions required against the risks of contamination.
For example, in LUC/VI/003: an additional solvent added for rinsing sampling equipment after the sampling; higher temperature for calcination of the sampling device elements.
For France, clarifications are provided on the method of determining the limit of quantification and measurement uncertainties, as well as on the reporting of results, to harmonize practices and allow comparison of results between facilities.

3.3 Key focus for implementation and performance of measurement methods

3.3.1 Limitation of methods described

A challenge when analysing PFAS in water and air is the identification of compounds that may still be unknown and which may be emitted but not currently targeted by the sampling and analytical method. This may result from a modification by the manufacturing/combustion processes of compounds initially present in the input process products. Even with several methods, the list of compounds that can potentially be measured remains very limited compared to the number of existing PFAS.

In addition, the quantification of compounds depends on the existence of standards, which are currently limited in number.

Unlike current development of index methods for water, there is currently no development of index methods in air, which would allow a wider range of compounds to be considered.

These issues are for example taken into account by Euramet via the European Metrology Network for Pollution Monitoring([72]) (EMN POLMO), which brings together 31 institutes from 21 countries. The aim is to develop and make available the references needed to harmonize analyses, notably through the organisation of interlaboratory comparisons or the development of index methods in air, to develop reference materials and analytical standards.

3.3.2 Quality controls

The risks of contamination at each stage of measurement, both for sampling and analysis, require special attention. Especially since the concentration levels can be very low requiring low LoQ.
This explains the numerous quality controls at the various stages of implementation of sampling and analysis.
It is important for laboratories to test their ability to implement sampling and analysis and to verify that they can meet the performance criteria required in the standardised methods (blanks to be done at several steps of sampling and analysis).
One way to evaluate the performance of both methods and laboratories is through interlaboratory comparisons (ILCs). Such exercises are being put in place. Analytical ILCs are proposed for water on a more or less extensive list of compounds. France, for example, already carried out one ILC on 30 PFAS in surface and wastewater in November 2023 and will be able to propose one for emissions to the

([72]) EMN PolMon, Chemical pollutants

atmosphere in 2025. In Flanders, an intercomparison has already been organised in 2024 for the implementation of the overall method (sampling and analysis) on a test bench.

3.3.3 Limit of Quantification

A second focus is the determination of limits of quantification (LoQ) which is a key parameter for evaluating the performance of a measurement method. Performance criteria to be achieved by laboratories can also be expressed in terms of the analysis LoQ and the measurement LoQ integrating analysis + sampling (for example for blanks).

To compare the capabilities of two analytical laboratories, it is essential that the analytical LoQs are calculated in the same way. And even more so in the case of compounds such as PFAS where the concentrations resulting from the analysis of several dozen compounds, or even several fractions analysed for each compound (for example in the case of OTM-45 method in air). However, there are many definitions and ways to determine it in analysis. This may be the reason why the LoD is sometimes used. In France, for example, analytical laboratories are required to apply the standard NF T 90-210 (Water quality - Protocol for the initial method performance assessment in a laboratory) to demonstrate their ability to implement an analysis method. The standard defines the LoQ based on a performance criterion to be achieved at the concentration level declared by the laboratory as corresponding to its LoQ.
In air, the measurement LoQ for a compound is calculated from the analysis LoQ divided by the volume of sampled air. To lower the measurement LoQ, it is possible to lower the analytical LoQ and/or increase the sampled volume.

Specific indication for measurement in water

Different LoQ are reported for the standardised methods discussed in Table 1. They ranged from ng/l to hundreds of ng/l. From a point of view that considers all the analytical chain (i.e., preparation of the sample, matrix, analysis and reporting) in the LoQ, those are generally influenced by 3 major factors:

- The identity of the compound: depending on the number and chemical sub-group of PFAS, the LoQ can be very different for a given method. Indeed, the response factor can vary between short and long chain of a same family of PFAS and even more between different family of PFAS.
- The preparation method involved: the method's LoQ are very dependent on the preparation step (solvent adding versus solid phase extraction) because the first one induces a step equivalent to dilution whereas the second involves a step of concentration of the sample.
- The water matrix in the scope: generally speaking, methods with wastewater included in their scope often report LoQ up to 100 ng/l whereas for potable water, 1 ng/l or less can be attained. This is explained by the complexity of the matrix which can cause interferences and an increase of the analytical baseline, making it impossible to confirm LoQ as low as "clean" water for more complex types of water.

As a result, it is difficult to determine a unique LoQ for all PFAS for all water matrices.

Specific indications for measurement in air

The OTM-45 method defines a Quantitative Reporting Limit (QRL) as the minimum quantitative level that can be reported; the QRL is based on the lowest concentration or level of the target PFAS compound used during calibration. It defines the Method Detection Limit (MDL) as the minimum signal qualitatively detectable during analyses with a 99% confidence level. QRL and MDL are provided for about thirty compounds. The QRLs range from 1.5 to 16 ng depending on the compounds (sum QRL of the fractions analysed). The values are to be divided by the volume of gas sampled to obtain the measurement LoQ as indicated above. For a minimum volume of gas withdrawn of 3 m^3 required by the standard, this leads to values of 0.5 to 5.3 ng/m^3.

The Flemish standard LUC/VI/003 gives LoQ values obtained for 18 compounds, with a sum of the LoQ for fractions 1 to 3 between 0.2 and 0.6 ng, which corresponds to 0.06 to 0.2 ng/m^3 for 3 m^3 of gas sampled. It is specified that for a quantitative analysis, an expanded uncertainty of no more than 50%.

In the French standard, a LoQ requirement is set for the 49 compounds: the analysis LoQ must not exceed 15 or 30 ng depending on the compound (sum of the LoQ of fractions 1 to 3), i.e. 5 to 10 ng/m^3 for 3 m^3 of gas sampled. In the NF T 90-210 standard applied to determine LoQs, the maximum acceptable deviation at the LoQ level is more than 60%. These analysis LoQ thresholds are set to evolve because they were proposed when analytical laboratories were only beginning to validate the implementation of the analytical method.

For the first 2 standards, the LoQ thresholds obtained (for some of the compounds) appear to be much lower than the threshold not to be exceeded in the French standard. In the case of LUC/VI/003 and the French standard, the performance conditions at the level of the LoQ are comparable.
In OTM-50, the QRLs provided for the 30 compounds 0.08 and 0.81 $µg/m^3$. The order of magnitude is therefore much higher than for semi-volatile compounds measured according to OTM-45 (factor ≈150).

3.3.4 Measurement uncertainty

The determination of measurement uncertainty is also a key parameter for evaluating the performance of a measurement method.

For example, in the case of air, neither OTM-45 nor OTM-50 describe the evaluation method of measurement uncertainty, and no obtained values or criteria are given.
In the LUC/VI/003 method, expanded uncertainty values obtained for 19 compounds range from 3 to 26% relative to measured concentration.

The French standard XP X 43-12 does not require any criteria or specify any uncertainty values of analysis or measurement (sampling + analysis). On the other hand, it requires that for the analysis, the uncertainty is determined according to ISO 11352 standard (Water quality - Estimation of measurement uncertainty based on validation and quality control data) and that the expanded uncertainty is provided at least at 3 concentration levels of the domain validated by the analysis laboratory, including the LoQ. The lower the concentration level, the greater the uncertainty, so it is advisable to know the analytical uncertainty as a function of the concentration level of the sample analysed. It should be noted that in some European standards describing measurement methods including a sampling step and an analysis step, as in the case of the measurement of semi-volatile PFAS, only an assessment of the repeatability of the analysis is required. However, this is only one of the contributions to the uncertainty associated with analysis. Finally, the French standard indicates that the measurement uncertainty must be calculated by combining the contribution of sampling and analysis, and by applying the uncertainty propagation law defined in the ISO/IEC GUIDE 98-3 or by propagation of the distribution laws by applying the Monte Carlo method according to ISO/IEC GUIDE 98-3/S1. An example of a calculation by applying the uncertainty propagation law is provided.

4. Monitoring campaigns

As a first step of elaborating PFAS regulation, countries often conduct exploratory monitoring campaigns allowing to target the relevant contributors and compounds and to provide a consistent regulatory framework. This chapter presents the feedback received from the benchmark regarding this topic.

4.1 Belgium (Flanders)

In term of measurement campaigns, the compendium method for measuring PFAS in air in Flanders has recently been published. This means targeted PFAS air emission measurements could be scheduled by the Flemish Enforcement department from 2024 onwards. The PFAS air emission measurements are being carried out at installations in the vicinity of locations where the Flanders Environment Agency (Vlaamse Milieumaatschappij - VMM) performs emission measurements.

The Flemish EPA has performed a dedicated monitoring campaign([73]) over the period 2021- 2023 in the wastewaters of several industrial sectors (Tank cleaning/ Waste Treatment, Laundries, Chemical Industry, Surface Treatment of Metals and Plastics, Municipal Wastewater Treatment Plants, Breweries, Textiles, Refineries, Photographic applications); these sectors have been chosen according to literature, previous screening campaigns and the major use sectors indicated in the broad PFAS REACH restriction dossier.
The results of the extensive measurement campaign on PFAS distribution in Flanders show that, although in the majority of samples the concentration is below the detection limit, at least one PFAS compound was detected at almost all measurement sites. This shows that the presence of PFAS is widespread in Flanders. In terms of PFAS concentrations, however, there are some clear hotspots. The selection of PFAS substances to be measured is clearly different between both the different matrices (wastewater, surface water, groundwater, biota) and the different industrial sectors investigated within a matrix. For wastewater, there is a clear PFAS fingerprint per sector with characteristic PFAS (both in presence and concentration).

In addition, the Flemish EPA performed PFAS monitoring in ambient air and deposition during 2022-2023 at background, coastal, urban background and hotspot locations across Flanders. This report ([74])showed high concentration and composition variability PFAS concentrations across Flanders with predominant prevalence of PFCA's and PFSA's.

4.2 Italy

Due to the discovery of PFAS pollution in ground-, surface and drinking water in various Italian regions over the last ten years or so, the National Environmental Protection System (SNPA) is monitoring groundwater and surface water, covering 185 stations relating to 20 autonomous Italian regions and provinces. In order to homogenise the activity, SNPA developed in 2018 the guideline n° 305/2019([75]). The SNPA Guideline n° 305/2019 also identifies the Ateco Codes of the activities that can potentially be sources of PFAS emissions/releases.

([73]) Exploratory research on PFAS distribution in Flanders. Wastewater, surface water, water bottom, biota & groundwater, Vlaanderen, 2023
([74]) Final report 'Research into PFAS in ambient air in Flanders' | Vlaanderen.be
([75]) Guidelines for the design of monitoring networks for perfluoroalkyl substances (PFAS) in surface and underground water bodies, SNPA, 2018

4.3 France

A French ministerial order(76) was published in June 2023 regarding the analysis of PFAS in water discharges from classified facilities subject to the authorisation regime (e.g. chemical plants, hazardous waste treatment plants, WWTP, surface treatment plants); 20 mandatory individual PFAS are included in this monitoring and additional PFAS can be included if relevant. The monitoring campaign will be finished end of 2024, and the assessment of the results will enable the definition of the future ELVs/monitoring requirements.

A French ministerial Decree(77), published in October 2024, concerns the analysis of PFAS in atmospheric emissions from waste incineration, co-incineration plants and other thermal waste treatment plants. The monitoring campaign will run from 2025 to 2028. It involves characterizing emissions for the semi-volatile compounds listed in standard XPX 43-126. This large-scale national campaign will provide a better understanding of the current situation and help set future emission limits. Sweden.

PFAS are monitored within the Swedish National monitoring programme (not associated with industry facilities). Within national monitoring (continuously ongoing) and screening campaigns targeting specific sectors and/or environmental matrixes, the specific PFAS monitored varies among matrixes and purposes. Targeted analysis is nowadays often performed in combination with total fluorine analyses, e.g. TOP-analysis. Industry and other business actors / enforcement agencies / hosts for national monitoring programs are recommended to use analysis accredited laboratories employing state-of-the-arts analysis packages of which several are commercial actors.

4.4 Switzerland

A measurement campaign in Wastewater Treatment Plans(78) is underway (2023–2025) on a national Swiss level. Inflows, outflows and digested sludges are analysed for a range of individual PFAS and for total organic fluorine. Furthermore, individual measurement campaigns for atmospheric PFAS emissions have been carried out or are currently being carried out, mainly in cement and in waste incineration plants.

4.5 Canada

ECCC conducts monitoring on a national scale to understand trends in PFAS occurrence in the Canadian environment. This monitoring is not focused on industry and is summarized in the publicly available Updated draft State of PFAS report(79).
Federal contaminated sites are located on land owned or leased by the federal government or on land where the federal government has accepted responsibility for the contamination. The Federal Contaminated Sites Inventory shows more than 23,000 suspected, active, and closed federal contaminated sites, of which there are over 100 sites with confirmed or suspected PFAS contamination(80). The most common sources of PFAS at federal contaminated sites are associated with the use of AFFF and include activities such as firefighting training and the maintenance of firefighting equipment. The Government of Canada continues to take action through the Federal

(76) Decree on the analysis of per- and polyfluoroalkyl substances in aqueous discharges from facilities classified for environmental protection, June 2023, France
(77) Decree on the analysis of PFAS in atmospheric emissions from waste incineration and, co-incineration plants and other thermal waste treatment plants, October 2024, France
(78) Occurrence of PFASs in Swiss Wastewater Treatment Plants, Swiss Federal Institute of Aquatic Science and Technology - Eawag
(79) Updated Draft state of per- and polyfluoroalkyl substances (PFAS) report - Canada.ca
(80) Federal Contaminated Sites Inventory, Canada

Contaminated Sites Action Plan[81] (FCSAP) to reduce environmental and human health risks from known federal contaminated sites.

4.6 Japan

Monitoring campaigns of PFOS and PFOA in public water bodies and groundwater are conducted in cooperation with local governments. In 2022, surveys were conducted at a total of 1258 sites nationwide; reports[82] are available. In cases where the provisional target value was exceeded, advice on prevention of exposure to drinking water is given based on the guidelines.

[81] Action plan for contaminated sites - Canada.ca
[82] Report on Environmental Survey and Monitoring of Chemicals, Japan

5. ELVs/EQSs

The results of the benchmark regarding ELVs and EQSs are gathered in a table presented below and the major outcomes are synthetised for water and air emissions.

5.1 Table presentation

The output of the benchmark is a table, provided as a link in the report in Excel format.

https://www.eionet.europa.eu/etcs/etc-he/products/etc-he-products/etc-he-reports/etc-he-report-2024-14-experiences-with-control-of-pfas-in-industries-of-the-world-threshold-settings-emission-monitoring-methods-and-campaigns/eionet-report-etc-he-2024-14_control-of-pfas-in-industries-table-elvs-eqss_publication-february-2025.xlsx

Several columns allow to have an overview of data provided in the questionnaire and during the interviews. They are divided by:

- Country,
- Compound: substance abbreviation, full name and CAS number,
- Regulation: reference of the administrative issuance, with link and year of application,
- ELV or EQS, and ELV/EQS status: in force, planned, indicative value or compound target by monitoring,
- Media: surface water, groundwater, wastewater or air,
- Value with its unit, with averaging period when available,
- Analytical method/standard, with limit of quantification when available,
- Substance: individual, sum or total,
- Monitoring purpose: wide-screening, compliance monitoring or operational control,
- Application level: national or regional (with name of the regio or site if relevant),
- Industrial sector,
- Regulatory status of the compound (banned, restricted, etc.)

A summary of the collected data is presented in the next paragraphs for water (for two mains regulated compounds, PFOS and PFOA, and then for others) and for air.

5.2 Results: water

5.2.1 PFOS

Surface water

In European Union regulation, PFOS is the only PFAS compound for which EQSs are in force in surface water; they are described in Environmental Quality Standards Directive (2008/105/EC), where:

- AA-EQS Inland surface waters = 0.65 ng/l
- AA-EQS Other surface waters = 0.13 ng/l
- MAC-EQS Inland surface waters = 36 000 ng/l
- MAC-EQS Other surface waters = 7 200 ng/l
- EQS Biota = 9.1 µg/kg wet weight

In the Netherlands, based on health-based limit for PFAS from European Authority for Food Safety (EFSA), RIVM has proposed in 2022 to decrease AA-EQS in surface water to 0.007 ng/l.
In Sweden, an EQS of 90 ng/l is defined for 11 compounds, including PFOS([83]).

Outside Europe, Japan has planned to set an EQS of 50 ng/l for the sum of PFOS and PFOA.

([83]) Sweden, this refers to the following compounds: PFOS, PFOA: PFBS, PFHxS, 6:2 FTS, PFBA, PFPeA, PFHxA, PFHpA, PFNA and PFDA.

In Canada, an EQS indicative value of 6 800 ng/l has been set in the Federal Environmental Quality Guidelines.

Groundwater

In Italy, at national level, EQS is in force for PFOS in groundwater with a value of 30 ng/l (Decree of July 6, 2016).
In Japan, an EQS of 50 ng/l for the sum of PFOS and PFOA has been planned in the 5th Report of Review of Environmental Standards Related to the Protection of Human Health from Water Pollution.
In Canada, an EQS indicative value of 600 ng/l has been set in the Groundwater Quality Guidelines for the Protection of Environmental and Human Health.

Wastewater

Regarding ELVs for industrial wastewater, no European value is available.
In the Piedmont region of Italy, one ELV is in force with the concentration of 0.65 ng/l (Legge regionale 19 ottobre 2021, n. 25. Article 74).
Also in Italy, an ELV of 500 ng/l has been planned in the national Draft Law No. 2392, but not yet adopted.
Article 4 of Annex 4.2.5.2 to Title II of the VLAREM, in Belgium (Flanders), specifies ELV indicative values of 20 ng/l for PFOS and 50 ng/l for PFOS total (Linear and branched forms).

5.2.2 PFOA

Surface water

In Italy, national EQSs are set for PFOA in surface water in Legislative Decree N° 172:

- AA-EQS Inland surface waters = 100 ng/l
- AA-EQS Other surface waters = 20 ng/l

In the Netherlands, a current EQS of 48 ng/l has been set as official standard by Dutch ministry, but based on health-based limit for PFAS from European Authority for Food Safety (EFSA), RIVM has proposed in 2022 to decrease it to 0.3 ng/l.
In Sweden, an EQS of 90 ng/l is defined for 11 compounds, including PFOA[83].

Outside Europe, Japan has planned to set an EQS of 50 ng/l for the sum of PFOS and PFOA.

Groundwater

In Italy, at national level, an EQS is in force for PFOA in groundwater with a value of 500 ng/l (Decree of July 6, 2016).
In Japan, an EQS of 50 ng/l for the sum of PFOS and PFOA has been planned in the 5th Report of Review of Environmental Standards Related to the Protection of Human Health from Water Pollution.

Wastewater

An ELV of 100 ng/l is in force in Italy, Piedmont region (Legge regionale 19 ottobre 2021, n. 25. Article 74).
An ELV of 500 ng/l has been planned in the national Draft Law No. 2392, but not yet adopted.
Article 4 of Annex 4.2.5.2 to Title II of the VLAREM, in Belgium (Flanders), precises ELVs indicative values of 20 ng/l for PFOA and 50 ng/l for PFOA total (Linear and branched forms).

5.2.3 Others PFAS with ELV/EQS (in force, planned)

Surface water

In Italy, in addition to PFOA, national AA-EQSs are also set for four others PFAS compounds in Legislative Decree N° 172:

- PFBA:
  - Inland surface waters = 7 000 ng/l
  - Other surface waters = 1 400 ng/l
- PFPeA:
  - Inland surface waters = 3 000 ng/l
  - Other surface waters = 600 ng/l
- PFBS:
  - Inland surface waters = 3 000 ng/l
  - Other surface waters = 600 ng/l
- PFHxA:
  - Inland surface waters = 1 000 ng/l
  - Other surface waters = 200 ng/l

In the Netherlands, a current EQS of 118 ng/l has been set for HFPO-DA (also called Gen X) as official standard by Dutch ministry, but based on health-based limit for PFAS from European Authority for Food Safety (EFSA), RIVM has proposed in 2022 to decrease it to 10 ng/l.

In Sweden, an EQS of 90 ng/l is defined for 11 compounds[83].

Groundwater

In Italy, at national level, EQSs are in force in groundwater for PFPeA (3 000 ng/l), PFBS (3 000 ng/l) and PFHxA (1 000 ng/l) (Decree of 6th July, 2016).

In Sweden, 24 PFAS are included in regulations for groundwater (SGU-FS 2023:1), with the general threshold value of 4.4 ng PFOA equivalents/l for the sum of these 24 PFAS. This value is based on the EU Commission's proposal for revising the groundwater directive from 2022. Revision of the groundwater directive is still ongoing and has not been decided – if the groundwater directive ends up in a different PFAS regulation than the proposed one, regulations may be updated with consideration for this. It should be noted that it is the water authorities that decide on threshold values for groundwater. The general threshold values in SGU-FS 2023:1 are available as support in the work of the water authorities but EQSs are decided occurrence-specific, usually at the end of each water management cycle. The current cycle runs from 2022– 2027, and until then the water authorities decide on new threshold values, it is still the sum of 11 PFAS and the value 90 ng/l that forms the basis of the environmental quality standard good chemical groundwater status. The value 90 ng/l is referred to in the Water authorities' regulations from 2021 as target value.

Wastewater

In Italy, ELVs are in force in Piedmont region (Legge regionale 19 ottobre 2021, n. 25. Article 74) for 14 compounds or group of compounds([84]). ELVs are from 500 to 7 000 ng/l.

([84]) Italy Piedmont, this refers to the following compounds or groups: PFBA, PFPeA, PFHxA, PFBS, PFHpA, PFHxS, PFNA, PFDeA, PFUnDA, PFDoA, C6O4, ADV, Other PFASs (molecules with 3-6 carbon atom chains, including new generation PFASs), Other PFASs (molecules with chains of 7 carbon atoms or more, including new generation PFASs).

In addition to PFOS and PFOA, individual ELVs of 500 ng/l have been planned in the national Draft Law N° 2392 for 22 individual compounds([85]). ELVs have been planned for 2 sums: Total PFAS: 5 000 ng/l and Sum of PFAS: 1 000 ng/l. But they are not yet adopted.
This draft law is targeting specific industrial sectors including:

- PFAS and fluoropolymer production, formulation, supply, and use facilities, and facilities technically connected to them;
- arising from landfill leachate treatment plants;
- arising from facilities performing waste management operations other than those in (b) where PFAS compounds referred to in this table are present in the input waste streams;
- civil sewage treatment plants for which the operator identifies, among the connected users, contributions of PFASs referred to in this table.

In addition to PFOS and PFOA, article 4 of Annex 4.2.5.2 to Title II of the VLAREM, in Belgium (Flanders), precises ELV indicative values of 20 or 50 ng/l for 40 additional individual compounds, including 4 in linear form and linear/branched forms (referred to as “total”)([86]).

In France, in addition of PFOS and PFOA, 18 other individual compounds([87]) are mandatory screened in the monitoring campaign planned according to the Ministerial order of 20 June, 2023, on the analysis of per- and polyfluoroalkyl substances in water discharges from classified facilities subject to the authorisation regime.
Adsorbable Organic Fluorine (AOF) is also mandatory to be measured.
Any other PFAS compounds mentioned in the list drawn up by the operator of a facility including PFAS substances used, produced, treated or discharged by his facility, as well as PFAS substances produced by degradation have to be additionally monitored. A list of 8 potential substances([88]) are proposed for screening.
This decree applies to facilities subject to authorisation, in various fields: refinery; production of chemicals including organics, inorganics, pesticides and pharmaceuticals; surface treatment; metal processing; treatment, disposal or storage of waste (hazardous or non-hazardous); textiles. The assessment of the results will enable the definition of the future ELVs/monitoring requirements

5.3 Results: air

Only two countries have reported data for atmospheric emission.
In the Netherlands, ELVs are in force for three compounds listed in “Annex III to the Besluit activiteiten leefomgeving”, and provided below:

- PFOS: 0.05 mg/Nm^3
- PFOA: 1 mg/Nm^3
- HFPO:-DA (Gen X): 1 mg/Nm^3

([85])Italy, this refers to the following compounds: PFOS, PFOA, PFBA, PFPeA, PFHxA, PFHpA, PFNA, PFDA, PFUnDA, PFDoA, PFTrDA, PFBS, PFPeS, PFHxS, PFHpS, PFNS, PFDS, PFUnDS, PFDoDS, PFTrDS, HFPO-DA (Gen X), ADONA, 6:2 FTSA and C6O4.
([86]) This refers to the following compounds: PFOS, PFOS total, PFOA, PFOA total, PFBA, PFPeA, PFHxA, PFHpA, PFNA, PFDA, PFUnDA, PFDoDA, PFTeDA, PFHxDA, PFBS, PFPeS, PFHxS, PFHpS, PFNS, PFDS, 4:2 FTS, 8:2 FTS, PFOSA, MePFOSA, EtPFOSA, MePFOSAA, EtPFOSAA, 8:2 in PAP, HFPO-DA, ADONA, PFECHS, PFBSA, MePFBSA, MePFBSAA, PFHxSA, PFTrDA, PFODA, PFDoDS, PFUnDS, PFTrDS, 10:2 FTSA, 6:2 in PAP, 6:2/8:2 in PAP, 6:2 FTSA, PFOSA total, MePFOSA total, EtPFOSA total, PFHxS total.
([87]) This refers to the following compounds: PFOS, PFOA, PFBA, PFPeA, PFHxA, PFHpA, PFNA, PFDA, PFUnDA, PFDoA/PFDoDA, PFTrDA/PFTrA, PFBS, PFPeS, PFHxS, PFNS, PFHpS, PFDS, PFUnDS, PFDoDS, PFTrDS.
([88]) This refers to the following compounds: PFTeA/PFTeDA, PFHxDA, PFODA, HFPO-DA (Gen X), DONA/ADONA, C6O4, 6:2 FTOH/FHET, 8:2 FTOH/FOET.

In November 2024, 289 additional PFAS have been included to their national list of substances of high concern, not yet mentionned in Annex III, with ELVs based on (estimated) vapour pressure. ELVs are either equal to 0.05 or 1 mg/Nm^3.

6. Substitution

Substitution is a preventive solution designed to limit emissions into the environment or limit public exposure at source. In the case of PFAS, several initiatives are underway to study the possibilities of substitution, either by substance or by type of use. These studies may be motivated by regulations, e.g. the Stockholm Convention or the REACH regulation. They may also stem from a request from civil society or from major strategic guidelines such as the Chemical Strategy for Sustainability([89]), which asks for the production and use of chemicals that are "safe and sustainable by design", aims at "phasing out the use of PFAS in the EU, unless their use is essential".

6.1 Stockholm convention

In the framework of the Stockholm Convention on Persistent Organic Pollutants, the process includes, before listing a chemical, a risk management evaluation (Annex E) which review possible alternatives. These documents are available for each of the PFAS listed in the convention (PFOS, PFOA, PFHxS) and also for long-chain PFCA([90]).
In the specific case of PFOS, the alternatives to the listed exemptions are reviewed periodically, and the report shared on UNEP website([91]).

6.2 REACH regulation

Under the REACH regulation, PFAS are subject to several restrictions (PFCA C9-C14, PFHxA, PFAS in firefighting foams, see above).
Furthermore, Denmark, Germany, the Netherlands, Norway and Sweden have prepared and submitted an ambitious restriction dossier to ECHA on 13 January 2023 on the restriction of all PFAS([92]). To date, the ECHA's scientific committees for Risk Assessment (RAC) and for Socio-Economic Analysis (SEAC) are evaluating the proposal. The aim of this restriction is to limit all the uses of all PFAS, including polymers, after a variable timeframe, depending on the availability of alternatives. The logic is as follows:

- If alternatives are known and easy to implement for a specific use, the restriction applies as soon as possible: a transition period of 18 months is systematically provided for implementation, but no additional transition period is proposed.
- If there is no technically or economically feasible alternative, but possible alternatives have been identified and are in the development phase, the consortium of countries having submitted the restriction has proposed an additional 5 years transition period (+ 18 months).
- In the total absence of a technically or economically feasible alternative and for uses requiring authorisation or certification, the consortium has proposed an additional 12 years transition period (+18 months).
- For a few uses, the consortium proposed a derogation of unlimited duration.

As a consequence, the restriction dossier[92] is the most comprehensive survey to date describing uses of PFAS and alternatives to their use. 261 applications in 15 sectors and 563 alternatives (representing 210/261 applications) are identified.
These sectors (+ firefighting foams) are listed in Section 6.4 below.

([89]) Chemicals strategy, European Commission
([90]) Except a 18-month transition period for all uses from the date of validation of the restriction
([91]) Stockholm Convention on Persistent Organic Pollutants, PFOS (pops.int)
([92]) https://echa.europa.eu/fr/registry-of-restriction-intentions/-/dislist/details/0b0236e18663449b. See Table 8 of the dossier, and Annexes A and E for uses and alternatives.

6.3 Other initiatives

In addition to the work carried out through the REACH restriction, other initiatives are documenting the existence of alternatives to PFAS. The purpose of this section is not to make an exhaustive inventory of these initiatives, but to illustrate them.

The OECD is working with countries and stakeholders to share best practices and knowledge on substitution. PFAS are of specific interest, and the OECD platform "Risk management, risk reduction and sustainable chemistry"([93]) provides several studies on alternatives to these substances.

The EU funded project ZeroPM([94]) (presented in Annex 3) has also built a database of alternatives to PFAS([95]). One major advantage of this database (notably built on the restriction dossier) is that it also provides useful information for future research for alternatives. In particular, the names of the PFAS compounds, their chemical functions in each application and each sector of use, and the names of certain alternatives are listed.

The Swedish NGO ChemSec is developing several approaches to raise awareness of alternatives to PFAS. Its Marketplace([96]) is a website on which producers of alternatives are invited to advertise their solutions, and conversely, companies looking for alternatives can browse the site.
Their webinar series([97]) "Beyond PFAS: The Safer Alternatives" provides information on potential alternatives to PFAS in specific applications such as technical textiles, F-gases, or solar panels.
Lastly, some countries are setting up information platforms on substitution, notably France via its substitution portal([98]) or the substances portal([99]) in which techno-economic factsheets including information on substitution are provided, and Germany with its Substitution Support Portal([100]).

6.4 Synthesis

Based on the information presented in this section, the Table 2 below provides a non-exhaustive summary of PFAS use sectors, the availability of alternatives and provides some useful references for exploring substitution possibilities beyond what is already present in the restriction dossier currently under consideration by ECHA's Technical Committees. A more detailed development of this work is available in Ineris (2024)([101]).

([93]) https://www.oecd.org/en/topics/risk-management-risk-reduction-and-sustainable-chemistry.html
([94]) https://zeropm.eu/
([95]) https://zeropm.eu/alternative-assessment-database/
([96]) https://marketplace.chemsec.org/
([97]) https://chemsec.org/knowledge/beyond-pfas/
([98]) https://substitution.ineris.fr/en
([99]) https://substances.ineris.fr/
([100]) https://www.subsportplus.eu/subsportplus/EN/Home/Home_node
([101]) Ineris, 2024, « Etat des lieux des usages des PFAS et alternatives documentées », réf : 209433-2799431

Table 2 Sectors of use, availability of alternatives and references on the substitution of PFAS

Sectors of use	No. of app.	Availability of alternatives (No. of applications)						Useful references beyond the REACH restriction dossier
Fluorinated gases	29	12	4	1		9	3	Chemsec
Biocides	4		4					
TULAC([102])	20	15	3			2		RISE DTSC Danish Ministry of the Environment Chemsec
Medical devices	20	3	4		4	9		
Manufacture of pluoropolymers	28				3	25		
Food contact materials and packaging	4	1	2		1			Washington State Department of Ecology OECD Clean Production Action Chemsec
Transport	27	12	4	1	4	6		
Construction products	17	8	1	2	1	5		The Danish Environmental Protection Agency
Electronics and semiconductors	29	5	2		8	14		Chemsec
Lubricants	40	39	1					The Danish Environmental Protection Agency
Petroleum and mining	10	2	2	3		2	1	Norwegian Environment Agency
Energy sector	19	6	2	2	4	3	2	Chemsec
Metal plating and manufacture of metal products	4	1		1		2		UBA
Cosmetics								OECD
Consumer mixtures	15	4	3			8		OECD
Fire fighting foams	5	5						EC / ECHA

Note: The numbers (No. of applications) are based on Ineris (2024). Colour code on the availability of alternatives, dark green: alternatives to PFAS are available ; light green: according to different sources some alternatives are available or at research and development stage; yellow: there is disagreement between different sources on the availability of relevant alternatives; orange: the availability of an alternatives is uncertain or still at a research and development stage; red: No alternatives to PFAS; grey: No information on the availability of alternatives.

([102]) Textiles, Upholstery, Leather, Apparel, Carpets

7. Conclusion

The benchmark of existing ELVs/EQSs on PFAS used in industry produced for this report is mainly based on feedback of six European countries and five non-European countries. State of the art was completed thanks to experts' opinions and monitoring of current projects regarding PFAS.

For atmospheric emission, only one country (The Netherlands) has reported ELVs for three PFAS; in November 2024, 289 additional PFAS have been included to their national list of substances of high concern, with ELV based on vapour pressure. In term of monitoring, methods begin to be developed and harmonised.

Regulation is more advanced for PFAS in water, even though a lot of discussions are on-going regarding the best way to regulate (in terms of compounds/parameters), in connection with the development of monitoring methods. Wastewater is up until now less investigated than ground- and surface water.

Regarding wastewater, Belgium (Flanders) has reported indicative ELVs for 42 individual compounds; there is no national ELV in force but ELVs have to be fixed case by case in permit of each industrial site, and to be updated regularly. In Italy, a draft law has been under preparation since 2021 to plan ELVs for 24 individual compounds, for the sum of these individual compounds, and also for a "Total PFAS" parameter; but the promulgation of the law is not yet effective. US-EPA reports that ELV can be set in permit, with an example from Minnesota.

Regarding groundwater, outside Europe, Canada has reported an indicative value for PFOS and Japan is planning values for PFOS and PFOA.
In Italy, EQSs are in force for 5 individual compounds. In Sweden, indicative values are proposed to Water Authorities for 11 individual compounds; but a new approach is underway, based on the current discussion for groundwater at European level, that means for 24 individual compounds expressed in equivalent PFOA.

Regarding surface water, some European countries go further than the current European regulation, which concerns only PFOS. In Italy, at national level, EQSs are in force for 5 individual compounds; at the same time, at regional level of Piedmont region, EQSs are in force for 14 individual compounds (including PFOS) and 2 groups (called "Other PFASs" molecules with 3-6 carbon atom chains or of 7 carbons atoms or more, including new generation PFASs). In The Netherlands, EQSs are in force for 2 additional individual compounds and in Sweden, 11 compounds are on the list.
Canada has an indicative value for PFOS, much higher than current European one. And Japan plans to set EQSs for PFOS and PFOA.

To improve population protection, the number of individual compounds regulated or monitored is increasing, but the "substances approach" can be questioned due to the high number of compounds, by-products and degradation products; some other parameters such as "Sum of PFAS" or "Total PFAS" begin to appear in regulation. Each approach has its own limitation:

- Listing the individual compounds and calculating a sum is relevant only if adequate compounds have been considered; if not, thresholds are not useful to protect humans and environment. Moreover, the relative toxicity of each compound has to be taken into account through appropriate risk factors; that is why discussions are on-going at EU level to calculate a response factor based on one compound (usually PFOA).

  For the "Sum of PFAS", reporting of measurements has also to be defined precisely in order to get comparable results from one site to another, or to assess the ELV compliance. It is necessary to define the way to report concentrations below the LoQ for all the sampled fractions (dissolved/particulate in water, gaseous/particulate in air emissions) and for the different compounds. The harmonization for the determination of LoQs is also important.

- Setting threshold for “Total PFAS” does not require the identification of the list of potential compounds but involves being able to measure and interpret this parameter. That is why numerous studies are ongoing to develop index methods, such as AOF, EOF or TOP assay. For the time being, the suitability of these methods is not proven, and they are not harmonised nor standardised.

At EU level, the current discussions on PFAS threshold provisions in the Drinking Water Directive, Groundwater Directive, and Environmental Quality Standards Directive, should ensure a consistent approach between standards and monitoring, mainly for Total PFAS. Moreover, the decisions to be taken under the Water Framework Directive to establish EQSs will be fundamental to the harmonised establishment of ELVs. Furthermore, as part of the Sevilla process, BATs on PFAS have been introduced in the recently revised BREFs, but without any associated BAT-AELs. It may be possible to define BAT-AELs in future revisions.

Ongoing developments of methods for PFAS monitoring (in particular those developed in projects or partnerships as Promisces and Parc) and of PFAS measurement campaigns (as done or ongoing in several countries) will allow to have a better understanding of the situation and set new thresholds in the coming months or years.
Some projects in progress also suggests delving into risk assessment from groups of PFAS with same risk profile capitalising on information on exposure, hazard and the use of new risk assessment modelling methods (e.g. Promisces and Parc).

Regarding substitution, the regulatory initiatives currently underway are leading to an ever-increasing inventory of substitution possibilities. And this work suggests:

- that substitution is likely to be complicated in certain sectors, and will require major R&D efforts (medical sector, energy transition),
- that substitution possibilities exist for most applications.

List of abbreviations

Abbreviation	Name	Reference
AA-EQS	Annual Average Environmental Quality Standard	
AOF	Adsorbable Organic Fluorine	
ASTM	American Society for Testing and Materials	astm.org
ARPAE	Regional Agency for Prevention, Environment and Energy of Emilia-Romagna	
BAT	Best Available Technique	
BREF	BAT Reference Document	eippcb.jrc.ec.europa.eu
CCME	Canadian Council of Ministers of the Environment	
CEPA	Canadian Environmental Protection Act	
CEQGs	Canadian Environmental Quality Guidelines	
CEN	European Committee for Standardization	
CLP	Classification, labelling and packaging of chemicals	echa.europa.eu/legislation
CMR	Carcinogenic, mutagenic and toxic for reproduction	
COP	Conference on Parties	
CSCL	Regulation of Manufacture and Evaluation of Chemical Substances (Japan)	
DIN	German Institute for Standardization (Deutsches Institut für Normung)	
DWD	Drinking Water Directive	
ECCC	Environment and Climate Change Canada	canada.ca/en/environment-climate-change.html
ECHA	European Chemicals Agency	echa.europa.eu
EDCs	Endocrine Disrupting Chemicals	
EEA	European Environment Agency	eea.europa.eu
EFSA	European Food Safety Authority	efsa.europa.eu
ELGs	Effluent Limit Guidelines	
ELV	Emission Limit Value	
EMC	Air Emission Measurement Center from US EPA	
EMN PolMo	European Metrology Network for Pollution Monitoring	euramet.org/european-metrology-networks/pollution-monitoring/
EPA	Environmental Protection Agency	
EQS	Environmental Quality Standard	
EQSD	Environmental Quality Standard Directive	
EU	European Union	
EURAMET	European Association of National Metrology Institutes	
FAQ	Frequently Asked Questions	
FEQGs	Federal Environmental Quality Guidelines (Canada)	
GC/MS	Gas Chromatography / Mass Spectrometry	
GWD	Groundwater Directive	environment.ec.europa.eu/topics/water/groundwater
IED	Industrial Emissions Directive	

Abbreviation	Name	Reference
iPM(T)s	industrial Mobile, Persistent and Potentially Toxic chemicals	
ILCs	InterLaboratory Comparisons	
ISO	International Organization for Standardization	
KEMI	Swedish Chemicals Agency (Kemikalieinspektionen)	
LC-MS/MS	liquid chromatography coupled with tandem mass spectrometry	
LoQ	Limit of Quantification	
MAC-EQS	Maximum Allowable Concentration – Environmental Quality Standard Measured Environmental	
MDL	Method Detection Limit	
MRM	Multiple Reaction Monitoring	
NPDES	National Pollution Discharge Elimination System (USA)	
NTS	Non-target screening	
OAQPS	Office of Air Quality Planning and Standards (US)	
OECD	Organisation for Economic Co-operation and Development	
ORD	Office of Research and Development (US)	
OTM	Other Test Methods	
PARC	Partnership for the Assessment of Risks from Chemicals	Eu-parc.eu
PBT	Persistent, Bioaccumulative and Toxic	
PFAA	PerFluoroAlkyl Acids	
PFAS	Per- and PolyFluoroAlkyl Substances	
PFBA	Perfluorobutanoic acid	CAS 375-22-4
PFBS	Perfluorobutane sulfonic acid	CAS 375-73-5
PFCA	PerFluoroalkyl Carboxylic Acids	
PFDA	Perfluorodecanoic acid	CAS 335-76-2
PFDS	Perfluorodecane sulfonic acid	CAS 335-77-3
PFDoA	Perfluorododecanoic acid	CAS 307-55-1
PFDoDS	Perfluorododecanesulfonic acid	CAS 79780-39-5
PFHpA	Perfluoroheptanoic acid	CAS 375-85-9
PFHpS	Perfluoroheptane sulfonic acid	CAS 375-92-8
PFHxA	Perfluorohexanoic acid	CAS 307-24-4
PFHxS	Perfluorohexane sulfonic acid	CAS 355-46-4
PFNA	Perfluorononanoic acid	CAS 375-95-1
PFNS	Perfluorononane sulfonic acid	CAS 68259-12-1
PFOA	Perfluorooctanoic acid	CAS 335-67-1
PFOS	Perfluorooctane sulfonic acid	CAS 1763-23-1
PFPeA	Perfluoropentanoic acid	CAS 2706-90-3
PFPeS	Perfluoropentanoic sulfonic acid	CAS 2706-91-4
PFSA	PerFluoroalkane Sulfonic Acids	
PFTrDA	Pentacosafluorotridecanoic acid	CAS 72629-94-8
PFTrDS	Perfluorotridecanesulfonic acid	CAS 791563-89-8
PFUnDA	Perfluoroundecanoic acid	CAS 2058-94-8

Abbreviation	Name	Reference
PFUnDS	Perfluoroundecane sulfonic acid	CAS 749786-16-1
POPs	Persistent Organic Pollutants	
PRTR	Pollutant Release and Transfer Register	
PTFE	Polytetrafluoroethylene	
QRL	Quantitative Reporting Limit	
RAC	Risk Assessment Committee (EU)	
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals	echa.europa.eu/legislation
REX	Experience feedback	
RIVM	Dutch National Institute of Public Health and the Environment (Rijksinstituut voor Volksgezondheid en Milieu)	rivm.nl/
RPF	Relative Potency Factor	
SEAC	Socio-Economic Analysis Committee (UE)	
SNPA	Italian National Environmental Protection System	
SPE	Solid-phase extraction	
SVHC	Substances of Very High Concern	
TBELs	Technology-based Effluents Limitations (US)	
TOC	Total Organic Carbon	
TOF	Total OrganoFluorine	
TOP	Total Oxidizable Precursor assay	
TRI	US Toxics Release Inventory	
TSS	Total suspended solids	
TULAC	Textiles, Upholstery, Leather, Apparel, Carpets	
TXT	Textile	
UNEP	United Nations Environment Program	unep.org
US EPA	United States Environmental Protection Agency	
VITO	Flemish Institute for Technological Research (Vlaamse Instelling voor Technologisch Onderzoek)	vito.be/en
VLAREM	Flemish Environmental Permit Regulations (Vlaams Reglement betreffende de Milieuvergunning)	
VMM	Flanders Environment Agency	en.vmm.be
vPvB	very Persistent and very Bioaccumulative	
WFD	Water Framework Directive	environment.ec.europa.eu/topics/water/water-framework-directive_en
WQBELs	Water quality-based Effluents Limitation (US)	
WT	Waste Treatment	
ZZS	National Substances of High Concern (in Dutch: Zeer Zorgwekkende Stoffen)	

References

All regulatory texts and information sheets are reported in footnotes directly in the report. References below only refers to reports or guidelines, and OTM standard.

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US EPA, Air Emission Measurement Center, *OTM-50 Sampling and Analysis of Volatile Fluorinated Compounds from Stationary Sources Using Passivated Stainless-Steel Canisters,* OTM-50

PARC, March 2024, *Inconsistencies in the EU regulatory risk assessment of PFAS call for readjustment*, Environment International 186 (2024) 108614, Inconsistencies in the EU regulatory risk assessment of PFAS call for readjustment

Annex 1 Contacts

<table>
<tr><th rowspan="2">Country</th><th rowspan="2">Organisation</th><th colspan="2">Participants</th><th rowspan="2">Answer</th></tr>
<tr><th>Name</th><th>Position</th></tr>
<tr><td rowspan="3">Belgium (Flanders)</td><td>Flemish government
Department of environment</td><td>Annelies Baert
Tom Boonen</td><td>Environmental Policy Advisor
Environmental Policy Advisor</td><td rowspan="3">Questionnaire fulfilled and sent back on 14/06/2024
Call 08/07/2024</td></tr>
<tr><td>Flemish EPA (VMM)</td><td>Lut Hoebeke</td><td></td></tr>
<tr><td>VITO</td><td>Sander Vander Aa
Jelle Hofman</td><td>Researcher
R&D Researcher</td></tr>
<tr><td>Canada</td><td>Environment and Climate Change Canada, Government of Canada</td><td>Anne Monette</td><td>Manager</td><td>Questionnaire fulfilled and sent back on 13/06/2024</td></tr>
<tr><td>France</td><td>INERIS (French National Institute for Industrial Environment and Risks)</td><td>Hélène Partaix</td><td>R&D Engineer</td><td>As technical support for the ministry of the Environment</td></tr>
<tr><td rowspan="3">Italy</td><td>Arpae Emilia-Romagna (Regional Agency for Prevention, Environment and Energy of Emilia-Romagna)</td><td>Adele Lo Monaco</td><td>Head of Technical Addressing and Environmental Reporting Service</td><td rowspan="3">Email on 13/05/2024 and 04/06/2024

Other potential contacts:
ARPA Veneto: General Director: ing. Loris Tomiato
ARPA Piemonte: General Director: ing. Secondo Barbero
ISPRA :
General Director: dr.ssa Maria Siclari
Director of the Department for Evaluation, Controls and Environmental Sustainability: ing. Valeria Frittelloni
Environmental Ministry: Direzione generale uso sostenibile del suolo e delle risorse idriche (USSRI) General Director: Dott. Giuseppe Lo Presti</td></tr>
<tr><td>Irsa
(Water research institute)</td><td>Sara Valsecchi</td><td></td></tr>
<tr><td>ARPA Piemonte
(Regional Agency for Environmental Protection of Piedmont)</td><td>Francesca Vietti</td><td>Production Operations Manager</td></tr>
</table>

Country	Organisation	Participants		Answer
		Name	Position	
Japan	Environmental Health Department, Ministry of the Environment	Wakana Matsunami Koki Takaki	Chemical Safety Division	Questionnaire fulfilled and sent back on 16/05/2024 Call on 13/05/2024
Korea	National Institute of Chemical Safety (NICS)	Sun Kyung Park Ph. D.	Deputy Director Accident Prevention and Examination Division	Questionnaire fulfilled and sent back on 25/07/2024
Netherlands	RIVM (National Institute for Public Health and the Environment)	Els Smit	Senior scientific advisor	Questionnaire fulfilled and sent back on 04/07/2024
Spain	Ministry for Ecological Transition and the Demographic Challenge	Olga Fraile Paredes	Head of Industrial Sustainability Area (SGALSI)	Email from 17/04/2024
Sweden	Swedish Environmental Protection Agency Waste and Chemicals Unit	Markus Klar	Chemicals Administrative Official	Email from 11/09/2024
Switzerland	Federal Department of the Environment, Transport, Energy and Communications DETEC Federal Office for the Environment FOEN Air Pollution Control and Chemicals Division	Simon Liechti	Head of division	Questionnaire fulfilled and sent back on 24/09/2024
USA	U.S. Environmental Protection Agency Office of Pollution Prevention and Toxics TRI Regulatory and Policy Branch	Stephanie Griffin		Questionnaire fulfilled and sent back on 23/09/2024

Annex 2 Questionnaire

Questions on PFAS ELVs/EQS

- Country:
- Organization:
- Participants:

Questions:

1/ ELVs

- Are there any discussions underway to set ELVs for industry? If so, same questions as for existing ELVs.

- Does it exist national provisions to set ELV's in atmospheric and/or water emissions?
  - If so, what are the industrial sectors concerned?
  - If so, in which national(s) text(s)?
  - Provide the link to access texts:
  - Are ELVs set (also) at local level/in permit? Can you share some examples?
  - For which compound(s) are/is ELVs set? What is the associated averaging period?
  - Could you provide an existing synthesis of ELVs at national level?
  - Are ELVs for sum or total PFAS set?
  - Does it exist ELV for integrative parameters such as AOF (Adsorbable Organic Fluorine) or EOF (Extractable Organic Fluorine)?
  - What is the purpose of monitoring?

2/ EQS

- Are there any discussions underway to set environmental quality standards (EQS)?

- Does it exist national provisions to set EQS in water emissions?
  - If so, in which national(s) text(s)?
  - Provide the link to access texts.
  - Are EQS set (also) at local level/in permit? Can you share some examples?
  - For which compound(s) are/is EQS set? Are there any EQS for sum or total PFAS? Could you provide an existing synthesis of EQS at national level?

3/ Monitoring

- What are the analytical method/standard used or required? Are the methods associated to individual compounds or is it an integrative method?
- What are the associated LoQ?
- What is the purpose of monitoring?
- What is the availability of laboratories capable of carrying out the measurements?

4/ Measurement campaigns

- Are there any measurement campaigns underway or planned? At national and/or site level?
- If so, for which industrial sectors? How were they chosen?
- What are the compounds targeted? Or the integrative parameters?
- What are the measurements methods applied?
- What are the expected outputs?
- Do you know what are the ranges of costs associated with the different monitoring technics?

5/ Reporting

- Are the measurement results reported at national level? If yes, is it public data and the link to the database can it be provided?
- For other PRTRs: How fast is it the addition of new compounds in the PRTR since they are proposed? Who proposes it? What is the process to add them to the list?

6/ Status of the compounds (Outside EU)

- What is the regulatory status of PFAS compounds that have ELVs/EQS (banned/restricted…)?

Annex 3 Other projects

Several ongoing European projects and partnerships are dealing with chemicals management and assessment, especially for PFAS. Some of them are presented below, with global objectives and examples of actions. For more information, data and contacts are available on the indicated websites.

PROMISCES

Promisces (https://promisces.eu/)
The PROMISCES Project is funded by the European Union under the Horizon 2020 Framework Programme to support Europe's Green Deal. It runs from November 2021 to April 2025.
PROMISCES means Preventing Recalcitrant Organic Mobile Industrial chemicalS for Circular Economy in the Soil-sediment-water system.

PROMISCES aims to increase the circularity of resources by overcoming barriers associated with the presence of per- and poly-fluoroalkyl substances (PFAS) and industrial Mobile, Persistent and Potentially Toxic chemicals (iPM(T)s) in the soil-sediment-water system. Main objectives, with current progress, are presented below:

- Enhance the ability to detect and monitor PFAS
  Ten targeted methods for a variety of matrices (drinking-, surface- and groundwater) were developed; a final set of 57 PFAS can be analysed. Ongoing works include the development of global PFAS approaches such as the AOF and TOP Assay methods.
- Improve the predictability of persistency and mobility of PFAS by developing in silico models specific to the unique properties of PFAS.
- Provide risk management solutions:
  PROMISCES develops and demonstrates effective and sustainable technologies to remediate PFAS in a variety of matrices (soils, sediments and water).
- A database mapping 492 substances has been developed, to allow the establishment of groups of PFAS compounds, with similar properties, facilitating their regulation.
  A Policy brief has been delivered addressing decision-making and management strategies on PFAS.

ZeroPM

ZeroPM (https://zeropm.eu/)
ZeroPM is a research project funded by EU's research and innovation funding programme, Horizon 2020. ZeroPM will enable the EU Green Deal's ambition towards Zero Pollution of Persistent, Mobile Substances.
The complex relationship between the necessity of prevention, prioritization and removal approaches to reduce persistent and mobile substance pollution will be addressed in ZeroPM via the establishment of an evidence-based multilevel framework.
There are 8 central work packages in ZeroPM, which are all interconnected. WP1 will be monitoring and in contact with all of these work packages, as listed below:

- WP1 Project Management
- WP2 Alternatives Assessment
- WP3 Policy
- WP4 Market Transition
- WP5 Substance Grouping
- WP6 Risk Assessment
- WP7 Technical Solutions
- WP8 Dissemination and Communication

Information can be found on the dedicated website.

PARC

Partnership for the Assessment of Risks from Chemicals (eu-parc.eu)
The Partnership for the Assessment of Risks from Chemicals (PARC) aims to develop next-generation chemical risk assessment to protect human health and the environment. It supports the European Union's Chemicals Strategy for Sustainability and the European Green Deal's "Zero pollution" ambition with new data, knowledge, methods and tools, expertise and networks.
There are four thematic areas:

- Risk assessment
- Tools and resources
- Building capacities
- Science to policy

Regarding PFAS, some actions are anchored in Work Package 4 "Environmental and multisource monitoring".

Two actions on PFAS are being conducted as part of a three-year pilot project that began in 2023 and will continue until 2025.
The first action aims to generate a baseline for PFAS, which can be used in connection with:

- Assessment of environmental levels caused by several decades of production and use of these chemicals;
- Monitoring the trends in environmental PFAS concentrations as a result of policy measures;
- Identifying hot spots as locations where concentrations are significantly higher than the baseline.

It was decided to base the study on existing data from national or regional monitoring campaigns and literature. New sampling campaigns are not included in this baseline approach but may be considered for future projects if significant data gaps are identified.

The second action consists of 18 case studies aimed at better understanding the fate and pathways of PFAS from sources to aquatic recipients. These studies address a significant gap regarding the role of precursors. In this context, new monitoring schemes for the entire PFAS family are applied, including non-target analysis and specific methods (e.g., TOP assays) to support risk assessment in line with EU regulatory frameworks such as the Water Framework Directive, the Drinking Water Directive, and the ECHA PFAS restriction proposal.

More details about these actions can be found in the PARC deliverable AD4.5 ([103])"Technical specifications of the study: Project design, hypotheses and research questions as well as analytical procedures including QA/QC and data flows" (published in November 2023).

In Work Package 5, actions are focused on the hazard assessment and model development. Goals of WP 4 and 5 is to provide enough data for risk assessment (Work Package 6).

All scientific publications([104]) or deliverables are available on PARC's website.

A scientific peer-reviewed article "Inconsistencies in the EU regulatory risk assessment of PFAS call for readjustment"([105]) by Reinikainen et al. 2024 was published as a deliverable from the PARC project. The abstract is reproduced below:

([103]) PARC, AD4.5, Technical specifications of the study
([104]) Scientific Publications | Parc (eu-parc.eu)
([105]) Inconsistencies in the EU regulatory risk assessment of PFAS call for readjustment

“Recognition of per- and polyfluoroalkyl substances (PFAS) as widespread environmental pollutants and a consequent risk to human health, has recently made the European Union (EU) adopt several regulatory measures for their management. The coherence of these measures is challenged by the diversity and the ubiquitous occurrence of PFAS, which also complicates the EU’s endeavour to advance justified, harmonised, and transparent approaches in the regulatory assessment of chemical risks. Our study critically reviews the European approach for the risk assessment of PFAS, by applying a comparative analysis of the current and pending regulatory thresholds issued for these chemicals in water bodies, drinking water, and certain foodstuffs. Our study shows that the level of health protection embedded in the studied thresholds may differ by three orders of magnitude, even in similar exposure settings. This is likely to confuse the common understanding of the toxicity and health risks of PFAS and undermine reasonable decision-making and the equal treatment of different stakeholders. We also indicate that currently, no consensus exists on the appropriate level of required health protection regarding PFAS and that the recently adopted tolerable intake value in the EU is too cautious. Based on our analysis, we propose some simple solutions on how the studied regulations and their implicit PFAS thresholds or their application could be improved. We further conclude that instead of setting EU-wide PFAS thresholds for all the environmental compartments, providing the member states with the flexibility to consider case-specific factors, such as regional background concentrations or food consumption rates, in their national regulatory procedures would likely result in more sustainable management of environmental PFAS without compromising the scientific foundation of risk assessment, the legitimacy of the EU policy framework and public health.”

NORMAN

norman-network.net
Norman is a network of reference laboratories, research centres and related organisations for monitoring of emerging environmental substances. Today, the network includes over 90 members from leading organisations across Europe, North America, Asia, and Australia.
The NORMAN network enhances the exchange of information on emerging environmental substances, and encourages the validation and harmonisation of common measurement methods and monitoring tools so that the requirements of risk assessors and risk managers can be better met. It specifically seeks both to promote and to benefit from the synergies between research teams from different countries in the field of emerging substances.

NORMAN organises the development and maintenance of various web-based databases for the collection & evaluation of data / information on emerging substances in the environment. The different modules are connected via a unique identifier and the constitute the NORMAN Database System (https://www.norman-network.com/nds/).
Main database is NORMAN SusDat([106]), a "living database" compiling information provided by NORMAN network members and external contributors via the NORMAN Suspect List Exchange (NORMAN-SLE) initiative. NORMAN SusDat merges the many chemical lists on the SLE into a common format and includes all data suitable for screening purposes. The NORMAN-SLE website([107]) includes more than 10 lists specifically addressing PFAS, covering more than 4000 compounds.
Building the capacity of laboratories in Europe and globally by systematic organisation and initiation of international Collaborative Trials is part of the regular activities of the NORMAN network. More than 20 Collaborative Trials have been organised by NORMAN since 2006 on a wide range of methods, including non-target screening in water, sediment, indoor dust and biota, in vitro and in vivo bioassays and passive sampling.
A Proficiency Test regarding "PFAS according to EU drinking water directive" (reference PT 7/22 TW S4) was organised in July 2022 by the University of Stuttgart. Report([108]) is available.
Several PFAS analytical exchanges were organised. For instance, in 2021, a questionnaire-based exchange was conducted by the Environment Agency (UK) in collaboration with other agencies and universities, to identify the PFAS laboratories were focusing on, current detection limits in various matrices, adopted analytical techniques, and future plans to better understand PFAS environmental exposure. A second analytical exchange survey was organised in 2022 on TOP Assay Method Comparison. The results of these studies are published on the NORMAN website https://www.norman-network.net/?q=interlab-studies (([109]) published in April 2023 and ([110]) published in February 2022).
In the Passive sampling Working Group, an intercomparison study on passive sampling and Not-Target Screening for PFASs was launched in 2024. The description is available in the NORMAN Joint Programme of Activities 2024([111]).

([106]) NORMAN Substance Database (norman-network.com)
([107]) NORMAN Suspect List Exchange | NORMAN (norman-network.net)
([108]) Norman, Report for proficiency test "PFAS according to EU drinking water directive"
([109]) Norman, Report on PFAS analytical exchange - TOP Assay Method comparison, 2023
([110]) Norman, Report on PFAS analytical exchange, 2022
([111]) Norman, Joint program of activities for 2024

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