PFAS in soils and biosolids: Narrowing the standardisation gap

Towards harmonised standards for PFAS detection in soils and biosolids

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Executive summary

Per- and polyfluoroalkyl substances (PFAS) contamination poses a challenge to soil health, food systems, ecosystems and humans. Discussion has largely focused on these persistent "forever chemicals" in consumer goods, like food contact materials and textiles, and in the water environment, especially drinking water. However, **PFAS can enter soils directly** through several means such as contaminated irrigation water, PFAS-containing pesticides and land application of treated sewage sludge.

A **universal ban on PFAS** usage is the most effective way to avoid and minimise damage which has already been caused by the proliferating use of these chemicals. Only recently adopted, the Soil Monitoring and Resilience Directive (EU) 2025/2360) now requires Member States to monitor soil contamination as part of a harmonised soil-health assessment framework. Other PFAS-related policies such as REACH are increasing the need for reliable and comparable PFAS data.

These regulatory processes depend on validated and comparable analytical methods – but a major gap remains: as methods continue to evolve, there is currently no harmonised and validated European or international analytical standard for comprehensive PFAS determination in solid matrices, such as soils and biosolids. Robust and reproducible analytical measurement standards are essential to effectively and accurately detect and monitor current PFAS contamination levels in soils and biosolids. Harmonisation and data integrity is critical: differences in methods or sampling techniques, instrumental calibration and analysis and data processing can produce inconsistent and incomparable PFAS concentrations potentially affecting whether a site is classified as contaminated or whether a regulatory threshold is exceeded.

Closing these gaps is not merely a technical exercise—it is a prerequisite for delivering comparable data and enabling the EU's PFAS and soil policy frameworks to function effectively for comprehensive environmental protection. This technical paper provides recommendations for **robust standardisation for PFAS detection in soils and biosolids**.

Robustness requires a sufficiently broad and adaptable analytical scope with consistent and complementary approaches, capable of revealing the "hidden" PFAS burden, including ultra-short-chain compounds such as TFA and emerging PFAS; support for the development of complementary methods for precursor and total organofluorine assessment; harmonised sampling and reporting conventions; aligned terminology with OECD definitions; clear procedures for expanding analytical scope as scientific knowledge evolves. Already developed standards for PFAS in water analysis can provide lessons, but limitations of its transferability to more complex and heterogeneous solid matrices such as soil need to be taken into account.

Contents

PFAS degrades soil health across the globe

Novel entities – including synthetic chemicals like PFAS - are one of the six planetary boundaries that our society has currently exceeded, suggesting that Earth is now well outside of the safe operating space for humanity.[1]

Discussion has largely focused on PFAS in consumer goods, e.g. food packaging and textiles. Less attention has been given to the **role of PFAS in soils and agriculture**, notwithstanding the fact that chemical contaminants like PFAS are currently degrading soil health across the globe. Soils act both as a reservoir for PFAS (receiving and storing these substances when emitted from contaminated products or directly applied to soils) and as a source of PFAS (releasing these substances into waterways and the wider environment).

Once in soil, long-chain PFAS tend to bind to soil organic matter and persist close to their point of entry, whereas short- and ultra-short-chain PFAS are far more mobile and migrate readily toward ground and surface waters.[2]

Due to their high environmental persistence and toxicity, soil contamination by PFAS is a serious concern that negatively affects soil health and soils' capacity to provide ecosystem services such as nutrient cycling and harbouring soil biodiversity.[3] PFAS can be taken up by food crops and grazing livestock, contaminating the food web and drinking groundwater, thus impacting human health and ecosystems.

While it is necessary to avoid and minimise further damage to soils by ensuring that a ban on PFAS[4] and remediation methods for contaminated sites are in place, other avenues must be explored in the meanwhile. **Robust analytical standards** offer an opportunity to effectively **detect and monitor** current PFAS contamination levels in soils. Nevertheless, challenges exist and need to be addressed.

What are PFAS?

Per- and polyfluoroalkyl substances (PFAS) are a large chemical class of synthetic substances characterised by carbon-fluorine bonds that are among the strongest in organic chemistry, giving them **extreme persistence, high thermal and chemical stability, and resistance to most environmental degradation pathways.**[5] These properties are sought after in many industrial production processes but come at a cost: once released into the environment, the fluorinated parts of PFAS resists degradation. Unlike biodegradable organic substances, PFAS cannot be broken down naturally into carbon dioxide or methane by bacteria, enzymes, or sunlight, earning them the name of **'forever chemicals'.**[6]

The class spans several **thousand individual substances**, from **long-chain** perfluoroalkyl carboxylic and sulfonic acids to **ultra-short-chain** acids, and include both directly manufactured **compounds** and **precursors** that transform into persistent PFAS **transformation products** in the environment.[7] [8] From the moment PFAS are produced to the moment they are found in the environment, PFAS may undergo changes that make them distinct from their original form. Transformation products are thus more challenging to be identified, monitored, and regulated.[6]

For example, **trifluoroacetic acid (TFA)** - the smallest perfluoroalkyl carboxylic acid – which is now recognised as by far the most abundant in the environment[9], arises not only from direct industrial use but as a transformation product of numerous precursor PFAS, including several fluorinated refrigerant gases, pharmaceuticals and, notably for agricultural soils, PFAS-containing pesticides.[10] Because TFA is highly water-soluble, weakly retained by soil, and shows no evidence of further environmental degradation, it behaves quite differently from longer-chain PFAS: rather than accumulating near its point of entry, it migrates readily *(mobile contaminant*) toward ground and surface waters while still being detectable (*persistent contaminant*) in soils, plants, rainwater and drinking water worldwide.[11]

Growing scientific evidence demonstrates the potential impacts of the ultra-short-chain fraction[i], even though regulatory limits and toxicological reference values for compounds such as TFA remain far less developed than those for legacy long-chain PFAS.[11]

Once in the environment, PFAS persistence results in prolonged exposure of organisms, which can eventually lead to bioaccumulation, trophic transfer, and consequent adverse effects on environmental health.[12] Exposure to PFAS can lead to serious problems for human health as well, including cancer, infertility, birth defects and immune system disorders.[6]

Soil contamination by PFAS

PFAS have been detected in **agricultural soils, industrial sites and landfills** across Europe, generally at concentrations reflecting **proximity to point sources** (fluorochemical manufacturing, firefighting-foam use at airports and firefighting-training areas, textile and paper mills), but increasingly also in soils with no obvious point-source history, consistent with **diffuse atmospheric and agricultural pathways.**[13] [14] [15]

The three settings differ importantly in exposure patterns: **industrial sites and firefighting-training facilities** generate localised but often severe hotspots: contaminated soil excavated from a former fire-training facility in Norway, for example, has been used as a test matrix for evaluating PFAS remediation approaches precisely because of its high and well-characterised legacy **aqueous film-forming foam (AFFF)** contamination[16] [17]. **Landfills** act as a slow, long-term secondary source, as waste consumer products containing PFAS contaminate surrounding soils and PFAS are leached into groundwaters (and/or landfill leachates) long after disposal.[2]

Agricultural soils are typically affected by pollution that comes from many widespread or scattered sources rather than one identifiable source, making it difficult to trace back to a single location or discharge point. Diffuse inputs usually are represented by irrigation with contaminated water or application of **PFAS-containing pesticides** which can directly enter the environment in different forms. For example, as a) active ingredients – controlling and killing targeted pests; b) "inert" ingredients or co-formulants, supporting the application of the pesticide; c) leaching from containers in which pesticides are stored and during manufacturing processes.[18] A 2023 study from PAN Europe showed that 12% (37) of the synthetic active ingredients authorised for pesticide use in the European Union are PFAS.[19]

Biosolids and treated sewage sludge are another particularly important, and often underestimated, PFAS contamination pathway to agricultural soils. Studies of European wastewater treatment plants have documented a broad suite of perfluorinated carboxylic acids, sulfonates and sulfonamides consistently partitioning from the wastewater phase into the solid sewage sludge fraction, confirming sludge as a continuous PFAS reservoir rather than an incidental PFAS carrier[20]. Treated sewage **sludges are then applied to agricultural land as an organic fertiliser or soil improver, creating a direct route from urban and industrial PFAS use to food and the environment,** via crop uptake and release into ground and surface waters.

[i] In June 2026, ECHA's Committee for Risk Assessment adopted its opinion on a German proposal for the harmonized classification of TFA and its salts, recommending classification as toxic to reproduction (Category 1B, H360Df) and as persistent, mobile and toxic (PMT) and very persistent and very mobile (vPvM), on the basis of developmental toxicity observed in rabbit and rat studies.

The need for data standardisation

Technical measures, such as standards, provide guidelines for various industries, - including the chemical sector - and if robust, play a crucial role in ensuring safety, quality, and environmental responsibility in chemical testing, measurement, production and handling.

They cover key aspects such as sampling, laboratory practices, quality control, documentation, safety measures, and data analysis, and are sometimes used to implement regulations. Environmental standards translate scientific methodologies into legally and commercially trustworthy operating procedures for addressing a topic of concern[21].

For PFAS concentrations in soils, where regulatory values in several countries sit in the low µg/kg range, the **analytical method itself becomes** decisive: **small differences in extraction efficiency, clean-up, calibration, quality check or data analysis and reporting practice can determine whether a soil sample or sampled area is classified as contaminated, or whether a compliance threshold is met**.

However, standardisation within PFAS-contaminated soils present several challenges:

- **Limited availability of analytical standards:** Chemical analytical standards are only available for 6% of the 10,000 PFAS in commercial use, and 2% of industrial PFAS. Although PFAS have been widely detected in soils with a broad range of concentrations, current **analytical methodologies to detect and analyse PFAS are restricted to a small group of known PFAS**.
- **Lack of harmonised criteria for soil contamination assessment**: agreed-upon criteria for identifying and analysing "significant" soil contaminations or hotspots, i.e. what soil concentration constitutes unacceptable risk, are currently absent.
- **Lack of standardised sampling guidance** specific to PFAS in heterogeneous solid matrices, particularly waste materials and biosolids, where cross-contamination risks (e.g. from PTFE-containing sampling equipment) are pronounced. **Sampling protocols are not harmonised, and differences in representative soil sampling depth, sample preparation and in the use of metrics lead to inconsistent PFAS concentration reporting.** This variability affects the interpretation and decision-making, having significant implications for data analysis and risk assessment. Harmonisation of data collection, sampling, and analytical methods is essential to develop effective soil contamination monitoring and management strategies.
- **Insufficient biosolids testing methodologies**: The issue of biosolids containing PFAS and other contaminants being applied to agricultural soils is global and pressing. This practice occurs in the EU, UK and US with **very few, if any, limits on contaminants or adequate testing methods to determine the levels of these contaminants in the biosolids and receiving soils**. Different countries and states have set very different PFAS thresholds, with no common measurement standard behind them.

PFAS regulatory developments in the EU

Regulating PFAS in products - REACH and PPWR

The EU is pursuing different measures to phase out PFAS under the EU Chemicals Strategy for Sustainability. The **EU regulation for the Registration, Evaluation, Authorisation, and Restriction of Chemicals (EC 1907/2006),** also known as REACH plays a central role in managing PFAS risks, targeting specific PFAS groups, based on bioaccumulation, persistence and toxicity profiles**.** The universal PFAS restriction, submitted by authorities in Denmark, Germany, the Netherlands, Norway and Sweden in 2023, proposes to ban the manufacture, import and use of PFAS in the EU, covering both consumer and industrial applications.[22] Earlier in 2026, the European Chemicals Agency (ECHA) published its opinion on the dossier, agreeing that **the risk of PFAS is not currently controlled well enough**. This conclusion supports restricting PFAS under REACH as the most appropriate EU-wide action to address the risks these chemicals pose to human health and the environment.[23]

ECHA's scientific evaluation of the PFAS restriction proposal will conclude at the end of 2026. Afterwards the opinion will be submitted to the European Commission for discussion and further action.

Two features of the proposed REACH restriction on PFAS bear directly on soils. First, where PFAS are used as active substances in plant protection products, biocidal products and human and veterinary medicinal products, they must be regulated under their own legislation. ECHA's Committee for Risk Assessment (RAC) has questioned whether those frameworks adequately address PFAS emissions to the environment and has recommended that emission-minimisation requirements be incorporated[24]. Second, the compliance thresholds proposed for the restriction are expressed in three different analytical units: 25 µg/kg for any individual PFAS determined by targeted analysis, 250 µg/kg for the sum of targeted PFAS after prior degradation of precursors, and 50 mg/kg for total PFAS including polymers[24]. Only the first can be measured with the EN ISO standard under development. The second is essentially a TOP-assay parameter and the third a total-fluorine parameter, and neither has a validated CEN or ISO method for solid matrices.

In the meantime, the Packaging and Packaging Waste Regulation (EU 2025/40) (PPWR), sets PFAS concentration limits for food-contact materials in packaging, functionally banning intentionally used PFAS in these materials from August 2026.

Regulating PFAS in water – Water Framework Directive

For many years the Water Framework Directive (WFD)(2000/60/EC) created a legal obligation to measure PFAS in water.

Both the updated Drinking Water Directive ((EU) 2020/2184), and the revised Environmental Quality Standards Directive (2008/105/EC) regulate PFAS as a group rather than compound-by-compound. The Drinking Water Directive gives Member States a choice between two options: **a 'PFAS Total' parameter** (limit 0.5 µg/L; using proxy/surrogate methods such as TOP assay) or a **'Sum of PFAS' parameter** that adds up a specific list of named compounds, covering 20 (limit 0.1 µg/L), backed by harmonised technical guidance recommending the EN 17892 method.[25] A parallel update to the Environmental Quality Standards Directive for surface waters introduced a quality standard for a sum of 25 PFAS, including TFA, set at 0.0044 µg/L.[26] The fact that an ultra-short-chain compound was explicitly added to a binding EU standard shows that regulatory scope can be updated as scientific understanding improves.

Regulating PFAS in biosolids and soils – SSD and SMRD

The EU Sewage Sludge Directive (SSD) (86/278/EEC) regulates only heavy metals and does not set PFAS limits, therefore **controls on PFAS in land-applied sludge are national**; Germany, Denmark, Sweden, and Norway are frontrunners in applying thresholds. Even between neighbouring countries, the compounds covered, the numerical values and the legal status of these thresholds differ widely (Table 1). For the same sum of 22 PFAS, the Swedish certification scheme applies an action level of 25 µg/kg dry matter, whereas the Danish limit value is 400 µg/kg – a sixteen-fold difference, with no common reference analytical method.[27]

Table 1. National PFAS thresholds for sewage sludge applied to agricultural land in selected European countries

Country	Type of threshold	PFAS parameter	Value (µg/kg dry matter)
Germany	Limit value (Fertiliser Ordinance)	Sum of PFOA and PFOS	100
Denmark	Limit values for sludge used in agriculture (2021)	Sum of 4 PFAS; sum of 22 PFAS	10; 400
Sweden	Action levels in the voluntary REVAQ certification scheme	Sum of 4 PFAS; sum of 22 PFAS	7.5; 25
Norway	Proposed limit value (2023)	Sum of PFOA and PFOS	40

In October 2025, the Soil Monitoring and Resilience Directive (SMRD) (EU) 2025/2360), was adopted, becoming the EU's first-ever law dedicated to soils, giving it the same legal status as water and air. This Directive requires Member States to **monitor soil contaminants – explicitly including PFAS and pesticide residues –** using a common EU sampling methodology, allowing contamination hotspots to be identified, and to establish an **indicative EU watch list of emerging substances**, within 18 months of entry into force. The list needs to be based on their potential to cause a significant risk to soil health, human health or the environment, their toxicity and exposure to them across the EU.

The SML proposes using European or International standards when available, and scientific literature or publicly available information when such standards are not available. At the moment of writing this paper, **no validated published European or international standard exists for PFAS in solid matrices.**[28]

CEN/TC 444 is currently working on developing a standard on determination of PFAS in soils by using target analysis (ISO 25652) under development: analysis of PFAS in soil, sediment, sludge and waste by HPLC and mass spectrometry).[ii]

The choice of method for analysing PFAS can have significant implications for soil analysis and risk assessment. The use of different methods may result in inconsistent and incomparable concentrations of PFAS being reported, which can affect the interpretation of the results and the decision-making process[29]. For an effective implementation of the SML and an effective PFAS regulation, harmonised standards are a precondition. **Without a harmonised analytical standard, Member States risk implementing the provisions using different methods, undermining the data comparability that the Directive is designed to deliver**.

Moreover, **trigger values** are explicitly set at Member State level, meaning up to 27 different national trigger values could, in principle, be applied to data generated by one common EU analytical standard. This divergence already exists in practice: Member States have developed their own soil screening values (SSVs) for contaminants, including PFAS, using differing derivation methodologies[29].

A standard therefore solves the harder half of the comparability problem, ensuring the underlying concentration measurements mean the same thing everywhere, but leaves out the agreement of what those measurements should trigger. The Commission's implementing guidance should specify how trigger values are to be derived, including the ecotoxicological and human-health reference points to be used, the exposure pathways to be covered and the normalisation of soil PFAS concentrations for organic carbon content and texture, so that the Member States can start from the same point and provide comparable numbers. A trigger value means little without a statement of which PFAS are summed, on what basis, and how results below the limit of quantification are treated, and those conventions should be fixed centrally rather than nationally.

[ii] For a full list of standards for PFAS in soils and biosolids see Annex I

A public, maintained register of national trigger values for soils together with their derivation, should be maintained, published and transparently accessible.

Harmonised standards to support effective PFAS regulation

Strengthening standards for PFAS detection in soils and biosolids require key considerations to be adopted to ensure consistency for measuring PFAS. The scope of this paper is limited to analytical detection and site-assessment standards rather than remediation technologies or product-level PFAS restrictions.

Sampling guidance

PFAS distribution in soils can be highly non-uniform and PFAS concentrations can vary substantially within and between samples. Soils are extremely heterogeneous with complex variations in soil types, textures and organic matter contents within sampling areas and under different land management practices. **PFAS concentrations can vary sharply with soil depth and distance from a contamination source**. Standard topsoil and subsoil sampling depths should be adhered to where possible. If a composite sample mixes soil from different depths or is collected without knowing how far and in which direction the contamination has spread, it can substantially under- or over-estimate contamination.[2] This makes **representativeness and robust soil sampling design** - including sampling location and area, depth intervals and compositing strategies -**a critical determinant of sample and data quality.**

Two timing questions deserve explicit treatment in any PFAS-specific sampling guidance. The first is timing relative to when and where PFAS-containing plant protection products are applied. The interval between application and sampling changes what is measurable: parent compounds degrade, and the ultra-short-chain products they generate are mobile enough to have been mobilised away from the sampled area within a single season. A field sampled some months after application can therefore return **low results while having received a substantial PFAS input**, and a monitoring program that does not record application history will **systematically under-detect this pathway**. The second is soil moisture history. Short-chain and anionic PFAS are leached downwards through soil profiles by rainfall or irrigation while long-chain compounds remain sorbed to organic matter (particularly in organic topsoils) and minerals (particularly in mineral subsoils), so the same field sampled after heavy rain and after a dry spell will **yield different concentrations and a different PFAS distribution** within soil profiles.

Minimising uncertainty associated with sample collection and representativeness is as important as ensuring analytical precision and accuracy, as both can substantially influence the reliability of compliance assessments and environmental risk evaluations. The standard should require:

- **Multiple sampling points with** a stated minimum number of points on heterogeneous sites, with mandatory reporting of soil **sampling depth and sampling design.**
- Depth-resolved soil sampling according to soil types, texture, pH, organic matter and land management/use at **defined intervals in space and time** rather than a single surface topsoil composite.

With biosolids, which are less heterogeneous than soils, sampling faces an additional problem: PFAS partitioning between the liquid and solid phases during treatment is process (e.g. anaerobic digestion, composting or lime stabilisation) - and sludge treatment plant-specific, so a sludge sample collected on one day, or from one treatment stage (primary, digested, or dewatered), may not represent the biosolids ultimately land-applied months later[27]. Biosolids properties such as organic matter contents and overall contaminant loading will also vary depending on sewage sludge treatment methods.

For biosolids, the standard should therefore require sampling of the material as it is actually land-applied (after final dewatering and storage), preferably as composite samples collected over a defined period rather than as single grab samples, together with reporting of the treatment stage, sampling dates and dry-matter content alongside the results.

Laboratory analysis

Analytical methods for accurate quantification of PFAS concentration in samples generally take two different approaches: **targeted analysis** or **non-targeted analysis**. Targeted methods focus on **known PFAS of concern** and use **solid-phase extraction with liquid chromatography-mass spectrometry (HPLC-MS/MS) detection**. HPLC separates the different PFAS so that the instrument can examine them individually. Once separated, MS/MS can examine them. The technique identifies which PFAS are present and gives indication on how much of each is there. This is analytically robust and consistent with best practice established for water analysis.

A standard that uses this method must set explicit quality-assurance requirements (sample replicates, method blanks, spiked samples or suitable certified reference materials (where available), calibration verification with appropriate blanks and standards within the sample concentration range, instrumental detection-limit checks, and acceptance ranges).

Non-targeted methods sacrifice the identification and quantification of specific PFAS compounds to look for evidence of PFAS suspected to be present (suspect screening) and that have not necessarily been identified beforehand (non-target screening). Non-targeted methods are usually supported by high-resolution mass spectrometry (HRMS).

Most instruments search specifically for targeted PFAS. Like most targeted LC-MS/MS methods, this can only report on the PFAS it was explicitly designed to look for. **Broader diagnostic tools** which can be used to identify emerging or regionally specific PFAS not on any target list are increasingly used in the peer-reviewed literature. They help specifically to reveal the hidden fraction and even to distinguish contamination sources from one another[30]. Examples are:

- **Total Oxidizable Precursor (TOP) assay**[31]which converts unmeasured precursors compounds to measurable terminal perfluoroalkyl acids and thereby reveals "hidden" PFAS burden. It has already demonstrated its diagnostic value in peer-reviewed research distinguishing AFFF-derived PFAS contamination from other sources[30 32].
- **Extractable Organofluorine (EOF)** and **Total Organic Fluorine (TOF)** methods, which provide a mass-balance check against the sum of individually quantified target compounds and help estimate the unidentified PFAS fraction.

No CEN/ISO standard yet specifies a validated method for total or extractable organofluorine (EOF) in solid matrices, despite growing regulatory interest in total-fluorine reporting thresholds (e.g. in the REACH restriction proposal). For the implementation of the SML, a companion validated EOF or TOP method for solid matrices would give the Directive a way of expressing 'relevant PFAS' as a category rather than as a list.

A standard should use tools that report a single total organofluoride or total PFAS burden rather than concentrations of individual named compounds and target screening, otherwise, the non-measured share of the soil PFAS burden stays unquantified, transformation (breakdown) products are not captured.

Analytical scope

Targeted analysis of a **wide range of legacy and emerging PFAS is essential**. However, PFAS detection shouldn't be limited to a fixed list of compounds. Because a PFAS compound that is not on a target list is never looked for, the absence of occurrence data for it is a product of the method's scope rather than evidence that it is absent from soil or harmless in them. The analytical scope is precisely what generates the data on which any subsequent risk argument would rest. Thus, particular attention should be paid to:

- The **precursor classes** that degrade into already-listed acids, notably fluorotelomer alcohols and polyfluoroalkyl phosphate esters (diPAPs), which are abundant in biosolids;
- PFAS used as **active substances or co-formulants in plant protection products**, given their direct relevance to agricultural soils;
- **Ultra-short-chain PFAS, including TFA and other C2–C3 perfluoroalkyl acids**, which are increasingly recognised as major contributors to environmental PFAS contamination. Target-compound methods calibrated for longer-chain PFAS routinely miss[33] them since dedicated ultra-short-chain methods typically require different chromatographic conditions (for example, ion chromatography or specialised reversed-phase approaches) than the C4-and-longer compounds).[33] A comprehensive detection standard should therefore include ultra-short-chain PFAS in its scope and explicitly accommodate complementary chromatographic methods where the main method cannot retain them, for example through a dedicated part or annex of the standard: this would reduce a significant source of underestimation and provide a more complete assessment of the total PFAS burden in soils.

As new compounds of concern are identified over time, the standard should **incorporate a harmonised mechanism for expanding the list of PFAS analytes to monitor as scientific knowledge evolves** (for example, a list of target analytes kept in an annex that can be updated without reupdating the whole standard, combined with a standing validation protocol that sets the performance criteria a laboratory must meet before reporting a new compound), ensuring that laboratories can adopt additional compounds while maintaining comparability of results. The compounds to prioritize for inclusion are those whose use or formation in soil is documented even where monitoring data remain thin. For example, occurrence data from forest soils are considerably sparser than for agricultural soils, which is itself an argument for ensuring that **a single validated method performs adequately across the full range of soil types**.

Data interpretation and comparability

Data comparability across laboratories and jurisdictions is still constrained by the **absence of harmonised reporting values for branched isomers, precursors and their transformation products and total organofluorine measures.** Independent reviews comparing PFAS-in-biosolids datasets across countries have already had to exclude or heavily caveat comparisons[iii] because underlying studies reported different compound subsets, different solid dry-weight conventions, and different treatment of non-detects, undermining efforts to build a coherent global picture of soils and biosolids contamination even before considering genuine differences in underlying PFAS levels[Error! Bookmark not defined.].

[iii] Between US jurisdictions alone, existing biosolids PFAS thresholds already diverge by more than sixfold (20–125 ng/g for PFOS, depending on state), and these figures are rarely accompanied by a specified reference analytical method, meaning a single biosolids sample could be classified as compliant in one jurisdiction and non-compliant in another purely as a function of which extraction efficiency, calibration approach or reporting convention was used.

To demonstrate that different laboratories applying an analysis (or standard) to the same material are arriving at the same answer, an interlaboratory trial, also called a ring test or collaborative study, is performed.

Portions of a single homogenised material are distributed to laboratories in several countries and analysed independently, so that the spread of their results measures the agreement between laboratories. The variations in the results are expressed as the coefficient of variation of reproducibility (CVR): this allows a user to state how much of the difference between two results is attributable to the method rather than to the soil. Without such a trial, a method can be internally consistent in the laboratory that developed it and still produce results that are not comparable anywhere else. **For a standard intended to support regulatory decisions on soils and biosolids, an interlaboratory trial covering the full range of matrices within its scope is therefore a prerequisite.**

In an interlaboratory trial, the "design" refers to what kind of test material is sent out to the participating laboratories. There are two kinds available:

- **Field-contaminated (native) material**. Real soil, sludge or biosolids in which PFAS arrived through actual contamination and have aged in place, sorbed to organic matter, alongside whatever else the matrix contains. It is realistic, but nobody knows the true concentration, so recovery cannot be measured against a reference value. It can only measure how closely the laboratories agree with each other. A lot of material is needed, and it needs to be homogenised well enough that differences between results reflect the method rather than the sub-sampling.
- **Spiked material**. A matrix to which known amounts of the target compounds have been added in the laboratory. Since there is a true value, recovery and bias are measurable, and compounds that don't happen to be present in any available field sample are covered. A potential downside is that freshly added compounds extract more easily than field contaminated material, so recoveries can be optimistic.

A non-mixed design uses one of the two. A mixed design uses both, usually as separate sample sets within the same trial, and reports them separately. A mixed design lets the trial demonstrate both realistic background performance and controlled recovery across the widest possible range of PFAS, but it also means that native co-contaminant and matrix-interference effects can be monitored in truly complex field samples, as opposed to spiked laboratory matrices.

Three risks follow from a validation that leans on spiked material: a laboratory can satisfy every quality-control criterion in the standard and still under-report PFAS concentration determined in a field sample; results from a heavily contaminated industrial soil may not be comparable with results from an agricultural soil even when both are produced under the same standard; and any trigger value calibrated against spiked-recovery performance will in practice be applied to samples that behave differently. The remedy is not to reject the validation but to extend it.

Performance is demonstrably matrix-dependent, so reporting limits of quantification, recovery windows and reproducibility criteria separately for each matrix (e.g. organic carbon content of soils/biosolids, soil textures and pH that influence PFAS sorption properties), and analyte class, rather than as a single global figure, would give users a more honest picture and would let a regulator set a trigger value knowing the uncertainty that attaches to it in the matrix at hand. Because PFAS added to a sample are not bound to the matrix in the way that contamination aged in place is, recoveries from spiked material are generally somewhat better than from field-contaminated material. Performance therefore also should be reported separately for spiked and native (field-contaminated) materials so that users can see which figure best applies to their situation.

Terminology

The OECD's 2021 harmonised nomenclature[34] remains **the only internationally agreed vocabulary for naming PFAS groups and subgroups**. When a legal instrument refers to 'relevant PFAS', or to a compound class without stating which structural definition it means, laboratories, competent authorities and duty holders can each read the same obligation differently, and the resulting data cease to be comparable. The standard should align with OECD terminology.

PFAS detection standards for water - Transferability to soil and biosolids

PFAS analytical standardisation is considerably more mature for water than for soil and biosolids which are far more complex and heterogenous.

ISO 21675:2019 (adopted in Europe as EN ISO 21675, mirrored through CEN/TC 230 in cooperation with ISO/TC 147) specifies a solid-phase-extraction LC-MS/MS method for around 30 PFAS in drinking, surface and wastewater, achieving limits of quantification down to approximately 0.2 ng/L, and was itself validated through an international interlaboratory trial coordinated by Japan's National Institute of Advanced Industrial Science and Technology (AIST) with laboratories from eleven countries.

The current understanding and approach to PFAS detection in water standards offers three transferable lessons for soil:

- **Group parameters: regulating PFAS as a group** instead of compound by compound, so that the parameter does not have to be renegotiated each time a new substance appears.
- **Method-linked guidance:** pair every numeric threshold with technical guidance clearly referring to the analytical method used to quantify PFAS concentrations, as Commission Notice C/2024/4910 does for drinking water.
- **A mechanism for adding substances**: the list of PFAS analytes should be kept open and responsive to new evidence, as the addition of TFA to the surface-water standard demonstrates.

Limitations on transferability from water to solids exist. From a toxicology perspective, water thresholds are derived largely from human exposure through drinking water, whereas soil trigger values have to account for effects on soil organisms, uptake into crops and leaching into groundwater, and are strongly modulated by soil properties such as organic carbon content and texture.

The numeric values therefore cannot be carried across, and for most PFAS, the soil ecotoxicological reference points needed to derive equivalents do not yet exist.

The TOP assay and organofluorine measurements used as proxy parameters in the water context are transferable in principle, but they require **matrix-specific validation for solids**, where extraction efficiency and co-extracted organic matter govern performance in a way they do not in water, and where the oxidant demand of the matrix itself can consume the reagent before precursor conversion is complete. Many elements of the water standard's approach can be transferred directly to the solid-matrix method:

- **Isotope-dilution internal standard calibration:** adding a known quantity of a mass-labelled version of each target compound at the start of sample preparation, so that losses during extraction and clean-up are corrected for automatically;
- **MRM transition selection:** choosing the pairs of parent and fragment ion masses that the mass spectrometer monitors in order to identify and quantify each compound;
- **Treatment of linear versus branched isomers:** whether the structural variants of a compound are quantified and reported separately or summed into a single value.

Compared to solid matrices, water is also the easier matrix analytically, being essentially homogeneous and requiring no extraction of analytes from a solid phase; solid-phase extraction of a water sample is a well-established and readily transferable operation, whereas extraction from soil, biosolids, sludge or waste has to be optimised against organic carbon content, texture, particle size and mineralogy, and needs a distinct clean-up step (activated carbon) to manage co-extracted matrix interferents.

Recommendations

Standardisation for PFAS detection in soils and biosolids should take into consideration:

- **Include extensive PFAS coverage** of ultra-short-chain PFAS such as TFA as well as precursors, PFAS used as active substances or co-formulants in plant protection products, and unidentified or unmeasurable PFAS.
- **Expand the scope** to monitor as scientific knowledge evolves, **through a mechanism for regularly updating and expanding the list of PFAS.**
- **Develop clear and harmonised guidance for sample collection, handling, pretreatment and extraction** that is tailored to the characteristics of environmental matrices while ensuring repeatability and consistent implementation across laboratories. **Guidance on representative soil (and biosolids) sampling strategies** must account for heterogeneity, soil types and land use/management (biosolids treatment methods), spatial and temporal variability, together with validation across a broad range of representative environmental matrices.
- **Incorporate total-fluorine methodologies** to help identify PFAS not captured by targeted analysis and align it with best practice already emerging in water analysis and academic PFAS research.
- Ensure the use of harmonised, matrix-specific analytical and reporting requirements so that interpretation and comparability for soil PFAS data are accurate, comparable and fit for regulatory decision-making across laboratories and jurisdictions.
- Ensure alignment with OECD PFAS related terminology and definitions.
- **Leverage water standards** and build on established PFAS approaches for water where appropriate, while ensuring that their application to soils and biosolids is subject to matrix-specific validation and takes into account the greater complexity, heterogeneity and different PFAS behaviour, transport and exposure pathways of solid matrices.

Annex I - Current standards landscape at CEN/ISO level

- **CEN/TC 444 Environmental characterization of solid matrices -** is the lead European committee for PFAS analytical methods in soil, sediment, sludge and waste. Its principal deliverable, **EN ISO 25652 – Sediment, soil, sludge and waste: Analysis of PFAS by HPLC and mass spectrometry**, is being developed jointly with ISO/TC 190/SC 3 (Soil quality – Chemical and physical characterization) under DIN's secretariat.
- **ISO/TC 190 Soil Quality** - the parent committee for soil-quality standardisation internationally,
    - **Subcommittee SC 3 (Chemical and physical characterization**) is co-developing EN ISO 25652 with CEN/TC 444.
    - **Subcommittee SC 4 (Biological characterisation)** is responsible for ISO 19204, a standard describing the soil-quality TRIAD approach to site-specific ecological risk assessment. 'TRIAD' refers to combining three types of evidence, i.e., chemical measurements, ecotoxicological tests (e.g. effects on test organisms), and ecological field observations, to assess whether contamination at a site poses a real risk (ISO 19204:2017). The current standard does not make explicit reference to PFAS-specific toxicity endpoints or bioassays, representing a gap between analytical detection capability and ecological risk interpretation. A revised Draft International Standard (ISO/DIS 19204) is currently in the ISO enquiry phase, intended to replace the 2017 edition.

- **CEN/TC 308 Characterization and Management of Sludge -** develops standards and technical reports on sludge characterization and good practice guidance for sludge use, treatment and disposal (covering sludges from urban wastewater treatment, storm-water handling and related sources). Its existing portfolio, covering land application, dewatering, drying, landfilling and incineration good practice, does not currently embed PFAS-specific sampling or analytical requirements.

Standard/draft	Body	Scope	Status (mid-2026)
EN ISO 25652	CEN/TC 444 + ISO/TC 190/SC3	PFAS in soil, sediment, sludge, waste by HPLC-MS/MS	Draft International Standard (ISO/DIS 25652); enquiry-stage, with a parallel prEN ISO text under national-body enquiry
ISO 19204:2017 / ISO/DIS 19204	ISO/TC 190/SC4	Soil quality TRIAD ecological risk assessment	Published (2017); revision at enquiry stage
CEN/TC 308 portfolio e.g. CEN/TR 16788, CEN/TR 13097	CEN/TC 308	Sludge characterization and good-practice guidance	Published (no PFAS-specific content)
ISO 18512 (sampling)	ISO/TC 190/SC 2	Soil sample storage guidance; cross-referenced by EN ISO 25652 for sample-storage conditions	Published; no PFAS-specific provisions
ISO 21675:2019 / EN ISO 21675	ISO/TC 147 + CEN/TC 230	PFAS in water by SPE-LC-MS/MS	Published standard (2019)

Definitions

- **Bioaccumulation:** progressive increase in the amount of a substance in an organism or part of an organism that occurs because the rate of intake from all contributing sources and by all possible routes exceeds the organism's ability to eliminate the substance from its body. *Adapted from IUPAC - bioaccumulation (14470)*
- **Biosolid**: treated wastewater solids, or sewage sludge, that have undergone processes to reduce pathogens, odours and other concerns so they can be managed, recycled or disposed of. *From What Are Biosolids? A Complete Guide to Treated Sewage Sludge | Cambi*
- **Isomer:** a chemical that has the same chemical formula as another chemical but a different arrangement of its atoms and hence different physical and/or chemical properties. PFAS can have linear or branched isomers. *Adapted from IUPAC - isomer (I03289)*
- **Chromatography:** a physical method of separation in which the components to be separated are distributed between two phases, one of which is stationary while the other moves in a definite direction. There are many types of chromatography including: thin layer chromatography, liquid chromatography, and gas chromatography. The chromatographic method known as liquid chromatography (LC) is used to separate and analyse mixtures of chemical components in solution to ascertain whether or not a particular component is present. LC is particularly useful for separating ions or molecules that have been dissolved in a solvent. Since the samples being analysed do not need to be vaporised, liquid chromatography is more popular than other techniques. In contrast to other forms of chromatography, temperature changes also barely affect liquid chromatography. *Adapted from IUPAC - chromatography (C01075) and Liquid Chromatography: Principle, Procedure, Application*.

- **Mass spectrometer:** an instrument in which beams of ions are separated (analysed) according to the quotient mass/charge, and in which the ions are measured electrically. *Adapted from IUPAC - mass spectrometer (M03732)*
- **Precursor:** substance from which another, usually more biologically active, substance is formed. PFAS precursors are often not captured by targeted methods but add to the PFAS burden over time. *Adapted from Duffus, J.H., Nordberg, M., Templeton, D.M. (2007). Glossary of terms used in toxicology, 2nd edition (IUPAC Recommendations 2007). Pure and Applied Chemistry, 79(7), 1153–1344*
- **Transformation**: chemical modification of substances in the environment. For PFAS, the end points of these transformations are typically perfluoroalkyl acids, which do not degrade further under environmental conditions. *Adapted from Duffus, J.H., Nordberg, M., Templeton, D.M. (2007). Glossary of terms used in toxicology, 2nd edition (IUPAC Recommendations 2007). Pure and Applied Chemistry, 79(7), 1153–1344*
- **Trophic transfer:** the movement of a substance from one level of a to another, usually when one organism eats another. *Adapted from IUPAC - trophic transfer (15115)*

References

[1] Diamond, M.L., Shalin, A., Boynton L., et al. (2026). Towards safe and just planetary boundaries for novel entities. Nature Sustainability. https://doi.org/10.1038/s41893-026-01906-8

[2] Brusseau, M.L., Anderson, R.H., Guo, B. (2020). PFAS concentrations in soils: background levels versus contaminated sites. Science of the Total Environment, 740, 140017.

[3] Wu, J.-Y., Ding, F.-G., Shen, Z.-W., Hua, Z.-L., Gu, L. (2022). Linking microbiomes with per- and poly-fluoroalkyl substances (PFASs) in soil ecosystems: microbial community assembly, stability, and trophic phylosymbiosis. Chemosphere, 305, 135403.

[4] Ban PFAS Manifesto. Manifesto for an urgent end to 'forever chemicals' PFAS (2022) https://banpfasmanifesto.org/en/

[5] Buck, R.C., Franklin, J., Berger, U., Conder, J.M., Cousins, I.T., de Voogt, P., Jensen, A.A., Kannan, K., Mabury, S.A., van Leeuwen, S.P.J. (2011). Perfluoroalkyl and polyfluoroalkyl substances in the environment: terminology, classification, and origins. Integrated Environmental Assessment and Management, 7(4), 513–541.

[6] European Environmental Bureau. Work Area: PFAS. (Accessed September 2026). https://eeb.org/en/work-areas/industry-health/pfas/

[7] Adeogun, A.O., Chukwuka, A.V., Ibor, O.R., Asimakopoulos, A.G., Zhang, J., Arukwe, A. (2024a). Occurrence, bioaccumulation and trophic dynamics of per- and polyfluoroalkyl substances in two tropical freshwater lakes. Environmental Pollution, 346, 123575.

[8] Adeogun, A.O., Ibor, O.R., Chukwuka, A.V., Asimakopoulos, A.G., Zhang, J., Arukwe, A. (2024b). Role of niche and micro-habitat preferences in per- and polyfluoroalkyl substances occurrence in the gills of tropical lake fish species. Science of the Total Environment, 933, 173245.

[9] Arp, H.P.H., Gredelj, A., Glüge, J., Scheringer, M., Cousins, I.T. The Global Threat from the Irreversible Accumulation of Trifluoroacetic Acid (TFA) (2024) https://pmc.ncbi.nlm.nih.gov/articles/PMC11562725/

[10] Joerss, H., Freeling, F., van Leeuwen, S., Hollender, J., Liu, X., Nödler, K., Wang, Z., Yu, B., Zahn, D., Sigmund, G. (2024). Pesticides can be a substantial source of trifluoroacetate (TFA) to water resources. Environment International, 193, 109061.

[11] Jagani, R., Chovatiya, J., Patel, H., Andra, S.S. (2025). Trifluoroacetic acid: an ultra-short PFAS with emerging environmental and public health concerns. ACS ES&T Water, 5(7), 3533–3537.

[12] Gkika, I.S., Vonk J.A., ter Laak, T.L., van Gestel, C.A.M., Dijkstra, J., Groffen, T., Bervoets, L., Kraas, M.H.S. Differential PFAS transfer through the terrestrial and aquatic food web to predatory spiders (2026). https://www.sciencedirect.com/science/article/pii/S0160412026003971

[13] Brusseau, M.L., Anderson, R.H., Guo, B. (2020). PFAS concentrations in soils: background levels versus contaminated sites. Science of the Total Environment, 740, 140017.

[14] Vistnes, H., Sossalla, N.A., Uhl, W., Sundsøy, A.W., Asimakopoulos, A.G., Spahr, S., Escher, B.I., Meyn, T. (2024). Effect of tunnel wash water treatment processes on trace elements, organic micropollutants, and biological effects. Journal of Hazardous Materials, 480, 136363.

[15] Langberg, H.A., Arp, H.P.H., Castro, G., Asimakopoulos, A.G., Knutsen, H. (2024). Recycling of paper, cardboard and its PFAS in Norway. Journal of Hazardous Materials Letters, 5, 10009.

[16] Sørmo, E., Castro, G., Hubert, M., Licul-Kucera, V., Quintanilla, M., Asimakopoulos, A.G., Cornelissen, G., Arp, H.P.H. (2023). The decomposition and emission factors of a wide range of PFAS in diverse, contaminated organic waste fractions undergoing dry pyrolysis. Journal of Hazardous Materials, 454, 131447.

[17] Sørmo, E., Lade, C.B.M., Zhang, J., Asimakopoulos, A.G., Åsli, G.W., Hubert, M., Goranov, A.I., Arp, H.P.H., Cornelissen, G. (2024). Stabilization of PFAS-contaminated soil with sewage sludge- and wood-based biochar sorbents. Science of the Total Environment, 922, 170971.
[18] PFAS Free. PFAS in Pesticides https://pfasfree.org.uk/pfas-in-pesticides#1739831425496-9aa0143e-7c99
[19] PAN Europe Europe's Toxic Harvest: Unmasking PFAS Pesticides Authorised in Europe (2023) https://www.pan-europe.info/resources/reports/2023/11/europes-toxic-harvest-unmasking-pfas-pesticides-authorities-europe
[20] Arvaniti, O.S., Asimakopoulos, A.G., Dasenaki, M.E., Ventouri, E.I., Stasinakis, A.S., Thomaidis, N.S. (2014). Simultaneous determination of eighteen perfluorinated compounds in dissolved and particulate phases of wastewater, and in sewage sludge by liquid chromatography-tandem mass spectrometry. Analytical Methods, 6(5), 1341–1349.
[21] ISO/IEC (2004). ISO/IEC Guide 2: Standardization and related activities – General vocabulary. International Organization for Standardization, Geneva.
[22] CHEMTrust Universal PFAS Restriction https://chemtrust.org/universal-pfas-restriction/
[23] NEW LEAF (2026) ECHA experts back EU-wide restriction of PFAS "forever chemicals https://meta.eeb.org/2026/03/26/echa-experts-back-eu-wide-restriction-of-pfas-forever-chemicals/
[24] ECHA (2026a). Committee for Risk Assessment (RAC), final opinion on the PFAS restriction Annex XV dossier, adopted 3 March 2026; Committee for Socio-Economic Analysis (SEAC), draft opinion published for consultation, 26 March 2026.
[25] European Commission (2024). Commission Notice – Technical guidelines regarding methods of analysis for monitoring of per- and polyfluoroalkyl substances (PFAS) in water intended for human consumption. OJ C, C/2024/4910, 7.8.2024.
[26] Council of the European Union (2025). Water pollution: Council and Parliament reach provisional deal to update priority substances in surface and ground waters. Press release, 23 September 2025.
[27] Saliu, T.D., Sauvé, S. (2024). A review of per- and polyfluoroalkyl substances in biosolids: geographical distribution and regulations. Frontiers in Environmental Chemistry, 5, 1383185.
[28] Yunta, F., van Eynde, E., Panagos, P. and Jones, A., Towards Harmonized Soil Monitoring in the EU: An Inventory of Existing International and European Standards, Publications Office of the European Union, Luxembourg, 2026, https://data.europa.eu/doi/10.2760/4452523, JRC144540.
[29]YUNTA, F., VIEIRA, D., VAN EYNDE, E., JONES, A., BOPP, S. et al., Harmonizing soil pollution data and knowledge in Europe: a collaborative effort towards achieving healthy soils by 2050, Publications Office of the European Union, Luxembourg, 2025, https://data.europa.eu/doi/10.2760/4402833, JRC142244.
[30] Ruyle, B.J., Pickard, H.M., LeBlanc, D.R., Tokranov, A.K., Thackray, C.P., Hu, X.C., Vecitis, C.D., Sunderland, E.M. (2021). Isolating the AFFF signature in coastal watersheds using oxidizable PFAS precursors and unexplained organofluorine. Environmental Science & Technology, 55(6), 3686–3695.
[31] Zhang, J., Cioni, L., Jaspers, V.L.B., Asimakopoulos, A.G., Peng, H.-B., Ross, T.A., Klaassen, M., Herzke, D. (2025). Shellfish and shorebirds from the East-Asian Australian flyway as bioindicators for unknown per- and polyfluoroalkyl substances using the total oxidizable precursor assay. Journal of Hazardous Materials, 487, 137189.
[32] Zhao, L., Zhang, J., Kubendraraj, S., Gonzalez, S.V., Ardelan, M.V., Mathew, K.A., Ansah, E., Kwawu, M., Gordon, C., Asimakopoulos, A.G., Yuan, B. (2025). Substantially underestimated PFAS pollution in diverse Ghana's land-use types revealed by a refined TOP assay. Journal of Hazardous Materials Letters, 6, 100165.
[33] Björnsdotter, M.K., Yeung, L.W.Y., Kärrman, A., Ericson Jogsten, I. (2020). Challenges in the analytical determination of ultra-short-chain perfluoroalkyl acids and implications for environmental and human health. Analytical and Bioanalytical Chemistry, 412, 4785–4796.
[34] OECD (2021). Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances: Recommendations and Practical Guidance. OECD Series on Risk Management of Chemicals No. 61, OECD Publishing, Paris.