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Method 1633

Analysis of Per- and Polyfluoroalkyl Substances (PFAS) in Aqueous, Solid, Biosolids, and Tissue Samples by LC-MS/MS

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Notice

Method 1633 for the analysis of PFAS was developed by the EPA Office of Water, Engineering and Analysis Division (EAD), in collaboration with the Department of Defense (DoD).

EPA issuing this method does not require its use for Clean Water Act compliance monitoring at the Federal level; that will only occur after it has been proposed and promulgated through rulemaking (e.g., added to 40 CFR Part 136). However, EPA recommends the use of this method, and it is currently the only PFAS method that has been validated in multiple laboratories for aqueous matrices that include wastewater, surface water, groundwater, and landfill leachate, as well as for soil, sediment, biosolids, and fish and shellfish tissue.

This January 2024 version of the method supersedes all previous versions.

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Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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Method 1633 - Analysis of Per- and Polyfluoroalkyl Substances (PFAS) in Aqueous, Solid, Biosolids, and Tissue Samples by LC-MS/MS

1.0 Scope and Application

1.1 Method 1633 is for use in the Clean Water Act (CWA) for the determination of the per- and polyfluoroalkyl substances (PFAS) in Table 1 in aqueous, solid (soil, biosolids, sediment) and tissue samples by liquid chromatography/mass spectrometry (LC-MS/MS).

1.2 The method calibrates and quantifies PFAS analytes using isotopically labeled standards. Where linear and branched isomers are present in the sample and either qualitative or quantitative standards containing branched and linear isomers are commercially available, the PFAS analyte is reported as a single result calculated from the combined responses of the linear and branched isomers.

1.3 The instrumental portion of this method is for use only by analysts experienced with LC-MS/MS or under the close supervision of such qualified persons. Each laboratory that uses this method must demonstrate the ability to generate acceptable results using the procedure in Section 9.2.

1.4 By their very nature, many components of PFAS present analytical challenges unique to this class of analytes. For example, PFAS analytes readily adhere to the walls of the sample containers and may also stratify in the container. EPA has included procedures in the method that must be employed to address such challenges (see Section 11.0 and Appendices A and B).

1.5 This method is "performance-based," which means that modifications may be made without additional EPA review to improve performance (e.g., overcome interferences, or improve the sensitivity, accuracy, or precision of the results) *provided that* all performance criteria in this method are met. Requirements for establishing equivalency are in Section 9.1.2 and include 9.1.2.2c. For CWA uses, additional flexibility is described at 40 CFR 136.6. Changes in performance, sensitivity, selectivity, precision, recovery, etc., that result from modifications within the scope of 40 CFR Part 136.6, and Section 9.0 of this method must be documented, as well as how these modifications compare to the specifications in this method. After promulgation, changes outside the scope of 40 CFR Part 136.6 and Section 9.0 of this method may require prior review or approval by EPA under the Clean Water Act Alternate Test Procedure program described at 40 CFR 136.4 and 136.5.

1.6 The target analytes in Table 1 were included in this method based in part on the availability of standards for both unlabeled and isotopically labeled PFAS compounds at the time that the method was first developed. Data from multi-laboratory validation study data (References 11-14) demonstrate that the method is suitable for the analysis of all 40 target analytes in all of the matrices studied, although there are some performance differences across the analyte classes, which is not surprising given the wide range of structures across the nine classes of compounds in that table. Therefore, EPA supports use of the method for those analytes, and has identified the analytes in Table 1 that that did not perform as well in the study as others in some sample matrices. (The analytes noted in Table 1 were able to achieve 50 – 150% accuracy or better in most of the analyses from the multi-laboratory validation study.) Data users and laboratories should take that information into account during project planning.

2.0 Summary of Method

Environmental samples are prepared and extracted using method-specific procedures. Sample extracts are subjected to cleanup procedures designed to remove interferences. Analyses of the sample extracts are conducted by LC-MS/MS in the multiple reaction monitoring (MRM) mode. Sample concentrations are determined by isotope dilution or extracted internal standard quantification (see Section 10.3) using isotopically labeled compounds added to the samples before extraction.

2.1 Extraction

2.1.1 Aqueous samples are spiked with isotopically labeled standards, extracted using solid-phase extraction (SPE) cartridges and undergo cleanup using carbon before analysis.

2.1.2 Solid samples are spiked with isotopically labeled standards, extracted into basic methanol, and cleaned up by carbon and SPE cartridges before analysis.

2.1.3 Tissue samples are spiked with isotopically labeled standards, extracted in potassium hydroxide and acetonitrile, followed by basic methanol, and cleaned up by carbon and SPE cartridges before analysis.

2.2 This method measures the analytes as either their anions or neutral forms. The default approach for Clean Water Act uses of the method is to report the analytes in their acid or neutral forms, using the equations in Section 15.2, although the differences between the anion and acid form concentrations are minimal (See Table 2). Other project-specific reporting schemes may be used where required.

2.3 Individual PFAS analytes are identified through peak analysis of the quantification and confirmation ions, where applicable.

2.4 Quantitative determination of target analyte concentrations is made with respect to an isotopically labeled PFAS standard; the concentrations are then used to convert raw peak areas in sample chromatograms to final concentrations.

2.5 By virtue of the use of isotope dilution and extracted internal standard quantification (see Section 10.3), the results for the target analytes are corrected for any losses that may occur during sample extraction, extract cleanup, and concentration. Isotope dilution calibration also may address matrix effects that lead to signal suppression or enhancement in the LC-MS/MS system and would otherwise lead to measurement bias. Isotopically labeled compound recoveries are determined by comparison to the responses of one of seven non-extracted internal standards (a.k.a., the "recovery" standards) and are used as general indicators of overall analytical quality.

2.6 The quality of the analysis is assured through reproducible calibration and testing of the extraction, cleanup, and LC-MS/MS systems.

3.0 Definitions

Definitions are provided in the glossary at the end of this method.

4.0 Contamination and Interferences

4.1 Solvents, reagents, glassware, and other sample processing hardware may contain PFAS constituents or may yield artifacts and elevated baselines causing misinterpretation of chromatograms. Specific selection of reagents and solvents may be required.

4.2 Clean all equipment prior to, and after each use to avoid PFAS cross-contamination. Typical cleaning solvents used include water, methanol, and methanolic ammonium hydroxide. The residual PFAS content of disposable plasticware and filters must be verified by batch/lot number and may be used without cleaning if the mass of any PFAS analyte found in a nominal 500-mL aqueous sample is less than the laboratory's method detection limit (MDL).

4.2.1 All glass equipment that is used in the preparation or storage of reagents is cleaned by washing with detergent and baking in a kiln or furnace (Section 6.2.2). After detergent washing, glassware should be rinsed immediately with reagent water. Prior to use, baked glassware must be solvent rinsed and then air dried. A solvent rinse procedure using methanolic ammonium hydroxide (1%), toluene, and methanol is recommended.

4.2.2 All parts of the SPE manifold must be cleaned between samples with methanolic ammonium hydroxide (1%) and air dried prior to use. Sonication with methanolic ammonium hydroxide (1%) may be used for components that will fit in an ultrasonic bath. Smaller parts, like the needles, adapters, reservoirs, and stopcocks associated with the manifold, require rinsing with reagent water prior to manual cleaning or sonicating with methanolic ammonium hydroxide (1%) and air drying. When in use, after loading the samples but prior to elution procedures, the chamber must be rinsed with methanolic ammonium hydroxide (1%). If using an automated SPE system, consult the manufacturer's procedures for equipment cleaning, however, the laboratory is responsible for ensuring that any such procedures are effective, as evidenced by method blanks and other QC results.

4.2.3 All equipment used in the filleting, dissecting, shucking, compositing, and homogenization of tissue must be cleaned with detergent and hot water, then rinsed with ultra-pure water followed by a series of solvent rinses. A typical solvent rinse procedure would be acetone, followed by toluene, and then methanol.

4.3 All materials used in the analysis must be demonstrated to be free from interferences by running method blanks (Section 9.5) at the beginning and with each sample batch (samples started through the extraction process in a given batch during the same work shift, to a maximum of 20 field samples).

4.3.1 The reference matrix must simulate, as closely as possible, the sample matrix being tested. Ideally, the reference matrix should not contain PFAS in detectable amounts (i.e., at or above the laboratory's method detection limits [MDLs]).

4.3.2 For tissue, chicken breast or other similar animal tissue (see Section 7.2.3) may be used as the reference matrix. The laboratory must verify that the source product used does not contain PFAS in detectable amounts (i.e., above the laboratory's MDLs).

4.3.3 When a reference matrix that simulates the sample matrix under test is not available, reagent water (Section 7.2.1) can be used to simulate water samples and Ottawa sand and/or reagent-grade sand (Section 7.2.2) can be used to simulate soils, sediments, and biosolids.

4.4 Interferences co-extracted from samples will vary considerably from source to source, depending on the diversity of the site being sampled. Interfering compounds may be present at concentrations several orders of magnitude higher than the native PFAS. Because low levels of PFAS are measured by this method, elimination of interferences is essential. The cleanup steps given in Section 12.0 can be used to reduce or eliminate these interferences and thereby permit reliable determination of the PFAS at the levels shown in Table 9. The most frequently encountered interferences are fluoropolymers; however, bile salts (e.g., Taurodeoxycholic Acid [TDCA]) may be present in various matrices, including fish and wastewaters, and can interfere in the chromatography. For this reason, analysis of a standard containing, at a minimum, TDCA is required as part of establishing the initial chromatographic conditions (see Sections 10.2.2.5 and 10.3.5) and each analytical sequence (see Section 13.3).

4.5 Each piece of reusable glassware may be numbered to associate that glassware with the processing of a particular sample. This may assist the laboratory in tracking possible sources of contamination for individual samples, identifying glassware associated with highly contaminated samples that may require extra cleaning, and determining when glassware should be discarded. If that approach is used, the numbered glassware should be assigned to field samples, QC samples, and method blanks in a random manner (e.g., do not use the same glassware for method blanks in every batch).

5.0 Safety

5.1 The toxicity or carcinogenicity of each chemical used in this method has not been precisely determined; however, each compound should be treated as a potential health hazard. Exposure to these compounds should be reduced to the lowest possible level.

5.1.1 Several PFAS, including PFOA, have been described as likely to be carcinogenic to humans. Pure standards and materials known or suspected to contain PFAS should be handled by trained personnel, with suitable protection to skin and eyes, and care should be taken not to breathe the vapors or ingest the materials.

5.1.2 It is recommended that the laboratory purchase dilute standard solutions of the analytes in this method. However, if primary solutions are prepared, they must be prepared in a hood, following universal safety measures.

5.2 The laboratory is responsible for maintaining a current awareness file of Occupational Safety and Health Administration (OSHA) regulations regarding the safe handling of the chemicals specified in this method. A reference file of safety data sheets (SDS) should also be made available to all personnel involved in these analyses. Additional information on laboratory safety can be found in References 1-4. The references and bibliography at the end of Reference 3 are particularly comprehensive in dealing with the general subject of laboratory safety.

5.3 Samples suspected to contain these compounds should be handled using essentially the same techniques employed in handling radioactive or infectious materials. Well-ventilated, controlled access laboratories are required. Assistance in evaluating the health hazards of particular laboratory conditions may be obtained from certain consulting laboratories and from State Departments of Health or Labor, many of which have an industrial health service. Each laboratory must develop a strict safety program for handling these compounds.

5.3.1 Facility – When finely divided samples (dusts, soils, dry chemicals) are handled, all operations (including removal of samples from sample containers, weighing, transferring, and mixing) should be performed in a glove box demonstrated to be leak tight or in a fume

hood demonstrated to have adequate face velocity. Gross losses to the laboratory ventilation system must not be allowed. Handling of the dilute solutions normally used in analytical work presents no inhalation hazards except in the case of an accident.

5.3.2 Protective equipment – Disposable plastic gloves, apron or lab coat, safety glasses or mask, and a glove box or fume hood with adequate face velocity should be used. During analytical operations that may give rise to aerosols or dusts, personnel should wear respirators equipped with activated carbon filters. Eye protection (preferably full-face shields) must be worn while working with exposed samples or pure analytical standards. Latex gloves are commonly used to reduce exposure of the hands.

5.3.3 Training – Workers must be trained in the proper method of removing contaminated gloves and clothing without contacting the exterior surfaces.

5.3.4 Personal hygiene – Hands and forearms should be washed thoroughly after each manipulation and before breaks (coffee, lunch, and shift) using soaps or detergents that are free of PFAS. Before starting work, staff should avoid the use of personal-care products on exposed skin, because such products may be a source of some PFAS.

5.3.5 Confinement – Isolated work areas posted with signs, segregated glassware and tools, and plastic absorbent paper on bench tops will aid in confining contamination.

5.3.6 Waste Handling – Good technique includes minimizing contaminated waste. Plastic bag liners should be used in waste cans. Janitors and other personnel should be trained in the safe handling of waste.

5.3.7 Laundry – Clothing known to be contaminated should be collected in plastic bags. Persons that convey the bags and launder the clothing should be advised of the hazard and trained in proper handling. The clothing may be put into a washer without contact if the launderer knows of the potential problem. The washer should be run through a cycle before being used again for other clothing.

5.4 Biosolids samples may contain high concentrations of biohazards and must be handled with gloves and opened in a fume hood or biological safety cabinet to prevent exposure. Laboratory staff should know and observe the safety procedures required in a microbiology laboratory that handles pathogenic organisms when handling biosolids samples.

6.0 Equipment and Supplies

Note: *Brand names, suppliers, and part numbers are for illustration purposes only and no endorsement is implied. Equivalent performance may be achieved using apparatus and materials other than those specified here. Meeting the performance requirements of this method is the responsibility of the laboratory. All equipment described below must be constructed of materials that will not react with or sorb PFAS constituents and before use must be demonstrated to be free of PFAS at levels that would be detectable (i.e., at or above the laboratory's MDLs) in blanks or samples. Where available, certification of the PFAS levels of the materials provided by the supplier will suffice. However, in the absence of such certification from the supplier, and in the event of persistent problems with method blanks and other QC samples, the laboratory is responsible for independent testing of all equipment and supplies.*

6.1 Sampling equipment for discrete or composite sampling.

6.1.1 Sample bottles and caps

Note: *Do not use PTFE-lined caps on sample containers. All containers must be demonstrated to be PFAS-free at or below the laboratory's MDLs for the target analytes by testing one or more representative containers from each lot.*

6.1.1.1 Liquid samples (waters, sludges, and similar materials containing < 50 mg solids per sample) – Sample bottle, HDPE, 500-mL, 250-mL, and 125-mL, with linerless HDPE or polypropylene caps.

6.1.1.2 Solid samples (soils, sediments, and biosolids that contain more than 50 mg solids) – Sample bottle or jar, wide-mouth, HDPE, 500-mL, with linerless HDPE or polypropylene caps.

6.1.1.3 Tissue samples – Sample jar, wide-mouth HDPE, 100-mL, with linerless HDPE or polypropylene caps.

6.1.2 Grab sampling equipment – Sample containers may be attached to a metal or wooden pole with stainless steel hose clamps or cable ties in order to reach into flowing waters. Stainless steel scoops or spoons may be used to collect samples of soils, sediments, and biosolids.

6.1.3 Compositing equipment – Because some PFAS are known surfactants, EPA strongly discourages composite sampling for compliance monitoring (see Section 8.2), but if composite sampling is approved for given project, the equipment described below may be used. Also see Section 8.2.1 for an alternative approach to composite sampling.

If approved and used for a project, automatic or manual compositing system must incorporate properly cleaned containers. An integrating flow meter must be used to collect proportional composite samples. Only HDPE tubing must be used. If the sampler uses a peristaltic pump, a minimum length of compressible silicone rubber tubing may be used in the pump only. Before use, each lot of tubing must be thoroughly rinsed with methanol, followed by repeated rinsing with reagent water to minimize sample contamination. The final reagent water rinse should be collected and analyzed for PFAS to confirm that the tubing is suitable for use.

6.2 Equipment for glassware cleaning

Note: *If blanks from glassware show no detectable PFAS at or above the laboratory's MDLs when using fewer cleaning steps than described above, unnecessary cleaning steps and equipment may be eliminated.*

6.2.1 Laboratory sink with overhead fume hood

6.2.2 Kiln – Capable of reaching 450 ºC within 2 hours and maintaining 450 - 500 ºC ± 10 ºC, with temperature controller and safety switch (Cress Manufacturing Co., Santa Fe Springs, CA, B31H, X31TS, or equivalent). For safety, the kiln or furnace should be vented outside the laboratory, or to a trapping system.

6.3 Equipment for sample preparation

6.3.1 Disposable polyethylene gloves

6.3.2 Laboratory fume hood (of sufficient size to contain the sample preparation equipment listed below)

6.3.3 Glove box (optional)

6.3.4 Meat grinder – Hobart, or equivalent, with 3- to 5-mm holes in inner plate

6.3.5 Equipment for determining percent moisture

6.3.5.1 Oven – Capable of maintaining a temperature of 105 ± 5 ºC

6.3.5.2 Desiccator

6.3.6 Balances

6.3.6.1 Analytical – Capable of weighing 0.1 mg

6.3.6.2 Top loading – Capable of weighing 10 mg

6.3.7 Aluminum foil - food grade

6.3.8 Disposable spoons, 10 mg, polypropylene or stainless steel

6.3.9 Ultrasonic mixer (sonicator) – Immersion style, for use with tissue samples

6.3.10 HDPE bottles, with linerless HDPE or polypropylene caps – 60 mL

6.3.11 pH Paper, range 0-14 - (Whatman® Panpeha™ or equivalent), 0.5-unit readability (papers with other pH ranges may be suitable as well)

6.3.12 Analog or digital vortex mixer, single or multi-tube (Fisher Scientific 02-215-452, or equivalent)

6.3.13 Volumetric flasks, Class A

6.3.14 Disposable polypropylene collection tubes (13 x 100 mm, 8 mL)

6.3.15 Variable speed mixing table (Fisherbrand™ Nutating mixer or equivalent)

6.4 Filtration

6.4.1 Silanized glass wool (Sigma-Aldrich, Cat # 20411 or equivalent) – store in a clean glass jar and rinsed with methanol (2 times) prior to use.

6.4.2 Disposable syringe filter, 25-mm, 0.2-µm Nylon membrane, PALL/Acrodisc or equivalent

6.4.3 Glass fiber filter, 47-mm, PALL A/E or equivalent, for use in determining total suspended solids

6.5 Centrifuge apparatus

6.5.1 Centrifuge (Thermo Scientific Legend RT+, 16-cm rotor, or equivalent), capable of reaching at least 1610 RCF (3,000 rpm for the model cited)

6.5.2 Centrifuge tubes – Disposable polypropylene centrifuge tubes (50 mL)

6.6 Pipettes

6.6.1 Norm-Ject® syringe (or equivalent), polypropylene/HDPE, 5 mL

6.6.2 Variable volume pipettes with disposable HDPE or polypropylene tips (10 µL to 5 mL) – used for preparation of calibration standards and spiked samples.

6.6.3 Disposable glass pipets

6.6.4 Calibrated mechanical pipettes or Hamilton graduated syringes

6.7 Solid-phase extraction

6.7.1 Solid-phase extraction (SPE) cartridges (Waters Oasis WAX 150 mg, Cat # 186002493 or equivalent). The SPE sorbent must have a conjugate acid pKa above 8 so that it remains positively charged during the extraction.

Note: *SPE cartridges with a different bed volume (e.g., 500 mg) may be used; however, the laboratory must demonstrate that the bed volume does not negatively affect analyte absorption and elution, by performing the initial demonstration of capability analyses described in Section 9.2.*

6.7.2 Vacuum manifold for SPE Cartridges (Waters™ extraction manifold #WAT200607 or equivalent)

6.8 Evaporation

6.8.1 Automatic or manual solvent evaporation system (TurboVap® LV or equivalent)

6.8.2 Evaporation/concentrator tubes: 60-mL clear glass vial, 30 x 125 mm, without caps (Wheaton Cat # W226060 or equivalent). Cover with foil if required.

6.9 Vials

6.9.1 Snap cap/crimp top vials, 300 µL, polypropylene (12 x 32 mm) – used in sample pre-screening (DWK Life Sciences Cat # 225180 or equivalent)

6.9.2 Polypropylene crimp/snap vials, 1 mL (Agilent Cat # 5182-0567 or equivalent)

6.9.3 Clear snap cap, polyethylene, 11 mm (Fisher Scientific # 03-375-24E, or equivalent)

6.9.4 Single step filter vials (Restek Thomson SINGLE StEP® Standard Filter Vials, 0.2-µm Nylon membrane, with Black Preslit caps Cat # 25891 or equivalent) – used in sample pre-screening.

6.10 Instrument

6.10.1 Ultra high-performance liquid chromatograph (UPLC, also called UHPLC) or high-performance liquid chromatograph (HPLC) equipped with tandem quadrupole mass spectrometer (Waters Xevo TQ-S Micro or equivalent) capable of collecting at least 10 scans across a chromatographic peak

6.10.2 C18 column, 1.7 µm, 50 x 2.1 mm (Waters Acquity UPLC® BEH or equivalent)

6.10.3 Guard column (Phenomenex Kinetex® Evo C18 or equivalent)

6.10.4 Trap/delay column (Purospher Star RP-18 endcapped [3 µm] Hibar® RT 50-4 or equivalent)

6.11 Bottles, HDPE or glass, with linerless HDPE or polypropylene caps. Various sizes. To store prepared reagents.

7.0 Reagents and Standards

7.1 Reagents

Reagents prepared by the laboratory may be stored in either glass or HDPE containers. Proper cleaning procedures (Section 4.2) must be followed prior to using the containers. Before use, all reagents described below must be demonstrated to be free of PFAS at levels that would be detectable in blanks or samples (i.e., at or above the laboratory's MDLs). Where available, certification of the PFAS levels of the reagents provided by the supplier will suffice. However, in the absence of such certification from the supplier, and in the event of persistent problems with method blanks and other QC samples, the laboratory is responsible for independent testing of each lot.

7.1.1 Acetic acid (concentrated) – ACS grade or equivalent, store at room temperature

7.1.2 Acetic acid (0.1%) – dissolve acetic acid (1 mL) in reagent water (1 L), store at room temperature, replace after 3 months.

7.1.3 Acetonitrile – UPLC grade or equivalent, verified before use, store at room temperature

7.1.4 Ammonium acetate – (Caledon Ultra LC/MS grade, or equivalent), store at 2-8 °C, replace 2 years after opening date

7.1.5 Ammonium hydroxide – certified ACS+ grade or equivalent, 30% in water, store at room temperature, and replace 2 years after opening date

7.1.6 Aqueous ammonium hydroxide (3%) – add ammonium hydroxide (10 mL, 30%) to reagent water (90 mL), store at room temperature, replace after 3 months

7.1.7 Methanolic ammonium hydroxide

7.1.7.1 Methanolic ammonium hydroxide (0.3% v/v) – add ammonium hydroxide (1 mL, 30%) to methanol (99 mL), store at room temperature, replace after 1 month

7.1.7.2 Methanolic ammonium hydroxide (1% v/v) – add ammonium hydroxide (3.3 mL, 30%) to methanol (97 mL), store at room temperature, replace after 1 month

7.1.7.3 Methanolic ammonium hydroxide (2% v/v) – add ammonium hydroxide (6.6 mL, 30%) to methanol (93.4 mL), store at room temperature, replace after 1 month

7.1.8 Methanolic potassium hydroxide (0.05 M) – add 3.3 g of potassium hydroxide to 1 L of methanol, store at room temperature, replace after 3 months

7.1.9 Methanol with 4% water, 1% ammonium hydroxide and 0.625% acetic acid (v/v) – add ammonium hydroxide (3.3 mL, 30%), reagent water (1.7 mL) and acetic acid (0.625 mL) to methanol (92 mL), store at room temperature, replace after 1 month. This solution is used to prepare the instrument blank (Section 7.3.6) and is used to dilute the extracts of samples that exceed the calibration range (see Section 15.3).

7.1.10 Eluent A – Acetonitrile, Caledon Ultra LCMS grade or equivalent

7.1.11 Eluent B – 2 mM ammonium acetate in 95:5 water/acetonitrile. Dissolve 0.154 g of ammonium acetate (Section 7.1.4) in 950 mL of water and 50 mL of acetonitrile (Caledon Ultra LCMS grade, or equivalent). Store at room temperature, shelf life 2 months.

7.1.12 Formic acid – (greater than 96% purity or equivalent), verified by lot number before use, store at room temperature

7.1.13 Formic acid

7.1.13.1 Formic acid (aqueous, 0.1 M) – dissolve formic acid (4.6 g) in reagent water (1 L), store at room temperature, replace after 2 years

7.1.13.2 Formic acid (aqueous, 0.3 M) – dissolve formic acid (13.8 g) in reagent water (1 L), store at room temperature, replace after 2 years

7.1.13.3 Formic acid (aqueous, 5% v/v) – mix 5 mL formic acid with 95 mL reagent water, store at room temperature, replace after 2 years

7.1.13.4 Formic acid (aqueous, 50% v/v) – mix 50 mL formic acid with 50 mL reagent water, store at room temperature, replace after 2 years

7.1.13.5 Formic acid (methanolic 1:1, 0.1 M formic acid/methanol) – mix equal volumes of methanol and 0.1 M formic acid, store at room temperature, replace after 2 years

7.1.14 Methanol – (HPLC grade or better, 99.9% purity), verified by lot number before use, store at room temperature

7.1.15 Potassium hydroxide – certified ACS or equivalent, store at room temperature, replace after 2 years

7.1.16 Reagent water – Laboratory reagent water, test by lot/batch number for residual PFAS content

7.1.17 Carbon – EnviCarb® 1-M-USP or equivalent, verified by lot number before use, store at room temperature. Loose carbon allows for better adsorption of interferent organics.

Note: *The single-laboratory validation laboratory achieved better performance with loose carbon than carbon cartridges and therefore loose carbon was used for the multi-laboratory validation to establish statistically based method performance criteria. Laboratories have the flexibility to implement the use of carbon cartridges, as long as all method QC criteria are met (see 40 CFR 136.6).*

7.1.18 Toluene – HPLC grade, verified by lot number before use. Store at room temperature.

7.1.19 Acetone – Pesticide grade, verified by lot number before use in rinsing tissue dissection and processing equipment.

7.2 Reference matrices – Matrices in which PFAS and interfering compounds are not detected by this method. These matrices are to be used to prepare the batch QC samples (e.g., method blanks, and ongoing precision and recovery samples).

7.2.1 Reagent water – purified water, Type I

7.2.2 Solids reference matrix – Ottawa or reagent-grade sand

7.2.3 Tissue reference matrix – chicken breast or similar animal tissue

7.3 Standard solutions – Prepare from materials of known purity and composition or purchase as solutions or mixtures with certification to their purity, concentration, and authenticity. Observe the safety precautions in Section 5.

Purchase of commercial standard solutions or mixtures is highly recommended for this method; however, when these are not available, preparation of stock solutions from neat materials may be necessary. Some PFAS, notably the fluorinated carboxylic acids, will esterify in anhydrous acidic methanol. To such prevent esterification, standards must be stored under basic conditions. If base is not already present, this may be accomplished by the addition of sodium hydroxide when standards are diluted in methanol. If the chemical purity is 98% or greater, the weight may be used without correction to calculate the concentration of the standard. Dissolve an appropriate amount of assayed reference material in the required solvent. For example, weigh 10 to 20 mg of an individual compound to three significant figures in a 10-mL ground-glass-stoppered volumetric flask and fill to the mark with the required solvent. Once the compound is completely dissolved, transfer the solution to a clean vial and cap.

When not being used, store standard solutions in the dark at less than 6 °C, but not frozen, unless the vendor recommends otherwise, in screw-capped vials with foiled-lined caps. Place a mark on the vial at the level of the solution so that solvent loss by evaporation can be detected. Discard the solution if solvent loss has occurred.

Note: *Native PFAS standards are available from several suppliers. Isotopically labeled compounds are available from Cambridge Isotope Laboratories and Wellington Laboratories but may also be available from other suppliers. Listing of these suppliers does not constitute a recommendation*

or endorsement for use. All diluted solutions must be stored in glass or HDPE containers that have been thoroughly rinsed with methanol.

^{18}O-mass labeled perfluoroalkyl sulfonates may undergo isotopic exchange with water under certain conditions, which lowers the isotopic purity of the standards over time. Similarly, some of the deuterated standards may undergo isotopic exchange in protic solvents such as methanol.

The laboratory must maintain records of the certificates for all standards, as well as records for the preparation of intermediate and working standards, for traceability purposes. Copies of the certificates must be provided as part of the data packages in order to check that proper calculations were performed.

7.3.1 Extracted Internal Standard (EIS) – (a.k.a. isotopically labeled compounds) The EIS solution containing the isotopically labeled compounds listed in Table 3 is prepared in methanol from prime stocks. An aliquot of EIS solution, typically 50 µL, is added to each sample prior to extraction. Table 3 presents the nominal amounts of the EIS compounds added to each sample and that reflect the masses of each EIS contained in the calibration standards.

Note: *Larger EIS amounts may be added to samples for which pre-screening results (see Section 11.0) indicate that the sample extract will require dilution, provided that the extract dilution will result in approximately the same masses of the EIS compounds as are found in the calibration standards (assuming 100% recovery). Alternatively, if a laboratory wishes to routinely use larger EIS amounts, the standards used for the initial calibration and calibration verification must be prepared with similar EIS amounts and new calibrations performed. Otherwise, the results of all such analyses using larger EIS amounts than specified in the method must be qualified as "estimates" for reporting purposes.*

The list of EIS compounds in Table 3 represents the compounds that were available at the time this method was validated. EPA strongly recommends that additional isotopically labeled PFAS compounds be included as EIS compounds as soon as practical once they become commercially available.

7.3.2 Non-Extracted Internal Standard (NIS) – The NIS solution containing the isotopically labeled compounds listed in Table 3 as non-extracted internal standards is prepared in methanol from prime stock. An aliquot of NIS solution, typically 50 µL, is added to each sample prior to instrumental analysis. Table 3 presents the nominal amounts of NIS compounds added to each sample. As with the EIS solution above, larger amounts of the NIS compounds may be used for samples known to require extract dilution.

7.3.3 Native Standards Solution – Prepare a spiking solution, containing the target analytes listed in Table 1, in methanol from prime stocks. The solution is used to prepare the calibration standards and to spike the known reference QC samples that are analyzed with every batch. Quantitative standards containing a mixture of branched and linear isomers must be used for target analytes if they are commercially available. Currently, these include PFOA, PFOS, PFHxS, PFOSA, PFNA, NMeFOSAA, NEtFOSAA, NMeFOSA, NEtFOSA, NMeFOSE, and NEtFOSE. Additional mixtures of branched and linear isomers must be included as soon as practical once they become commercially available.

7.3.4 Calibration standard solutions – A series of calibration solutions containing the target analytes and the ^{13}C-, ^{18}O-, and deuterium-labeled EIS and NIS compounds is used to

establish the initial calibration of the analytical instrument. The concentration of the target analytes in the solutions varies to encompass the working range of the instrument, while the concentrations of the EIS and NIS remain constant. The calibration solutions are prepared using methanol, 2% methanolic ammonium hydroxide, reagent water, acetic acid, and the target analyte and isotopically labeled compound standard solutions. After dilution, the solvent composition of the final calibration solutions will approximate the solvent composition of the sample extracts, which contain methanol with roughly 4% water (due to the solubility of water from the sample in the methanolic extraction fluid), 1% ammonium hydroxide and about 0.6% acetic acid (also see Section 7.1.9). Calibration standard solutions do not undergo solid-phase extraction/cleanup.

Concentrations for the seven calibration solutions used in the validation studies are presented in Table 4. A minimum of six contiguous calibrations standards is required for a valid analysis when using a linear calibration model, with at least five of the six calibration standards being within the quantitation range (e.g., from the Limit of Quantitation [LOQ] to the highest calibration standard). If a second-order calibration model is used, then a minimum of seven calibration standards is required, with at least six of the seven calibration standards within the quantitation range. The lowest level calibration standard must meet a signal-to-noise ratio of 3:1 for the quantitation ions and confirmation ions, and 10:1 for quantitation ions that have no confirmation ion, and be at a concentration less than or equal to the LOQ. The calibration is verified with a standard in the middle of the laboratory's calibration range, i.e., the CS4 standard in Table 4 if using the default calibration range in that table. In addition, an instrument sensitivity check (ISC) standard at the concentration of the laboratory's LOQ must be analyzed at the beginning of each analytical run (Section 10.3.3.1 and Section 13.3). The concentration of ISC will be laboratory-specific, based on the demonstrated LOQ in each laboratory (i.e., it is not necessarily the lowest calibration standard analyzed).

Note: *Laboratories may choose to analyze standards at levels lower than the lowest calibration standard listed in the method when the instrument sensitivity allows, and the S/N ratio criterion is met. Conversely, laboratories may choose to eliminate or add calibration standards at the upper end of the calibration, depending on the linearity of their instrument. At a minimum, the EIS compounds in Table 3 must be used, but laboratories are strongly encouraged to include additional stable isotope analogues to quantify the associated target analytes as they become commercially available. Laboratories are also encouraged to replace the deuterated EIS compounds with the corresponding ^{13}C- or ^{18}O-labeled analogues of the target analytes, if and when they become commercially available.*

7.3.5 Qualitative Identification Standards – Standards that contain mixtures of the branched and linear isomers of the target analytes and that are used for comparison against suspected branched isomer peaks in field samples. These qualitative identification standards are **not** required for those analytes where the quantitative standards in Section 7.3.3 already contain the branched and linear isomers. Qualitative identification standards must be included as soon as practical once they become commercially available.

7.3.6 Instrument Blank – During the analysis of a batch of samples, a solvent blank is analyzed after standards (e.g., calibration, CV) and based on screening results or prior knowledge of the source, after samples containing high levels of target analytes to monitor carryover from the previous injection. The instrument blank consists of the solution in Section 7.1.9 fortified with the EIS and NIS compounds for quantitation purposes.

7.3.7 Stability of solutions – Standard solutions used for quantitative purposes (Sections 7.3.1 through 7.3.5) should be assayed periodically (e.g., every 6 months) against certified standard reference materials (SRMs) from the National Institute of Science and Technology (NIST), if available, or certified reference materials from a source accredited under ISO Guide 17034 (Reference 16) that attests to the concentration, to assure that the composition and concentrations have not changed.

7.4 Mass calibration and mass calibration verification solutions – Use the mass calibration solution specified by the instrument manufacturer.

7.5 Bile salt interference check standard containing Taurodeoxycholic Acid (TDCA) or Sodium taurodeoxychloate hydrate – (Sigma Aldrich 580221-5GM, or equivalent). This standard is used to evaluate the chromatographic program relative to the risk of an interference from bile salts in samples when using acetonitrile as the mobile phase in the instrument. Prepare solution at a concentration of 1 µg/mL in the same solvent as the calibration standards. If using other mobile phases, it will be necessary to evaluate taurochenodeoxycholic acid (TCDCA) (Sigma Aldrich T6260-1G, or equivalent) and tauroursodeoxycholic acid (TUDCA) (Sigma Aldrich 580549-1GM, or equivalent) as well.

8.0 Sample Collection, Preservation, Storage, and Holding Times

8.1 Collect samples in HDPE containers following conventional sampling practices (Reference 5). All sample containers must have linerless HDPE or polypropylene caps. Other sample collection techniques, or sample volumes may be used, if documented.

8.2 Aqueous samples

8.2.1 Because some PFAS are known surfactants, EPA strongly discourages composite sampling for Clean Water Act compliance monitoring. Therefore, samples from sources that flow freely (e.g., effluents or in-process waste streams) are collected as grab samples. Collect multiple sample aliquots in HDPE bottles that have been lot-certified to be PFAS-free. Do not fill the bottle past the shoulder, to allow room for expansion during frozen storage, if needed.

In addition, PFAS have been shown to be enriched in the surface layer of natural waters (References 17 - 19). Therefore, procedures used to collect samples from still waters in particular must consider that enrichment. For example, if the purpose of the sampling is to characterize the PFAS content of the waterbody, samples should be collected from below the surface to avoid the enrichment in the surface layer. Conversely, if the purpose is to make a worst-case assessment of the transfer of PFAS from the waterbody to the atmosphere or biota in contact with the surface layer, the sampling procedures should include the surface layer. As with all sampling activities, the specific procedures used should be documented in a sampling plan or other quality system documentation.

For aqueous sources other than leachates that have not been analyzed previously, the nominal sample size is 500-mL. For sources that are known or expected to contain levels of any target analytes above the calibration range, smaller samples may be collected in smaller size containers, provided that the volume analyzed is sufficient to meet any regulatory limits. Because the target analytes are known to bind to the interior surface of the sample container, the entire aqueous sample that is collected must be prepared and analyzed and subsampling avoided whenever possible. Therefore, if a sample volume

smaller than 500 mL is to be used for analysis, collect the sample in an appropriately sized HDPE container.

Note: *In the absence of source-specific information (e.g., historical data) on the levels of PFAS or project-specific requirements, collect at least three aliquots of all aqueous samples to allow sufficient volume for an original whole-volume analysis, a re-extraction and second analysis, and for the determination of percent solids and for pre-screening analysis. That third aliquot may be collected in a smaller sample container (e.g., 250-mL or 125-mL).*

If composite sampling is approved for given project, the equipment described in Section 6.1.3 may be used to collect samples in refrigerated bottles using automated sampling equipment. Alternatively, a manual composite sample can be created by collecting multiple small-volume samples in appropriately sized HDPE containers, manually combining them in a 500-mL HDPE container in the laboratory, rinsing each of the original containers with basic methanol, using those rinsates to rinse the 500-mL container, and then adding the combined rinsate to the SPE cartridge as described in Sec. 12.2.2.

8.2.2 Leachate samples from landfills can present significant challenges and therefore only 100 mL of sample is collected for the analysis. Collect three 100-mL leachate sample aliquots in a similar manner as described in Section 8.2.1, using appropriately sized containers that have been lot-certified to be PFAS-free.

8.2.3 Maintain all aqueous samples protected from light and at or below 6 ºC from the time of collection until shipped to the laboratory. Samples must be shipped with sufficient ice to maintain the sample temperature at or below 6 ºC during transport for a period of at least 48 hours to allow for shipping delays. The laboratory must confirm that the sample temperature is at or below 6 ºC upon receipt. Once received by the laboratory, the samples may be stored at 0 - 6 ºC or at or below -20 ºC, until sample preparation. However, the allowable holding time for samples depends on the storage temperature, as described in Section 8.5, so samples should be shipped to the laboratory as soon as practical.

8.3 Solid (soil, sediment, biosolids), excluding tissue

8.3.1 Collect samples using wide-mouth HDPE jars that have been lot-certified to be PFAS-free and fill no more than ¾ full (see Section 6.1.1.2 for container size and type).

8.3.2 Maintain solid samples protected from light (in HDPE containers) from the time of collection until receipt at the laboratory. Samples must be shipped with sufficient ice to maintain the sample temperature at or below 6 ºC for a period of at least 48 hours to allow for shipping delays. The laboratory must confirm that the sample temperature is at or below 6 ºC upon receipt. Once received by the laboratory, the samples may be stored at 0 - 6 ºC or at or below -20 ºC, until sample preparation. However, the allowable holding times for samples depend on the storage temperature, as described in Section 8.5, so samples should be shipped to the laboratory as soon as practical.

8.4 Fish and other tissue samples

The nature of the tissues of interest may vary by project. Field sampling plans and protocols should explicitly state the samples to be collected and if any processing will be conducted in the field (e.g., filleting of whole fish or removal of organs) and those details are beyond the scope of this method. All field procedures must involve materials and equipment that have been shown to be free of PFAS.

8.4.1 Fish may be cleaned, filleted, or processed in other ways in the field, such that the laboratory may expect to receive whole fish, fish fillets, or other tissues for analysis.

8.4.2 If whole fish are collected, wrap the fish in aluminum foil or insert into food-grade polyethylene tubing, and maintain at or below 6 ºC from the time of collection until receipt at the laboratory, to a maximum time of 24 hours. The laboratory must confirm that the sample temperature is at or below 6 ºC upon receipt. If a longer transport time is necessary, freeze the sample before shipping. Ideally, fish should be frozen upon collection and shipped to the laboratory on dry ice. Other project-specific holding times and shipping conditions may be used where required.

8.4.3 Once received by the laboratory, the samples must be maintained protected from light at or below -20 ºC until prepared. If subsequently homogenized in Section 11.4, store unused sample tissue mass in HDPE containers or wrapped in aluminum foil at or below -20 ºC.

8.5 Holding times

8.5.1 Aqueous samples (including leachates) should be analyzed as soon as possible; however, samples may be held in the laboratory for up to 28 days from collection, when stored at or below 6 ºC and protected from the light, with the caveat that issues have been observed with certain perfluorooctane sulfonamide ethanols and perfluorooctane sulfonamidoacetic acids after 7 days. These issues are more likely to elevate the observed concentrations of other PFAS compounds via the transformation of these precursors if they are present in the sample (see References 10 and 15).

When stored at or below -20 ºC and protected from the light, aqueous samples may be held for up to 90 days.

8.5.2 Soil and sediment samples may be held for up to 90 days, if stored by the laboratory in the dark at either 0 - 6 ºC, or at below -20 ºC, with the caveat that samples may need to be extracted as soon as possible if NFDHA is an important analyte for a given project (see Reference 10). However, some soils and sediments may exhibit microbial growth when stored at 0 - 6 ºC.

8.5.3 If whole fish or other seafood samples are frozen within 48 hours of the time of collection (i.e., either in the field or as soon as the samples are received at the laboratory or other storage facility), the holding time for tissue samples does **not** begin at the time of collection of the whole fish or other seafood, but at the time when the whole fish or other seafood is processed for analysis (e.g., filleting, grinding, or removal of specific tissues for analysis). Prepared tissue sample aliquots may be held for up to 90 days, if stored by the laboratory in the dark at or below -20 ºC, with the same caveat regarding NFDHA.

8.5.4 Biosolids samples may be held for up to 90 days, if stored by the laboratory in the dark at 0 - 6 ºC, but preferably at or below -20 ºC (see Reference 10). Because microbiological activity in biosolids samples at 0 - 6 ºC may lead to production of gases which may cause the sample to be expelled from the container when it is opened, as well as producing noxious odors, EPA recommends that samples be frozen if they need to be stored for more than a few days before extraction.

8.5.5 Store sample extracts in the dark at or below 6 ºC until analyzed. If stored in the dark at or below 0 ºC, sample extracts may be stored for up to 90 days, with the caveat that issues were observed for some ether sulfonates after 28 days (see Reference 10). These issues

may elevate the observed concentrations of the ether sulfonates in the extract over time. Samples may need to be extracted as soon as possible if NFDHA is an important analyte.

9.0 Quality Control

9.1 Each laboratory that uses this method is required to operate a formal quality assurance program (Reference 6). The minimum requirements of this program consist of an initial demonstration of laboratory capability, analysis of samples spiked with isotopically labeled compounds to evaluate and document data quality, and analysis of standards and blanks as tests of continued performance. Laboratory performance is compared to established performance criteria to determine if the results of analyses meet the performance characteristics of the method.

If the method is to be applied to a sample matrix other than water (e.g., solids and tissues), the appropriate alternative reference matrix (Sections 7.2.2 - 7.2.3) is substituted for the reagent water matrix (Section 7.2.1) in all performance tests.

9.1.1 The laboratory must make an initial demonstration of the ability to generate acceptable precision and recovery with this method. This demonstration is given in Section 9.2.

9.1.2 In recognition of advances that are occurring in analytical technology, and to overcome matrix interferences, the laboratory is permitted certain options to improve separations or lower the costs of measurements. These options include alternative extraction, concentration, and cleanup procedures, and changes in sample volumes, columns, and detectors. Alternative determinative techniques and changes that degrade method performance are *not* allowed without prior review and approval (see 40 CFR 136.4 and 136.5).

Note: *For additional flexibility to make modifications without prior EPA review, see 40 CFR Part 136.6.*

9.1.2.1 Each time a modification is made to this method, the laboratory is required to repeat the procedure in Section 9.2. If calibration will be affected by the change, the instrument must be recalibrated per Section 10. Once the modification is demonstrated to produce results in a relevant reference matrix and are equivalent or superior to results produced by this method as written, that modification may be used routinely thereafter, so long as the other requirements in this method (e.g., isotopically labeled compound recovery) are met in both the initial demonstration in Section 9.2 and in field samples and other QC samples.

9.1.2.2 The laboratory is required to maintain records of any modifications made to this method. These records include the following, at a minimum:

a) The names, titles, business addresses, and telephone numbers of the analyst(s) that performed the analyses and modification, and of the quality control officer that witnessed and will verify the analyses and modifications.

b) A listing of pollutant(s) measured, by name and CAS Registry number.

c) A narrative stating reason(s) for the modifications (see Section 1.5).

d) Results from all quality control (QC) tests comparing the modified method to this method, including:

i. Calibration (Section 10)
ii. Calibration verification (Section 14.3)
iii. Initial precision and recovery (Section 9.2.1)
iv. Isotopically labeled compound recovery (Section 9.3)
v. Analysis of blanks (Section 9.5)
vi. Accuracy assessment (Section 9.4)

e) Data that will allow an independent reviewer to validate each determination by tracing the instrument output (peak height, area, or other signal) to the final result. These data are to include:

i. Sample numbers and other identifiers
ii. Extraction dates
iii. Analysis dates and times
iv. Analysis sequence/run chronology
v. Sample weight or volume (Section 11)
vi. Extract volume prior to each cleanup step (Section 12)
vii. Extract volume after each cleanup step (Section 12)
viii. Injection volume (Section 13.3)
ix. Dilution data, differentiating between dilution of a sample or an extract (Section 15.3)
x. Instrument
xi. Column (dimensions, liquid phase, solid support, film thickness, etc.)
xii. Operating conditions (temperatures, temperature program, flow rates)
xiii. Detector (type, operating conditions, etc.)
xiv. Chromatograms, printer tapes, and other recordings of raw data
xv. Quantitation reports, data system outputs, and other data to link the raw data to the results reported

9.1.2.3 Alternative columns and column systems – If a column or column system other than those specified in this method is used, that column or column system must meet all the requirements of this method.

Note: *The use of alternative columns or programs will likely result in a different elution order.*

9.1.3 Analyses of method blanks are required on an on-going basis to demonstrate the extent of background contamination in any reagents or equipment used to prepare and analyze field samples (Section 4.3). The procedures and criteria for analysis of a method blank are described in Section 9.5.

9.1.4 The laboratory must spike all samples with isotopically labeled compounds to monitor method performance. This test is described in Section 9.3. When results of these spikes indicate atypical method performance for samples, the samples are diluted to evaluate whether the performance issue is caused by the sample matrix. Procedures for dilution are given in Section 15.3.

9.1.5 The laboratory must, on an ongoing basis, demonstrate that the analytical system is in control through calibration verification and the analysis of ongoing precision and recovery standards (OPR), spiked at low (LLOPR) and mid-level, and blanks. These procedures are

given in Sections 14.3 through 14.7. Other important checks of the analytical system include the ISC (Section 14.1), the bile salt interference check (Section 14.2), and the use of the qualitative identification standard (Section 14.8).

9.1.6 The laboratory must maintain records to define the quality of data generated. Development of accuracy statements is described in Section 9.4.

9.2 Initial Demonstration of Capability

9.2.1 Initial precision and recovery (IPR) – To establish the ability to generate acceptable precision and recovery, the laboratory must perform the following operations for each sample matrix type to which the method will be applied by that laboratory.

9.2.1.1 Extract, concentrate, and analyze four aliquots of the matrix type to be tested (Section 7.2.1 through 7.2.3), spiked with 200 µL of the native standard solution (Section 7.3.3), 50 µL of the EIS solution (Section 7.3.1), and 50 µL of NIS solution (Section 7.3.2). At least one method blank matching the matrix being analyzed must be prepared with the IPR batch. In the event that more than one method blank was prepared and analyzed with the IPR batch, all blank results must be reported. All sample processing steps that are to be used for processing samples, including preparation and extraction (Sections 11.2 – 11.4), cleanup (Section 12.0) and concentration (Section 12.0), must be included in this test.

9.2.1.2 Using results of the set of four analyses, compute the average percent recovery of the extracts and the relative standard deviation (RSD) of the concentration for each target analyte and EIS compound.

9.2.1.3 For each target analyte, compare RSD and % recovery with the corresponding limits for initial precision and recovery in Tables 5 and 7. Table 5 includes the required IPR QC acceptance limits for the target analytes in aqueous samples that were derived from the multi-laboratory validation study. Table 6 contains the required acceptance limits for the EIS compounds in both aqueous QC samples (including the IPR, OPR, and LLOPR) and field samples that were derived from the multi-laboratory validation study. Table 7 includes the required IPR QC acceptance limits for the target analytes in solids and biosolids, and tissues. Table 8 contains the required acceptance limits for the EIS compounds in both solid, biosolid, and tissue QC samples (including the IPR, OPR, and LLOPR) and field samples that were derived from the multi-laboratory validation study. For all matrices, if RSD and % recovery for all target analytes meet the acceptance criteria, system performance is acceptable, and analysis of blanks and samples may begin. If, however, any individual RSD exceeds the precision limit or any individual % recovery falls outside the range for recovery, system performance is unacceptable for that compound. Correct the problem and repeat the test (Section 9.2).

The NIS recoveries *in each IPR aliquot* must be meet the acceptance limits in Section 14.9. There are no limits for mean NIS recovery or NIS RSD in the IPR aliquots.

9.2.2 Method detection limit (MDL) - Each laboratory must also establish MDLs for all the target analytes using the MDL procedure at 40 CFR Part 136, Appendix B. Example matrix-specific pooled method detection limits are listed in Table 9.

9.2.3 The limit of quantitation (LOQ) is the smallest concentration that produces a quantitative result with known and recorded precision and bias. In this method, the LOQ is established by each laboratory at or above the concentration of the lowest initial calibration standard that falls within their demonstrated quantitation range. For the purposes of this method, EPA considers the terms "Minimum Level," "reporting limit," "quantitation limit," and "limit of quantitation" to be synonymous.

9.2.4 Historically in other methods, EPA has calculated the minimum level of quantification (ML) by multiplying the MDL by 3.18 and rounding the result to the nearest 1, 2 or 5 x 10^n, where n is zero or an integer, or tied the ML to the concentration of the lowest calibration standard (see the Glossary for further details), thus providing a simple benchmark for the overall sensitivity of a method. With the addition of the LOQ concept in Section 9.2.3 above, the ML for this method has been tied to the LOQ.

9.3 To assess method performance on the sample matrix, the laboratory must spike all samples with the EIS solution (Section 7.3.1) and all sample extracts with the NIS solution (Section 7.3.2).

9.3.1 Analyze each sample according to the procedures in Sections 11.0 through 16.0.

9.3.2 Compute the percent recovery of the EIS compounds using the non-extracted internal standard method (Section 15.2) and the equation in Section 14.5.2.

9.3.3 The recovery of each EIS compound in an aqueous sample must be within the limits in Table 6, which are the required QC acceptance limits for aqueous samples, including landfill leachates, that were derived from the multi-laboratory validation study. The recovery of each EIS compound in soil, sediment, biosolid, or tissue sample must be within the limits in Table 8, which are the required QC acceptance limits for those matrices that were derived from the multi-laboratory validation study. If the recovery of any EIS falls outside of these limits, method performance is unacceptable for that EIS in that sample. Additional cleanup procedures or limited dilution of the sample extract may be employed to attempt to bring the EIS recovery within the acceptance normal range.

If the recovery cannot be brought within the acceptance limits after extract dilution or additional cleanup procedures have been employed, then the laboratory must take a smaller aliquot of any affected aqueous sample, dilute it to 500 mL with reagent water and prepare an analyze the diluted sample, or must prepare and analyze a smaller aliquot of soil, sediment, biosolid, or tissue sample, per Section 15.3.

9.4 Records of the recovery of EIS and NIS compounds from samples must be maintained and should be assessed periodically.

9.4.1 After the analysis of 30 samples of a given matrix type (aqueous, solids, tissues, etc.), compute the recovery and the standard deviation of the percent recovery (S_R) for the isotopically labeled compounds only. Express the assessment as a percent recovery interval from R - $2S_R$ to R + $2S_R$ for each matrix. For example, if R = 90% and S_R = 10% for 30 analyses of soil, the recovery interval is expressed as 70 to 110%.

9.4.2 Update the accuracy assessment for each isotopically labeled compound in each matrix on a regular basis (e.g., after each five to ten new preparation batches).

9.5 Method blanks – A method blank is analyzed with each sample batch (Section 4.3) to demonstrate freedom from contamination. The matrix for the method blank must be similar to the sample

matrix for the batch (e.g., reagent water blank [Section 7.2.1], solids blank [Section 7.2.2], or tissue blank [Section 7.2.3]).

9.5.1 Analyze the cleaned extract (Section 12.0) of the method blank aliquot before the analysis of the OPRs (Section 14.5).

9.5.2 If any PFAS is found in the blank at 1) at a concentration greater than the LOQ for the analyte, 2) at a concentration greater than one-third the regulatory compliance limit, or 3) at a concentration greater than one-tenth the concentration in a sample in the extraction batch, whichever is greatest, analysis of samples must be halted, and the problem corrected. Other project-specific requirements may apply; therefore, the laboratory may adopt more stringent acceptance limits for the method blank at their discretion. If the contamination is traceable to the extraction batch, the laboratory should check solvents, glassware, and other potential sources of PFAS contamination. Samples affected by the blank must be re-extracted and analyzed along with a new method blank and other batch-specific QC, provided that enough sample volume is available, and the sample are still within holding time.

If the new blank also exhibits contamination and additional volume of the associated samples is not available for re-extraction ana analysis, the laboratory must document and report the failures (e.g., as qualifiers on results), unless the failures are not required to be reported as determined by the regulatory/control authority. Results associated with blank contamination for an analyte regulated in a discharge cannot be used to demonstrate regulatory compliance. QC failures do not relieve a discharger or permittee of reporting timely results.

9.6 The specifications contained in this method can be met if the apparatus used is calibrated properly and then maintained in a calibrated state. The standards used for initial calibration (Section 10.3), calibration verification (Section 14.3), and for initial (Section 9.2.1) and ongoing (Section 14.5) precision and recovery may be prepared from the same source; however, the use of a secondary source for calibration verification is highly recommended whenever available. If standards from a different vendor are not available, a different lot number from the same vendor can be considered a secondary source. A LC-MS/MS instrument will provide the most reproducible results if dedicated to the settings and conditions required for determination of PFAS by this method.

9.7 Laboratory duplicates –A laboratory duplicate analysis is not required for NPDES compliance monitoring. There are established concerns about partitioning of some PFAS to surfaces and suspended solids in aqueous samples. If a particular project specifically requests a laboratory duplicate be performed for aqueous samples, then the requestor is responsible for providing additional container(s) of that sample, must provide their acceptance criterion for the relative percent difference (% RPD) of such laboratory duplicates, and provide any corrective actions that must be taken when the % RPD criterion is not met. For samples of other matrices, the requestor either must provide sufficient additional sample mass in the original container or an additional container, along with the acceptance criterion and corrective actions.

9.8 Depending on specific program requirements, field duplicates may be collected to determine the precision of the sampling technique.

Note: *Laboratory Duplicates and Field Duplicates are not one in the same. Field Duplicates are meant to evaluate potential sampling error and are evaluated by the project, not the laboratory. If the requestor provides field duplicates for a given project, the laboratory should not be held to an acceptance criterion because of the potential sampling error involved in field duplicates.*

9.9 Matrix spikes generally are not required for methods that employ isotope dilution quantification because any deleterious effects of the matrix should be evident in the recoveries of the EIS compounds spiked into every sample. The analysis of matrix spike samples may help diagnose the potential impact of matrix interferences for specific target analytes or sample matrices.

10.0 Calibration and Standardization

10.1 Mass Calibration

The mass spectrometer must undergo mass calibration to ensure accurate assignments of m/z's by the instrument. This mass calibration must be performed at least annually or as recommended by the instrument manufacturer, whichever is more frequent, to maintain instrument sensitivity and stability. Mass calibration must be repeated on an as-needed basis (e.g., QC failures, ion masses fall outside of the required mass window, major instrument maintenance, or if the instrument is moved). Mass calibration must be performed using the calibration compounds and procedures prescribed by the manufacturer.

Multiple Reaction Monitoring (MRM) analysis is required to achieve better sensitivity than full-scan analysis. The default parent ions, quantitation ions (Q1), and confirmation (Q2) ions that were monitored during the validation of this method are listed in Table 10 for each target analyte, EIS, and NIS.

10.1.1 During the development of this method, instrumental parameters were optimized for the precursor and product ions of the linear isomers of the target analytes listed on Table 9. If a qualitative or quantitative standard containing an isomeric mixture (branched and linear isomers) of an analyte is commercially available for an analyte, the quantification ion used must be the quantification ion identified in Table 9, unless interferences render the product ion unusable as the quantification ion. In cases where interferences render the product ion unusable, consult the client before using the alternative product ion and document the reason for the change when reporting results. However, the use of ions with lower masses or common ions that may not provide sufficient discrimination between target analytes and co-eluting interferences must be avoided.

10.1.2 Optimize the response of the precursor ion $[M\text{-}H]^-$ or $[M\text{-}CO_2]^-$ for each target analyte, EIS, and NIS following the manufacturer's guidance. MS parameters (e.g., source voltages, source and desolvation temperatures, gas flow, etc.) must be methodically changed until optimal analyte responses are determined. Typically, carboxylic acids have similar MS/MS conditions and sulfonic acids have similar MS/MS conditions. However, since analytes may have different optimal parameters, some compromise on the final operating conditions may be required.

10.1.3 Establish suitable operating conditions using the manufacturer's instructions and use the MS conditions below that were used during the development of this method as guidance.

Operating Conditions for Waters Acquity UPLC, TQ-S Xevo MS/MS

Injection volume	2.0 µL (*This is the default volume, and may be changed to improve performance*)	
MS/MS Conditions	Ionization Mode	Negative ESI
	Source Temp (ºC)	140
	Desolvation Temp (°C)	500
	Capillary Voltage (kV)	0.70
	Cone Gas (L/h)	~70
	Desolvation gas (L/h)	~800

10.1.4 As noted above, perform the mass calibration following the instrument manufacturer's instructions, using the calibrant prescribed by the manufacturer.

10.1.5 Regardless of the calibrant used, mass calibration is judged on the basis of the presence or absence of the exact calibration masses (e.g., a limit on the number of masses that are "missed"). If peaks are missing or not correctly identified, adjust the MS/MS, and repeat the test. Only after the MS/MS is properly calibrated may standards, blanks, and samples be analyzed.

10.1.6 Mass spectrometer optimization – Prior to measurements of a given analyte the mass spectrometer must be separately optimized for that analyte.

10.1.6.1 Using the post-column pump, separately infuse a solution containing each compound in methanol into the MS.

10.1.6.2 Optimize sensitivity for the product ion m/z for each analyte. Precursor-product ion m/z's other than those listed may be used provided requirements in this method are met.

10.1.6.3 After MS calibration and optimization and LC-MS/MS calibration, the same LC-MS/MS conditions must be used for analysis of all standards, blanks, IPR and OPR standards, and samples.

10.1.7 Mass Calibration Verification

The mass calibration must be verified prior to the analysis of any standards and samples and after each subsequent mass calibration. Each laboratory must follow the instructions for their instrument software to confirm the mass calibration, mass resolution, and peak relative response. In addition to the mass calibration verification performed using a standard specified by the manufacturer, the mass calibration must also be verified with respect to the ion masses monitored by this method.

10.1.7.1 Check the instrument mass resolution to ensure that it is at least unit resolution. Inject a mid-level calibration standard under LC-MS/MS conditions to obtain the retention times of each method analyte. Divide the chromatogram into segments or retention time ranges, each of which contains one or more chromatographic peaks. During MS/MS analysis, fragment a small number of selected precursor ions ($[M-H]^-$ or $[M-CO2]^-$) for the analytes in each window and choose the most abundant product ion. The product ions (also the quantification and confirmation ions) chosen during method development are listed in Table 9, although these will be instrument dependent. Unit resolution must meet the manufacturer's criteria.

10.1.7.2 Check the mass calibration by measuring the amount of peak drift from the expected masses. If the peak apex has shifted more than approximately 0.2 Da, recalibrate the mass axis following the manufacturer's instructions.

10.2 Chromatographic conditions

10.2.1 The chromatographic conditions should be optimized for compound separation (including analytes with both linear and branched isomers) and for sensitivity. The same optimized operating conditions must be used for the analysis of all standards, blanks, IPR and OPR standards, and samples. The following table gives the suggested chromatographic conditions for this method using the specified instrument and column. Different instruments may require slightly different operating conditions. **Modification of the solvent composition of the standard or extract by increasing the aqueous content to prevent poor peak shape is not permitted.** The peak shape of early eluting compounds may be improved by increasing the volume of the injection loop or increasing the aqueous content of the initial mobile phase composition.

General LC Conditions

Column Temp (°C) 40

Max Pressure (bar) 1100.0

LC Gradient Program

Time (min)	Flow mixture [1,2]	Flow Rate Program	Gradient Curve
0.0	2% eluent A, 98% eluent B	0.35 mL/min	Initial
0.2	2% eluent A, 98% eluent B	0.35 mL/min	2
4.0	30% eluent A, 70% eluent B	0.40 mL/min	7
7.0	55% eluent A, 45% eluent B	0.40 mL/min	8
9.0	75% eluent A, 25% eluent B	0.40 mL/min	8
10.0	95% eluent A, 5% eluent B	0.40 mL/min	6
10.4	2% eluent A, 98% eluent B	0.40 mL/min	10
11.8	2% eluent A, 98% eluent B	0.40 mL/min	7
12.0	2% eluent A, 98% eluent B	0.35 mL/min	1

[1] Eluent A = Acetonitrile
[2] Eluent B = 2 mM ammonium acetate in 95:5 water/acetonitrile

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Note: *LC system components, as well as the mobile phase constituents, may contain many of the analytes in this method. Thus, these PFAS will build up on the head of the LC column during mobile phase equilibration. To minimize the occurrence of background PFAS peaks and to keep baseline levels constant, the time that the LC column sits at initial conditions must be kept constant and as short as possible (while ensuring reproducible retention times). In addition, priming the mobile phase and flushing the column with at least 90% methanol before initiating a sequence may reduce background contamination.*

10.2.2 Retention time calibration

10.2.2.1 Inject solution(s) containing the target analytes and the EIS and NIS compounds to determine their retention times. The laboratory may want to inject analytes/compounds separately the first time they perform the calibration. All target compounds for which there is an isotopically labeled analog will elute slightly before or with the labeled analog. Store the retention time (RT) for each compound in the data system. The retention time window must include all isomers present in the isomeric standard mixtures (qualitative or quantitative).

10.2.2.2 Once RT windows have been confirmed for each target analyte, EIS, and NIS compound, then once per ICAL and at the beginning of the analytical sequence, the position of all target analyte, EIS, and NIS peaks shall be set using the midpoint standard of the ICAL curve when ICAL is performed. When an ICAL is not performed, the initial CV retention times or the midpoint standard of the ICAL curve can be used to establish the RT window position.

10.2.2.3 The RTs for the target analytes, EIS, and NIS compounds must fall within 0.4 minutes of the predicted retention times from the midpoint standard of the ICAL or initial CV, whichever was used to establish the RT window position for the analytical batch. All branched isomer peaks identified in either the calibration standard or the qualitative (technical grade) standard also must fall within 0.4 minutes of the predicted retention times from the midpoint standard of the ICAL or initial CV.

10.2.2.4 For all target analytes with exact corresponding isotopically labeled analogs, target analytes must elute within 0.1 minutes of the associated EIS compound. (The laboratory may use relative retention times (RRTs) of the target analytes and their labeled analogs as an alternative, provided that they also develop corresponding RRT acceptance criteria that are at least as stringent as those described here.)

10.2.2.5 When establishing the chromatographic conditions, it is important to ensure adequate chromatographic separation to avoid potential interference from bile salts during analyses of samples. Inject the bile salt interference check standard containing TDCA (see Section 7.5 if the mobile phase is not acetonitrile) during the retention time calibration process and adjust the conditions to ensure that TDCA (or TDCA, TCDCA and TUDCA) does not coelute with any of the target analytes, EIS, or NIS compounds. The laboratory must demonstrate that the analytical conditions provide a separation of at least 1 minute between the bile salts and the retention time window of PFOS, as described in Section 7.3.3. In order to ensure adequate chromatographic separation of the target analytes, the method requires this evaluation when establishing the chromatographic conditions and on an ongoing basis, **regardless of the sample matrices to be analyzed**.

10.3 Initial calibration

Initial calibration is performed using a series of at least six solutions, with at least five of the six calibration standards being within the quantitation range, and with the lowest standard at or below the LOQ. (If a second-order calibration model is used, then one additional concentration is required, with at least six of the seven calibration standards within the quantitation range.) The initial calibration solutions contain the entire suite of EIS and NIS compounds, and target analytes. Calibration is verified with a calibration verification (CV) standard prior to sample analysis, at least once every ten injections of a field sample extract, and at the end of the analytical sequence by analysis of a mid-level calibration solution. Calibration verification uses the mean RRs or RFs determined from the initial calibration to calculate the analyte concentrations in the verification standard.

Note: *Six calibration standards is the minimum number that must be used in the initial calibration; however, the laboratory may use more standards, as long as the criteria in Section 10.3.3.3 can be met.*

Prior to the analysis of samples, and after the mass calibration verification has met all criteria in Sections 10.1.4 and 10.1.7, each LC-MS/MS system must be calibrated at a minimum of six standard concentrations (Section 7.3.4 and Table 4). This method procedure calibrates and quantifies 40 target analytes, using the isotopically labeled compounds added to the sample prior to extraction, by one of two approaches:

- True isotope dilution quantification (ID), whereby the response of the target analyte is compared to the response of its isotopically labeled analog. Twenty-four target compounds are quantified in this way.
- Extracted internal standard quantification (EIS), whereby the response of the target analyte is compared to the response of the isotopically labeled analog of another compound with chemical and retention time similarities. Sixteen target compounds are quantified in this way.

10.3.1 Initial calibration frequency

Each LC-MS/MS system must be calibrated whenever the laboratory takes an action that changes the chromatographic conditions or might change or affect the initial calibration criteria, or if either the CV or Instrument Sensitivity Check (ISC) acceptance criteria have not been met.

10.3.2 Initial calibration procedure

Prepare calibration standards containing the target compounds, EIS, and NIS compounds. The concentrations described in Table 4 are those used in the validation studies and are provided as guidance. Standards at other concentrations may be used, and wider calibration ranges with standards either above or below the concentrations in Table 4 are allowed, provided that at least 6 contiguous standards are used, with the lowest standard at or below the LOQ (see Section 10.3), and that all of the conditions in Section 10.3.3 are met. Analyze each calibration standard by injecting 2.0 µL (this volume may be changed to improve performance).

Note: *The same injection volume must be used for all standards, samples, blanks, and QC samples.*

10.3.3 Initial calibration calculations

10.3.3.1 Instrument sensitivity

Sufficient instrument sensitivity is established if a signal-to-noise ratio ≥ 3:1 for the quantification ions and the confirmation ions, or ≥ 10:1 if the analyte only has a quantification ion, can be achieved when analyzing the lowest concentration standard within the quantitation range that the laboratory includes in its assessment of calibration linearity.

10.3.3.2 Response Ratios (RR) and Response Factors (RF)

The response ratio (RR) for each native compound calibrated by isotope dilution is calculated according to the equation below, separately for each of the calibration standards, using the areas of the quantification ions (Q1) with the m/z shown in Table 9. RR is used for the 24 compounds measured by true isotope dilution quantification.

$$RR = \frac{Area_t\, M_{EIS}}{Area_{EIS}\, M_t}$$

where:

$Area_t$ = Measured area of the Q1 m/z for the target analyte

$Area_{EIS}$ = Measured area at the Q1 m/z for the corresponding isotopically labeled PFAS used as the EIS in the calibration standard

M_{EIS} = Mass of the isotopically labeled PFAS used as the EIS in the calibration standard

M_t = Mass of the target analyte in the calibration standard

Similarly, the response factor (RF) for each native compound calibrated by extracted internal standard is calculated according to the equation below. RF is used for the 16 compounds measured by extracted internal standard quantification.

$$RF = \frac{Area_t\, M_{EIS}}{Area_{EIS}\, M_t}$$

where:

$Area_t$ = Measured area of the Q1 m/z for the target analyte

$Area_{EIS}$ = Measured area at the Q1 m/z for the isotopically labeled PFAS used as the EIS in the calibration standard

M_{EIS} = Mass of the isotopically labeled PFAS used as the EIS in the calibration standard

M_t = Mass of the target analyte in the calibration standard

A response factor (RF_s) is calculated for each EIS compound in the calibration standard using the equation below. RF_s is used for the 24 isotopically labeled compounds measured by non-extracted internal standard quantification.

$$RF_s = \frac{Area_{EIS}\, M_{NIS}}{Area_{NIS}\, M_{EIS}}$$

where:

$Area_{EIS}$ = Measured area of the Q1 m/z for the EIS compound added to the sample before extraction

$Area_{NIS}$ = Measured area at the Q1 m/z for the NIS compound in the calibration standard

M_{NIS} = Mass of the NIS compound in the calibration standard

M_{EIS} = Mass of the EIS compound added to the sample before extraction

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Note: *Other calculation approaches may be used, such as a weighted linear regression or non-linear regression, based on the capability of the data system used by the laboratory. If used, the regression must be weighted inversely proportional to concentration and must not be forced through zero. Analysts should consult their instrument vendor for details on regression calibration models. When using a weighted regression calibration, linearity must be assessed using Option 2 below.*

10.3.3.3 Instrument Linearity

One of the following two approaches must be used to evaluate the linearity of the instrument calibration:

Option 1: Calculate the relative standard deviation (RSD) of the RR or RF values for each target analyte and isotopically labeled compound for

all the initial calibration standards that were analyzed. The RSD must be ≤ 20% to establish instrument linearity.

$$mean\ RR\ or\ RF = \frac{\sum_{i=1}^{n}(RR\ or\ RF)_i}{n}$$

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(RR\ or\ RF_i - \text{mean RR or RF})^2}{n}}$$

$$RSD = \frac{SD}{mean}\ x\ 100$$

where:

$RR\ or\ RF_i$ = RR or RF for calibration standard *i*

n = Number of calibration standards

Option 2: Calculate the relative standard error (RSE) for each target analyte and EIS compound for all the initial calibration standards that were analyzed. The RSE for all target analytes and EIS compounds must be ≤ 20% to establish instrument linearity.

$$RSE = 100 \times \sqrt{\sum_{i=1}^{n} \frac{\left[\frac{x_i' - x_i}{x_i}\right]^2}{n-p}}$$

where,

x_i = Nominal concentration (true value) of each calibration standard

x_i' = Measured concentration of each calibration standard

n = Number of standard levels in the curve

p = Type of curve (2 = linear, 3 = quadratic)

In addition, although not required, it may be useful to compare the actual responses for each standard to the calibration model. Differences outside of a window of 70 – 130% of the modeled concentration may be cause for concern.

Note: *The correlation coefficient, r, and the coefficient of determination, r^2, are no longer considered appropriate metrics for linearity and shall not be used in conjunction with this method.*

10.3.3.4 Non-extracted Internal Standard Area

Each time an initial calibration is performed, use the data from all the initial calibration standards used to meet the linearity test in Section 10.3.3.3 to calculate the mean area response for each of the NIS compounds, using the equation below.

$$Mean\ Area_{NIS_i} = \frac{\sum Area_{NIS_i}}{n}$$

where:

$Area_{NIS_i}$ = Area counts for the *ith* NIS, where *i* ranges from 1 to 7, for the seven NIS compounds listed in Table 1

n = Number of ICAL standards (the default value is n = 6). If a different number of standards is used for the ICAL, for example, to increase the

calibration range or by dropping a point at either end of the range to meet the linearity criterion, change 6 to match the actual number of standards used.

Record the mean areas for each NIS compound for use in evaluating results for sample analyses (see Section 14.9).

10.3.4 Initial calibration corrective actions

If the instrument sensitivity or the instrument linearity criteria for initial calibration are not met, inspect the system for problems and take corrective actions to achieve the criteria. This may require the preparation and analysis of fresh calibration standards or performing a new initial calibration. All initial calibration criteria must be met before any samples or required blanks are analyzed.

10.3.5 Bile salts interference check

The laboratory must analyze a bile salt interference check standard (see Section 7.5) after the initial calibration and during each analytical sequence (see Section 13.3) as a check on the chromatographic conditions, **regardless of the sample matrix to be analyzed**. If an interference is present, the chromatographic conditions must be modified to eliminate the interference from the bile salts (e.g., changing the conditions such that the retention time of the bile salts fall outside the retention time window for any of the linear or branched PFOS isomers in the standard described in Section 7.3.3 by at least one minute), and the initial calibration repeated.

11.0 Sample Preparation and Extraction

For aqueous samples that contain particles and solid samples, percent solids are determined using the procedures in Section 11.1. This section describes the sample preparation procedures for aqueous samples with < 50 mg solids in the sample volume to be extracted (Section 11.2), solid (soil, sediment or biosolid) samples (Section 11.3) and tissue samples (Section 11.4).

Absent of source-specific knowledge of the PFAS levels in samples or project-specific requirements, the laboratory must pre-screen all samples prior to performing the quantitative analysis (see Appendix A). For aqueous samples, use the secondary container provided for percent solids to perform the pre-screening. If high levels of PFAS are present in the sample, a lower volume may be required for analysis.

Note: *The laboratory may subsample the aqueous samples as described in Appendix B; however, subsampling must meet project-specific requirements. The laboratory must notify the client before proceeding with the preparation of a subsample, in the event that a more appropriate size sample can be collected and sent to the laboratory. Once the laboratory becomes familiar with the levels of PFAS in the samples for their clients, the samples should be collected in the appropriate sample container size to avoid subsampling. The sample data report must state when subsampling has been employed.*
Do not use any fluoropolymer articles or task wipes in these extraction procedures. Use only HDPE or polypropylene wash bottles and centrifuge tubes. Reagents and solvents for cleaning syringes may be kept in glass containers.

11.1 Determination of solids contents of samples

Two types of solids determinations are described in this method. The first is the determination of the total suspended solids (TSS) content of aqueous samples. Because aqueous samples are processed with SPE cartridges that can be clogged by suspended solids in the sample, the method recommends a limit of 50 mg of solids in the total volume of sample that is processed by SPE.

The second type of solids determination is the percent solids (% solids) of soil, sediment, and biosolids samples. The percent solids is used to report results for these sample matrices as dry-weight concentrations. (Tissue samples do not require any solids determination.)

Note: *The earlier drafts of Method 1633 described the determination of percent solids for both aqueous and solid matrices, in an attempt to "simplify" the procedures across matrix types. However, in practice, the use of TSS for aqueous matrices is a more straightforward way to examine the risk of clogging the SPE and the results do not need to be as accurate as the percent solids data used for reporting dry-weight concentrations of the other matrices.*

11.1.1 Determination of total suspended solids (TSS) in aqueous matrices

11.1.1.1 Desiccate and weigh a glass fiber filter (Section 6.4.3) in milligrams (mg) to two significant figures.

11.1.1.2 Filter 10.0 ± 0.02 mL of well-mixed sample through the filter. This volume is sufficient for the purposes of assessing the risk of clogging the SPE cartridge.

11.1.1.3 Dry the filter a minimum of 1 hour at 103 - 105 ºC and cool in a desiccator.

11.1.1.4 Calculate TSS as follows:

$$TSS\ (mg/L) = \frac{weight\ of\ sample\ aliquot\ after\ drying\ (mg) - weight\ of\ filter\ (mg)}{0.01\ L}$$

11.1.1.5 Multiply the TSS by the volume of the sample aliquot to be extracted, in liters, to obtain the milligrams of solids in the sample. If the sample volume contains more than 50 mg of TSS, at a minimum, the analyst may choose to prepare a second SPE cartridge (see the Note in Section 12.1.4) prior to start the extraction in the event of clogging. Subject to project-specific approval, laboratories may utilize other documented strategies for minimizing the disruptions due to SPE clogging and slow extractions, including centrifuging the sample before adding the EIS and treating the supernatant aqueous phase and the solid phase as separate samples. In this case, a rinse of the original container must be included in the extraction of either the aqueous phase or solid phase. The bottle rinse for an aqueous sample should be added to the aqueous portion of the sample in most cases, but if there is visible solid left in the bottle, the laboratory has discretion to add the bottle rinse to the solid portion of the sample. In extreme cases, such as aqueous samples with TSS >10%, the entire sample might be treated as a sediment sample.

11.1.1.6 In the absence of client-specific requirements, an alternative to determining the TSS may be to identify samples likely to contain more than 50 mg of solids by visual comparison to examples maintained in the laboratory. More specifically, a trained analyst should be able to distinguish samples with very low TSS and

focus the TSS determinations on only those samples that might present a risk of clogging. However, given the translucent nature of HDPE containers, this may require pouring a small volume of sample from the container designated for the solids determination into a clear glass vessel. If this is done, that volume should be discarded after the assessment.

11.1.1.7 Regardless of the approach used, the laboratory must maintain records of the manner in which the solids content of each aqueous sample was assessed.

11.1.2 Determination of percent solids in soils, sediments, and biosolids

11.1.2.1 Weigh 5 to 10 g of sample to three significant figures in a tared beaker.

11.1.2.2 Dry a minimum of 12 hours at 110 ± 5 ºC, and cool in a desiccator and weigh the beaker.

11.1.2.3 Calculate percent solids as follows:

$$\%\ solids = \frac{weight\ of\ sample\ aliquot\ after\ drying\ (g)}{weight\ of\ sample\ aliquot\ before\ drying\ (g)} \times\ 100$$

11.2 Aqueous sample processing

This method was validated with aqueous samples containing no more than 50 mg of suspended solids per sample. The procedure requires the preparation of the entire sample and samples containing large amounts of suspended solids are likely to clog the SPE media, dramatically slowing or precluding sample extraction. Smaller sample volumes may be analyzed for samples containing solids greater than that specified for this method, or when unavoidable due to high levels of PFAS; however, subsampling should be avoided whenever possible. The preferred approach is to collect samples in smaller-size containers (e.g., less than 500 mL) and analyze the entire sample, provided that any regulatory limits can be met using the smaller volume.

The nominal sample size for wastewater, surface water, and groundwater and their associated QC samples is 500 mL; however, sample size may be increased up to 1,000 mL if required for a specific project. The sample is to be analyzed in its entirety and must not be filtered. Leachate samples and their associated QC samples are analyzed using a 100-mL sample volume. Therefore, leachates must not be included in the same sample preparation batch as other aqueous samples that are analyzed using 500-mL sample volumes.

11.2.1 Homogenize the sample by inverting the sample 3 – 4 times and allowing the sample to settle. Do not filter the sample. The standard procedure is to analyze the entire sample, plus a basic methanol rinse of the container (Sec. 12.2.2).

11.2.2 The volume of the aqueous sample analyzed is determined by weighing the full sample bottle and then the empty sample bottle (see Section 12.2). Weigh each sample bottle (with the lid) to 0.1 g.

11.2.3 Prepare a method blank and two OPRs using PFAS-free water in HDPE bottles. Select a volume of water that is typical of the samples in the batch (nominally 500 mL). Spike one OPR sample with native standard solution (Section 7.3.3) at 2x the LOQ (LLOPR). This aliquot will serve to verify the LOQ. Spike the other OPR sample at the concentration of

the mid-level calibration point (e.g., CS4 in Table 4). This aliquot will serve as the traditional OPR.

Note: *If matrix spikes are required for a specific project, spike the field sample bottles designated for use as MS/MSD samples with the native standards solution (Section 7.3.3) at concentrations roughly 3 to 5 times the background concentration determined during screening of the unspiked sample, but not to exceed the calibration range. This may require multiple spiking solutions. If screening was not performed, then spike those samples at the concentration of the mid-level calibration point.*

11.2.4 Spike an aliquot of EIS solution (Section 7.3.1) directly into the sample in the original bottle (or subsampled bottle) as well as to the bottles prepared for the QC samples. Mix by swirling the sample container. If centrifugation is used to prevent samples with high TSS from clogging the SPE, the EIS compounds must be spiked into the original sample container prior to centrifugation.

11.2.5 Using a PFAS-free pipette or other device, transfer a few drops of the sample to pH paper and check that the pH is 6.5 ± 0.5. If necessary, adjust pH with 50% formic acid (Section 7.1.13.4) or ammonium hydroxide (or with 5% formic acid [Section 7.1.13.3] and 3% aqueous ammonium hydroxide [Section 7.1.6.2]). The sample is now ready for solid-phase extraction (SPE) and cleanup (Section 12.0).

11.3 Solid sample processing (excluding tissues)

Use a stainless spoon to mix the sample in its original jar. If it is impractical to mix the sample within its container, transfer the sample to a larger container. Remove rocks, invertebrates, and foreign objects. Vegetation can either be removed from the sample before homogenization or cut into small pieces and included in the sample, based on project requirements. Mix the sample thoroughly, stirring from the bottom to the top and in a circular motion along the sides of the jar, breaking particles to less than 1 mm by pressing against the side of the container. The homogenized sample should be even in color and have no separate layers. Store the homogenized material in its original container or in multiple smaller containers. Determine the percent solids per Section 11.1.2.

Note: *The maximum sample weight for sediment or soil is 5 g dry-weight. The maximum sample weight for biosolids is 0.5 g dry-weight.*

Small amounts of the PFAS-free reagent water (10% of sample weight or less) can be added to unusually dry samples to facilitate extraction. This is an option, not a requirement, and if used, the solid method blank, OPR, and LLOPR associated with the samples must contain similar amounts of added water.

11.3.1 Weigh out an aliquot of solid sample, not dried (aliquot should provide 5 g dry-weight for soil and sediment or 0.5 g dry-weight for biosolids) into a 50-mL polypropylene centrifuge tube. Because biosolids samples are analyzed with a 0.5-g sample, they must not be included in the same sample preparation batch as solid samples analyzed with nominal 5-g sample masses.

11.3.2 Prepare batch QC samples using 5 g of reference solid (Section 7.2.2) wetted with 2.5 g of reagent water for the method blank and two OPRs (use 0.5 g of reference solid with 0.25 g of reagent water for biosolid sample batches). The addition of reagent water to the sand provides a matrix closer in composition to real-world samples. Spike one OPR sample with the native standards solution (Section 7.3.3) at 2x the LOQ (LLOPR). This aliquot will

serve to verify the LOQ. Spike the other OPR sample at the concentration of the mid-level calibration point. This aliquot will serve as the traditional OPR.

Note: *If matrix spikes are required for a specific project, spike the field sample aliquots designated as MS/MSD samples with the native standards solution (Section 7.3.3) at concentrations roughly 3 to 5 times the background concentration determined during screening of the unspiked sample, but not to exceed the calibration range. This may require multiple spiking solutions. If screening was not performed, then spike those samples at the concentration of the mid-level calibration point.*

11.3.3 Spike an aliquot of EIS solution (Section 7.3.1) directly into each centrifuge tube containing the aliquoted field and QC samples. Vortex the sample to disperse the standard and allow to equilibrate for at least 30 minutes.

11.3.4 Add 10 mL of 0.3% methanolic ammonium hydroxide (Section 7.1.7.1) to each centrifuge tube. Vortex to disperse, then shake for 30 minutes on a variable speed mixing table. Centrifuge at 1400 RCF (e.g., 2800 rpm for the centrifuge listed in Section 6.5) for 10 minutes and transfer the supernatant to a clean 50-mL polypropylene centrifuge tube.

11.3.5 Add 15 mL of 0.3% methanolic ammonium hydroxide (Section 7.1.7.1) to the remaining solid sample in each centrifuge tube. Vortex to disperse, then shake for 30 minutes on a variable speed mixing table. Centrifuge at 1400 RCF (e.g., 2800 rpm for the centrifuge listed in Section 6.5) for 10 minutes and decant the supernatant from the second extraction into the centrifuge tube with the supernatant from the first extraction.

11.3.6 Add another 5 mL of 0.3% methanolic ammonium hydroxide (Section 7.1.7.1) to the remaining sample in each centrifuge tube. Shake by hand to disperse, centrifuge at 1400 RCF (e.g., 2800 rpm for the centrifuge listed in Section 6.5) for 10 minutes and decant the supernatant from the third extraction into the centrifuge tube with supernatant from the first and second extractions.

11.3.7 Using a 10-mg scoop, add 10 mg of carbon (Section 7.1.17) to the combined extract, mix by occasional hand shaking for 5 minutes and no more, and then centrifuge at 1400 RCF (e.g., 2800 rpm for the centrifuge listed in Section 6.5) for 10 minutes. Immediately decant the extract into a 60-mL glass evaporation or concentrator tube.

11.3.8 The laboratory has the option to dilute the extract to approximately 35 mL with reagent water. (Some laboratories may prefer not to add any additional water; therefore, this dilution is optional.) A separate concentrator tube marked at the 35-mL level may be kept for a visual reference to get the approximate volume. Samples containing more than 50% water may yield extracts that are greater than 35 mL in volume; therefore, do not add water to these. Determine the water content in the sample as follows (percent moisture is determined from the % solids):

$$Water\ Content\ in\ Sample = \frac{Sample\ Weight\ (g) \times Moisture\ (\%)}{100} + any\ water\ added\ in\ 11.3.2\ and\ 11.3.8$$

11.3.9 Concentrate each extract at approximately 55 ºC with a N_2 flow of approximately 1.2 L/min to a final volume that is based on the water content of the sample (*see table below*). Allow extracts to concentrate for 25 minutes, then mix (by vortex if the volume is < 20 mL or using a glass pipette if the volume is > 20 mL). Continue concentrating and mixing every 10 minutes until the extract has been reduced to the required volume as specified in the table below. If the extract volume appears to stop dropping, the concentration must be

stopped and the volume at which it was stopped recorded. The concentrated extract must still contain some methanol, about 5-10 mL. The pre-cleanup extract in 11.3.10 should contain no more than 20% methanol. The laboratory has flexibility to modify the volumes used to achieve this goal. Some laboratories may prefer not to add water in Section 11.3.8. The following table provides guidance to help determine the final extract volume, based on the water content of the original solid sample.

Water Content in Sample*	Concentrated Final Volume
< 5 g	7 mL
5 - 8 g	8 mL
8 - 9 g	9 mL
9 - 10 g	10 mL

* Based on the % solids result determined in Section 11.1.2.3, and including any water added to the sample in Sections 11.3.2 or the extract in Section 11.3.8.

A good rule of thumb is to make the "Concentrated Final Volume" 7 - 10 mL above the "Water Content in Sample" value.

Note: *Slowly concentrating extracts, in 1-mL increments, is necessary to prevent excessive concentration and the loss of neutral compounds (N-methyl and N-ethyl FOSEs and FOSAs) and other more volatile compounds. The extract must be concentrated to remove the methanol because excess methanol present during SPE clean-up results in poor recovery of C_{13} and C_{14} carboxylic acids and C_{10} and C_{12} sulfonates.*

If all of the methanol is evaporated, the aforementioned neutral compounds are likely to have poor recovery, if too much methanol is in the final concentrated extract, then the aforementioned longer-chain compounds are likely to have poor recovery.

11.3.10 Add 40 - 50 mL of reagent water to the extract and vortex. Check that the pH is 6.5 ±0.5 and adjust as necessary with 50% formic acid (Section 7.1.13.4) or 30% ammonium hydroxide (or with 5% formic acid [Section 7.1.13.3] and 3% aqueous ammonium hydroxide [Section 7.1.6]). The extracts are ready for SPE and cleanup (Section 12.0).

11.4. Tissue sample processing

Prior to processing tissue samples, the laboratory must determine the exact tissue to be analyzed. Common requests for analysis of fish tissue include whole fish with the skin on, whole fish with the skin removed, edible fish fillets (filleted in the field or by the laboratory), specific organs, and other portions. Once the appropriate tissue has been determined, the samples must be prepared and homogenized.

If the laboratory must dissect the whole fish to obtain the appropriate tissue for analysis, cover the benchtop with clean aluminum foil and use clean processing equipment (e.g., knives, scalpels, tweezers) to dissect each sample to prevent cross-contamination. Samples should be handled in a semi-thawed state for compositing and/or homogenization. All tissue comprising a sample is collected in a tared stainless-steel bowl during grinding or maceration, the total tissue mass weighed, and then mixed using a stainless-steel spoon. If not aliquoted immediately, homogenized samples must be stored in clean HDPE containers and stored frozen for subsequent use.

If using a meat grinder, chilling it by briefly grinding a few pellets of dry ice may keep the tissue from sticking to the equipment. Pellets of dry ice also may be added to the tissue as it enters the grinder. After

the entire sample has been processed, mix the ground tissue with a spoon, transfer back to the grinder, and repeat the grinding at least two more times until the homogenized tissue has a consistent texture and color. Between samples, disassemble the grinder or maceration device, remove any remaining tissue, and wash all parts with PFAS-free detergents, rinse with tap water, then reagent water, and finally methanol. Do not bake the grinder parts.

Once during the preparation of each batch of tissue samples (up to 20), prepare an equipment blank by pouring 500 mL of reagent water through the reassembled grinder and collecting the rinsate in a 500-mL HDPE container. Process that rinsate as an aqueous sample but record the result in nanograms (ng) of each analyte. Barring other project-specific requirements, assess the levels of any PFAS in the rinsate by assuming that the entire mass of the analyte in the rinsate was transferred to the smallest mass of any bulk tissue sample that was collected during the grinding process (not the 2-g aliquot taken for analysis below). For example, if the smallest fish sample in the batch yields 500 g of ground tissue, divide the mass of each target analyte in the rinsate by 500, and compare those amounts to the MDLs for tissue samples.

11.4.1 For each sample, weigh a 2-g aliquot of homogenized tissue into a 15-mL polypropylene centrifuge tube. Reseal the container with the remaining homogenized portion of the sample and return it to frozen storage in the event that it needs to be used for reanalysis.

Note: *The default sample weight for tissue is 2 g wet weight; however, a 1-g sample may be used. Higher sample weights are not recommended for this method.*

11.4.2 Prepare the batch QC samples using 2 g of reference tissue matrix (Section 7.2.3) for the method blank and two OPRs. Spike one OPR sample with the native standards solution (Section 7.3.3) at 2x the LOQ (LLOPR). This aliquot will serve to verify the LOQ. Spike the other OPR sample at the concentration of the mid-level calibration point. This aliquot will serve as the traditional OPR.

Note: *If matrix spikes are required for a specific project, spike the field sample aliquots designated as MS/MSD samples with the native standards solution (Section 7.3.3) at concentrations roughly 3 to 5 times the background concentration determined during screening of the unspiked sample, but not to exceed the calibration range. This may require multiple spiking solutions. If screening was not performed, then spike those samples at the concentration of the mid-level calibration point.*

11.4.3 Spike an aliquot of EIS solution (Section 7.3.1) directly into each field and QC sample. Vortex and allow to equilibrate for at least 30 minutes.

11.4.4 Add 10 mL of 0.05M KOH in methanol (Section 7.1.8) to each sample. Vortex to disperse the tissue then place tubes on a variable speed mixing table set at low speed to extract for at least 16 hours. Avoid violent shaking of the samples. Centrifuge at 1400 RCF (e.g., 2800 rpm for the centrifuge listed in Section 6.5) for 10 minutes and collect the supernatant in a 50-mL polypropylene centrifuge tube.

11.4.5 Add 10 mL of acetonitrile to remaining tissue in the 15-mL centrifuge tube, vortex to mix and disperse the tissue. Sonicate for 30 minutes. Centrifuge at 1400 RCF (e.g., 2800 rpm for the centrifuge listed in Section 6.5) for 10 minutes and collect the supernatant, adding it to the 50-mL centrifuge tube containing the initial extract.

11.4.6 Add 5 mL of 0.05M KOH in methanol (Section 7.1.8) to the remaining sample in each centrifuge tube. Vortex to disperse the tissue and hand mix briefly. Centrifuge at 1400

RCF (e.g., 2800 rpm for the centrifuge listed in Section 6.5) for 10 minutes and collect the supernatant, adding it to the 50-mL centrifuge tube containing the first two extracts.

11.4.7 Using a 10-mg scoop, add 10 mg of carbon (Section 7.1.17) to the combined extract, mix by occasional hand shaking over a period of 5 minutes and no more, then centrifuge at 1400 RCF (e.g., 2800 rpm for the centrifuge listed in Section 6.5) for 10 minutes. Immediately decant the extract into a 60-mL glass evaporation or concentrator tube.

11.4.8 Add 1 mL of reagent water to each evaporation/concentrator tube, set the evaporator/concentrator to 55 ºC with a N_2 flow of 1.2 L/min and concentrate the extract to 2.5 mL (only ~1 mL of the methanol should remain).

11.4.9 Add reagent water to each evaporation/concentrator tube to dilute the extracts to 50 mL. Check that the pH = 6.5 ± 0.5 and adjust as needed with 50% formic acid (Section 7.1.13.4) or ammonium hydroxide (or with 5% formic acid [Section 7.1.13.3] and 3% aqueous ammonium hydroxide [Section 7.1.6.2]). The extracts are ready for SPE and cleanup (Section 12.0).

12.0 Extraction, Cleanup, and Concentration

Samples of all matrices (and the associated batch QC) must undergo SPE and carbon cleanup to remove interferences (Section 12.1). Sample elution as well as any further extract treatment is matrix specific and may be found in Sections 12.2 through 12.4.

Note: *Carbon cleanup is required. Carbon cleanup may remove analytes if the sample has a very low organic carbon content (this is unusual for non-drinking water environmental samples). This will be apparent if the EIS recoveries are significantly higher on the reanalysis. However, if the laboratory can demonstrate that the carbon cleanup is detrimental to the analysis of samples from a particular source (by comparing results when skipping the carbon cleanup during reanalysis), then the carbon cleanup may be skipped for samples from that specific source, with client approval.*

12.1 All sample matrices

12.1.1 Pack clean silanized glass wool to half the height of the WAX SPE cartridge barrel (Section 6.7.1).

12.1.2 Set up the vacuum manifold with one WAX SPE cartridge plus a reservoir and reservoir adaptor for each cartridge for each sample and QC sample.

12.1.3 Pre-condition the cartridges by washing them with 15 mL of 1% methanolic ammonium hydroxide (Section 7.1.7.2), followed by 5 mL of 0.3M formic acid (Section 7.1.13.2) (do not use the vacuum for this step). Do not allow the WAX SPE to go dry. Discard the wash solvents.

12.1.4 Pour the sample into the reservoir (do not use a pipette), taking care to avoid splashing while loading. Adjust the vacuum and pass the sample through the cartridge at 5 mL/min. Retain the empty sample bottle and allow it to air dry for later rinsing (Section 12.2.2). Discard the eluate.

Note: *For aqueous samples, in the event the SPE cartridge clogs during sample loading, place a second pre-conditioned cartridge and continue loading the remaining sample aliquot using the same reservoir. Proceed to Section 12.1.5.*

12.1.5 Rinse the walls of the reservoir with 5 mL reagent water (twice) followed by 5 mL of 1:1 0.1M formic acid/methanol (Section 7.1.13.5) and pass those rinses through the cartridge using vacuum. Dry the cartridge by pulling air through for 15 seconds. Discard the rinse solution. Continue to the elution steps based on the matrix (see Section 12.2 – Aqueous, Section 12.3 – Solids, and Section 12.4 – Tissue).

12.2 Elution of aqueous samples

Note: *If two cartridges were used, perform the steps in Sections 12.2.1 through 12.2.3 with each cartridge. Filter the eluates through a 25-mm, 0.2-µm syringe filter. Combine both sets of filtered eluates into a clean tube, add the NIS solution, and vortex to mix. Transfer 350 µL of the filtered extract into a 1-mL polypropylene microvial and mark the level. Add another 350-µL portion and using a gentle stream of nitrogen (water bath at 40 ºC), concentrate to the 350-µL mark and submit for LC-MS/MS analysis. This concentration step is only applicable to situations where two SPE cartridges were eluted, each with 5 mL of elution solvent.*

12.2.1 Place clean collection tubes (13 x 100 mm polypropylene) inside the manifold, ensuring that the extract delivery needles do not touch the walls of the tubes. DO NOT add the NIS solution to these collection tubes.

12.2.2 Rinse the inside of the sample bottle with 5 mL of 1% methanolic ammonium hydroxide (Section 7.1.7.2), then, using a glass pipette, transfer the rinse to the SPE reservoir, washing the walls of the reservoir. Use vacuum to pull the elution solvent through the cartridge and into the collection tubes.

Note: *Air dry the empty sample bottle after the rinse is transferred. Weigh the empty bottle with the cap on and subtract from the weight with the sample determined in Section 11.2.2.*

12.2.3 Add 25 µL of concentrated acetic acid to each sample extract in the collection tubes and vortex to mix. Add 10 mg of carbon (Section 7.1.17) to each sample extract and batch QC sample extract, using a 10-mg scoop. Hand-shake occasionally for 5 minutes and no more. It is important to minimize the time the extract is in contact with the carbon. Immediately vortex (30 seconds) and centrifuge at 1400 RCF (e.g., 2800 rpm for the centrifuge listed in Section 6.5) for 10 minutes (other rotational speeds may be used for centrifuges other than the one described in Section 6.5.1).

Note: *The use of two stacked SPE cartridges, the first containing the WAX sorbent and the second containing activated carbon, or other cartridge configurations may be employed in place of the use of the loose carbon described above.* ***However, each laboratory seeking to apply such an approach must document their specific approach and demonstrate its effectiveness in meeting the QC specifications of this method, as described in Sec. 9.1.2.***

12.2.4 Add an aliquot of the NIS solution (Section 7.3.2) to a clean collection tube. Place a syringe filter (25-mm filter, 0.2-µm nylon membrane) on a 5-mL polypropylene syringe. Take the plunger out and carefully decant the sample supernatant into the syringe barrel. Replace the plunger and filter the entire extract into the new collection tube containing the

NIS solution. Vortex to mix and transfer a portion of the extract into a 1-mL polypropylene microvial for LC-MS/MS analysis. Cap the collection tube containing the remaining extract and store at or below 6 °C.

12.3 Elution of solid samples

12.3.1 Add NIS solution (Section 7.3.2) to a clean collection tube (13 x 100 mm polypropylene) for each sample and QC aliquot and place them into the manifold rack, ensuring the extract delivery needles are not touching the walls of the tubes.

12.3.2 Rinse the inside of the evaporation/concentrator tube using 5 mL of 1% methanolic ammonium hydroxide (Section 7.1.7.2), then, using a glass pipette, transfer the rinse to the reservoir, washing the walls of the reservoir. Use the vacuum to pull the elution solvent through the cartridge and into the collection tubes.

12.3.3 Add 25 µL of concentrated acetic acid to each sample extract in its collection tube and swirl to mix. Place a syringe filter (25-mm filter, 0.2-µm nylon membrane) on a 5 mL polypropylene syringe. Take the plunger out and carefully decant ~1 mL of extract into the syringe barrel. Replace the plunger and filter into a 1-mL polypropylene microvial for LC-MS/MS analysis. Cap the collection tube containing the remaining extract and store at 0 - 6 °C.

12.4 Elution of tissue samples

12.4.1 Add NIS solution (Section 7.3.2) to clean collection tubes (13 x 100 mm, polypropylene) for each sample and QC aliquot. Place the tubes into the manifold rack and ensure the extract delivery needles are not touching the walls of the tubes.

12.4.2 Rinse the inside of the evaporation/concentrator tube using 5 mL of 1% methanolic ammonium hydroxide (Section 7.1.7.2), then, using a glass pipette, transfer the rinse to the reservoir, washing the walls of the reservoir. Use the vacuum to pull the elution solvent through the cartridge and into the collection tubes.

12.4.3 Add 25 µL of concentrated acetic acid to each sample extract. Place a syringe filter (25-mm filter, 0.2-µm nylon membrane) on a 5-mL polypropylene syringe. Take the plunger out and carefully decant an aliquot (~1 mL) of the extract into the syringe barrel. Replace the plunger and filter into a 1-mL polypropylene microvial for LC-MS/MS analysis. Cap the collection tube containing the remaining extract and store at or below 6 °C (see Section 8.5.5).

13.0 Instrumental Analysis

Analysis of sample extracts for PFAS by LC-MS/MS is performed on an ultrahigh performance liquid chromatograph coupled to a triple quadrupole mass spectrometer, running manufacturer's software. The mass spectrometer is run with unit mass resolution in the multiple reaction monitoring (MRM) mode.

13.1 Perform mass calibration, including mass calibration verification (Section 10.1), establish the operating conditions (Section 10.2), and perform an initial calibration (Section 10.3) at the frequencies described in those sections prior to analyzing samples.

13.2 Only after all performance criteria in Sections 10.1, 10.2, and 10.3 are met may blanks, MDLs, IPRs/OPRs, and samples be analyzed.

13.3 After a successful initial calibration has been completed, the analytical sequence for a batch of samples analyzed during the same time period is as follows. The volume injected for samples and QC samples must be identical to the volume used for calibration (Section 10.2.3). Standards and sample extracts **must** be brought to room temperature and vortexed prior to aliquoting into an instrument vial in order to ensure homogeneity of the extract.

1. Instrument Blank
2. Instrument Sensitivity Check (see Section 7.3.4)
3. Calibration Verification Standard
4. Qualitative Identification Standards
5. Instrument Blank
6. Method Blank
7. Low-level OPR (LLOPR)
8. OPR
9. Bile salt interference check standard (Section 7.5)
10. Injections of sample extracts, diluted extracts, and QC sample extracts (10 or fewer field sample extracts)
11. Calibration Verification Standard
12. Instrument Blank
13. Injections (10 or fewer field sample extracts)
14. Calibration Verification Standard
15. Instrument Blank

If the results are acceptable, the closing calibration verification solution (#14 above) may be used as the opening solution for the next analytical sequence.

13.4 If the response exceeds the calibration range for any target analyte, the sample extract is diluted as per Section 15.3 to bring those target analyte responses within the calibration range.

Note: *If the analytes that exceed the calibration range in the original analysis are known to **not** be of concern for the specific project (e.g., are **not** listed in a discharge permit), then the laboratory may consult with the client regarding the possibility of reporting sample results over the calibration range from the undiluted analysis, provided that they are clearly identified as such and appropriately qualified.*

14.0 Performance Tests during Routine Operations

The following performance tests must be successfully completed as part of each routine instrumental analysis sequence described in Section 13.3 above (also see Table 11).

14.1 Instrument sensitivity check

The signal-to-noise ratio of the ISC standard (Section 7.3.4) must be greater than or equal to 3:1 for the quantitation and confirmation ions that exist and must meet the ion ratio requirements in Section 15.1.3. If the analyte has no confirmation ions, then a 10:1 signal to noise ratio is required. If the requirements cannot be met, the problem must be corrected before analyses can proceed. In addition, the measured concentration of each target analyte in the ISC must fall within ± 30% of its

nominal concentration. If that requirement cannot be met for any target analyte relevant to a project, analysis must be halted, and the sensitivity of the LC-MS/MS system adjusted before analysis of field or QC samples.

14.2 Bile salt interference check

The retention time of the bile salts in the standard in Section 7.5 must fall at least one minute outside the retention time window for any of the linear or branched PFOS isomers in the standard described in Section 7.3.3. If this requirement is not met, the chromatographic conditions must be adjusted to meet the requirement and the initial calibration must be repeated before any field sample are analyzed.

14.3 Calibration verification (CV)

After a passing instrument sensitivity check (Section 14.1) and a successful initial calibration (Section 10.3.3.3) are achieved, prior to the analysis of any samples, analyze a mid-level calibration standard (Section 7.3.4).

14.3.1 The calibration is verified by analyzing a CV standard at the beginning of each analytical sequence, every ten samples or less, and at the end of the analytical sequence.

14.3.2 Calculate concentration for each target analyte and EIS compound in the CV using the equation in Section 15.2.

14.3.3 The recovery of target analyte for the CVs must be within 70 - 130% unless the analyte is not of concern for a given project.

14.3.4 If the CV criterion in Section 14.3.3 is not met, take corrective action and reanalyze any extracts that were analyzed between the last passing CV and the one that failed. However, if an analyte in the CV failed because of high recovery, but that analyte was not detected in a sample extract associate with that failure, then that sample extract need not be reanalyzed. In some instances the laboratory may need to recalibrate the LC-MS/MS instrument according to Section 10.3.

14.3.5 Ion abundance ratios

Using the data from the CV standard, compute the ion abundance ratio (IAR) for each target analyte listed with a confirmation ion mass in Table 9, using the equation below. These ion abundance ratios will be used a part of the qualitative identification criteria in Section 15.1.

$$IAR = \frac{Area_{Q1}}{Area_{Q2}}$$

where:

IAR = Ion abundance ratio

$Area_{Q1}$ = Measured area of the Q1 m/z for the analyte in the mid-point calibration standard or initial CV standard, depending on the analyte concentration, as described in Section 15.1.3

$Area_{Q2}$ = Measured area of the Q2 m/z for the analyte in the mid-point calibration standard or initial CV standard, depending on the analyte concentration, as described in Section 15.1.3

Note: *Some of the target analytes in Table 9 do not produce confirmation ions or produce confirmation ions with very low relative abundances; therefore, for those analytes, the IAR does not apply.*

Construct an acceptance window for the IAR of each target analyte as 50% to 150% of the IAR in the mid-point calibration standard or the CV standard at the beginning of the analytical sequence, as applicable, per Section 15.1.3.

14.4 Retention times and resolution

14.4.1 For all target analytes with exact corresponding isotopically labeled analogs, target analytes must elute within ± 0.1 minutes of the associated EIS compound.

14.4.2 The retention times of each target analyte and isotopically labeled compound must be within ± 0.4 minutes of the ICAL or CV used to establish the RT windows.

14.5 Ongoing precision and recovery (OPR)

14.5.1 After completing the first 6 steps in the analytical sequence described in Section 13.3, analyze the extracts of the low-level OPR (LLOPR) and the mid-level OPR) (Sections 11.3.3, 11.3.2, and 11.4.2) prior to analysis of samples from the same batch to ensure the analytical process is under control.

14.5.2 Compute the percent recovery of the native compounds by the appropriate quantification method depending on the compound (Section 10.3). Compute the percent recovery of each EIS compound by the non-extracted internal standard method (Sections 1.2 and 10.3).

$$Recovery\ (\%) = \frac{Concentration\ found\ (ng/mL)}{Concentration\ spiked\ (ng/mL)} \times 100$$

14.5.3 For the target analytes and EIS compounds, compare the recovery to the OPR and LLOPR limits given in Tables 5, 6, 7, and 8. OPR, LLOPR, and EIS results must meet the acceptance criteria in these tables. If all compounds meet the acceptance criteria, system performance is acceptable, and analysis of blanks and aqueous samples may proceed. If, however, any individual concentration falls outside of the given range, the extraction/concentration processes are not being performed properly for that compound. In this event, correct the problem, re-prepare, extract, and clean up the sample batch, including any QC samples, and repeat the ongoing precision and recovery test.

14.6 Instrument blank – At the beginning of the analytical sequence and after the analysis of high concentration samples and standards (e.g., highest calibration standard, CV), analyze an instrument blank to ensure no instrument contamination has occurred. The instrument blank must not contain any target analyte that would yield a response equivalent to the mass of the analyte that would be present in a whole-volume sample at or above the analyte's MDL. If an analyte is present at such levels, analyze one or more additional instrument blanks until the response of the analyte is no longer detectable, or perform additional troubleshooting steps to identify and minimize other potential sources of PFAS contamination.

14.7 Method blank – After the analysis of the solvent blank and prior to the analysis of samples, analyze a method blank (Section 9.5).

14.8 Qualitative identification standard – Analyze a qualitative identification standard (Section 7.3.5) containing all available isomers (branched and linear) once at the beginning of the analytical sequence, to confirm the retention time of each linear and known branched isomer or isomer group.

14.9 Instrument sensitivity

Calculate the ratio of the NIS peak areas from the QC and field samples relative to the mean area of the corresponding NIS in the most recent initial calibration to check for possible bad injections of NIS solution or loss of instrument sensitivity.

$$Area\ Ratio_{NIS_i}(\%) = 100\ \times \frac{Area\ of\ NIS_i\ in\ the\ Sample}{Mean\ Area_{NIS_i}} \times\ DF$$

where:

Area of NIS_i in the Sample = Observed area counts for NIS_i in the sample

Mean $Area_{NISi}$ = The mean area counts for the corresponding NIS from the most recent initial calibration, calculated as described in Section 10.3.3.4

i = Indicates each of the seven NIS compounds listed in Table 1

DF = Any dilution factor applied to the extract. If no dilution was performed, then DF=1.

The NIS areas in the field samples and QC samples must be within 50 to 200% of the mean area of the corresponding NIS in the most recent initial calibration (i.e., a factor of 2). If the areas are low for all the field samples and QC samples in the batch, it suggests a loss of instrument sensitivity, while low areas in only some field or QC samples suggests a possible bad injection.

15.0 Data Analysis and Calculations

15.1 Qualitative peak identification

A native or isotopically labeled compound is qualitatively identified in a standard, blank, sample, or QC sample when all of the criteria in Sections 15.1.1 through 15.1.4 are met.

15.1.1 For target analytes or EIS compounds to be identified, peak responses of the quantitation and confirmation ions must be at least three times the background noise level (S/N 3:1). The quantitation ion must have a S/N ≥ 10:1 if there is no confirmation ion. If the S/N ratio is not met due to high background noise, the laboratory must correct the issue (e.g., perform instrument troubleshooting and any necessary maintenance, such as cleaning the ion source, replacing the LC column, or if needed, repeat the cleanup steps to remove background due to the sample matrix). If the S/N ratio is not met but the background is low, then the analyte is to be considered a non-detect.

15.1.2 Target analyte, EIS compound, and NIS compound RTs must fall within ± 0.4 minutes of their predicted retention times from the midpoint standard of the ICAL or initial CV, whichever was used to establish the RT window position for the analytical batch. The retention time window used must be of sufficient width to detect earlier-eluting branched isomers. For all target analytes with exact corresponding isotopically labeled analogs, target analytes must elute within ± 0.1 minutes of the associated EIS.

15.1.3 The laboratory must follow the identification requirements specified by the client for the project. In the event there are no project-specific requirements, the following general requirements apply. For concentrations at or above the LOQ, the IAR must fall within

± 50% of the IAR observed in the mid-point initial calibration standard. If project-specific requirements involve reporting sample concentrations below the LOQ, the IAR must fall within ± 50% of the IAR observed in either the mid-point initial calibration standard or the initial CV (see Section 14.3.5 for applicability).

The total response of all isomers (branched and linear) in the quantitative standards must be used to define the IAR. In samples, the total response should include only the branched isomer peaks that have been identified in either the quantitative or qualitative standard (see Section 7.3 regarding records of traceability of all standards). If standards (either quantitative or qualitative) are not available for purchase, only the linear isomer can be identified and quantitated in samples. The ratio requirement does not apply for PFBA, PFPeA, NMeFOSE, NEtFOSE, PFMPA, and PFMBA because suitable (not detectable or inadequate S/N) secondary transitions (Q2) are not available.

15.1.4 If the field sample result does not all meet the criteria stated in Sections 15.1.1 through 15.1.3, and all sample preparation avenues (e.g., extract cleanup, sample dilution, etc.) have been exhausted, the result may only be reported with a data qualifier alerting the data user that the result could not be confirmed because it did not meet the method-required criteria and therefore should be considered a tentative identification and an estimated value. If the criteria listed above are not met for the standards, the laboratory must stop analysis of samples and correct the issue.

15.2 Quantitative determination

Concentrations of the target analytes are determined with respect to the extracted internal standard (EIS) which is added to the sample prior to extraction. The EIS is quantitated with respect to a non-extracted internal standard (NIS), as shown in Table 9, using the response ratios or response factors from the most recent multi-level initial calibration (Section 10.3). Other equations may be used if the laboratory demonstrates that those equations produce the same numerical result as produced by the equations below.

For the target analytes:

$$Concentration\ (ng/L\ or\ ng/g) = \frac{Area_t\ M_{EIS}}{Area_{EIS}(\overline{RR}\ or\ \overline{RF})} \times DF \times \frac{1}{W_S}$$

where:

$Area_t$ = Measured area of the Q1 m/z for the target analyte

$Area_{EIS}$ = Measured area at the Q1 m/z for the EIS. *See note below.*

M_{EIS} = Mass of the EIS added (ng)

$\overline{RR}$ = Average response ratio used to quantify target analytes by the isotope dilution method

$\overline{RF}$ = Average response factor used to quantify target analytes by the extracted internal standard method

DF = Dilution factor. If no dilution was performed, then DF=1.

W_S = Sample volume (L) or weight (g)

Note: *For better accuracy, EPA recommends that PFTrDA be quantified using the average of the areas of labeled compounds $^{13}C_2$-PFTeDA and $^{13}C_2$-PFDoA.*

And for the EIS compounds:

$$Concentration\ (ng/L\ or\ ng/g) = \frac{Area_{EIS}\ M_{NIS}}{Area_{NIS}\overline{RF_s}} \times DF\ \times \frac{1}{W_S}$$

where:

$Area_{EIS}$ = Measured area at the Q1 m/z for the EIS

$Area_{NIS}$ = Measured area of the Q1 m/z for the NIS

M_{NIS} = Mass of the NIS added (ng)

DF = Dilution factor. If no dilution was performed, then DF=1.

W_S = Sample volume (L) or weight (g)

$\overline{RF_s}$ = Average response factor used to quantify the EIS by the non-extracted internal standard method

Results for target analytes are recovery corrected by the method of quantification. EIS recoveries are determined against the NIS and are used as general indicators of overall analytical quality. The NIS has no impact on the target analyte result.

The instrument measures the target analytes as either their anions or neutral forms. **The default approach for Clean Water Act uses of the method is to report the analytes in their acid or neutral forms,** using the following equation to convert the concentrations:

$$C_{Acid} = C_{Anion} \times \frac{MW_{Acid}}{MW_{Anion}}$$

where:

C_{Anion} = Analyte concentration in anion form

MW_{Acid} = Molecular weight of the acid form

MW_{Anion} = Molecular weight of the anion form

15.3 Sample dilutions

15.3.1 If the Q1 area for any compound exceeds the calibration range of the system, dilute a subsample of the sample extract with the methanolic ammonium hydroxide and acetic acid solution in Section 7.1.9 and analyze the diluted extract for the analyte(s) that exceeded the calibration range. If the responses for any EIS in the diluted extract that is associated with one of those analytes meet the S/N and retention time requirements in Sections 15.1.1 and 15.1.2, and the EIS recoveries from the analysis of the diluted extract are greater than 5%, then the compounds associated with those EIS compounds may be quantified using the EIS response. Adjust the compound concentrations, detection limits, minimum levels, and LOQs to account for the dilution.

If the EIS responses in the diluted extract do not meet those S/N and retention time requirements, then the compound cannot be measured reliably by isotope dilution in the diluted extract. In such cases, the laboratory must take a smaller aliquot of any affected aqueous sample and dilute it to 500 mL with reagent water and prepare and analyze the diluted aqueous sample, or prepare and analyze a smaller aliquot of soil, biosolid, sediment, or tissue sample. Adjust the calibration ranges, detection limits, and LOQs to account for the tested sample mass/volume and any dilution factors.

If a dilution results in an EIS recovery less than 5% for the analyte that required the dilution, then the laboratory must prepare and analyze a diluted aqueous sample or a smaller aliquot of a solid sample.

Note: *Target analyte results with a corresponding EIS that has less than 5% EIS recovery cannot be used for monitoring compliance with an NPDES permit. If the EIS recovery is less than 5% but has a S/N greater than or equal to 20:1, the result may have some utility as an estimated value. Some non-NPDES projects may accept such an estimated value if the result is so high that it is well above the project criteria or action level, especially if additional sampling is planned for that site.*

15.3.2 If the recovery of any EIS in a sample is outside of the acceptance limits in Tables 6 or 8, then a diluted sample extract must be analyzed, or a smaller sample mass/volume must be extracted (Section 15.3.1). If the recovery of any EIS in the diluted sample extract is below 5%, the method does not apply to the sample being analyzed and the result may not be reported or used for permitting or regulatory compliance purposes. If all cleanup procedures in this method and EIS recovery remains outside of the acceptance range, extraction and/or cleanup procedures that are beyond this scope of this method may be needed to analyze the sample.

15.4 Reporting of analytical results (acid/neutral forms)

The data reporting practices described here are focused on Clean Water Act National Pollutant Discharge Elimination System monitoring needs and may not be relevant to other uses of the method. For analytes reported in their acid form, use the equations in Section 15.2 and the analyte names or abbreviations in Table 1. For analytes reported in their anion form, see Table 2 for the appropriate names, abbreviations, and CAS Registry Numbers.

15.4.1 Report results for aqueous samples in ng/L. Report results for solid samples in ng/g, on a dry-weight basis, and report the percent solids for each sample separately. Report results for tissue samples in ng/g, on a wet-weight basis. Other units may be used if required in a permit or for a project. Report all QC data with the sample results.

15.4.2 Reporting level

Unless specified otherwise by a regulatory authority or in a discharge permit, results for analytes that meet the identification criteria are reported down to the concentration of the LOQ established by the laboratory through calibration of the instrument (see the glossary for the derivation of the LOQ).

15.4.2.1 Report a result for each analyte in each field sample or QC standard at or above the laboratory's LOQ to 3 significant figures. Report a result for each analyte found in each field sample or QC standard below the LOQ as "<LOQ," where LOQ is the concentration of the analyte at the laboratory's LOQ, or as required by the regulatory/control authority or permit.

15.4.2.2 Report a result for each analyte in a blank at or above the MDL to 2 significant figures. Report a result for each analyte found in a blank below the MDL as "<MDL," where MDL is the concentration of the analyte at the MDL, or as required by the regulatory/control authority or permit.

15.4.2.3 Report a result for an analyte found in a sample at the least dilute level at which the area at the quantitation m/z is within the calibration range (e.g., above the LOQ for the analyte and below the highest calibration standard) and with isotopically labeled compound recoveries within their respective QC acceptance

criteria. This may require reporting results for some analytes from different analyses.

15.4.2.4 Report recoveries of all associated EIS compounds for all field samples and QC standards. If a sample extract was diluted and analyzed, report the EIS compound recoveries from both the original analysis and the analysis of the dilution.

15.4.3 Results from tests performed with an analytical system that is not in control (i.e., that does not meet acceptance criteria for any QC tests in this method) must be documented and reported (e.g., with a qualifier on results), unless the failure is not required to be reported as determined by the regulatory/control authority. Results associated with a QC failure cannot be used to demonstrate Clean Water Act regulatory compliance. QC failures do not relieve a discharger or permittee of reporting timely results. If the holding time would be exceeded for a reanalysis of the sample, the regulatory/control authority should be consulted for disposition.

16.0 Method Performance

Initial method performance is validated through analysis of matrix-specific reference samples, including IPRs and MDLs. Ongoing method performance is monitored through QC samples analyzed alongside samples. The parameters monitored include percent recovery of isotopically labeled compounds, blank concentrations, and native compound recoveries.

This method has been validated, and performance specifications were developed using data from DoD's interlaboratory validation study (References 11- 14). Data from the QC samples in that study were used to develop the QC acceptance criteria in Tables 5 through 8. Table 9 provides the pooled MDL results and the range of LOQs from the multi-laboratory validation study as examples of the sensitivity of the method, but as noted in the footnotes to that table, the MDLs and LOQs generated in each laboratory should be used for data reporting and data quality assessments.

17.0 Pollution Prevention

17.1 Pollution prevention encompasses any technique that reduces or eliminates the quantity or toxicity of waste at the point of generation. Many opportunities for pollution prevention exist in laboratory operations. EPA has established a preferred hierarchy of environmental management techniques that places pollution prevention as the management option of first choice. Whenever feasible, laboratory personnel should use pollution prevention techniques to minimize waste generation. When wastes cannot be reduced feasibly at the source, EPA recommends recycling as the next best option.

17.2 The compounds in this method are used in extremely small amounts and pose little threat to the environment when managed properly. Standards should be prepared in volumes consistent with laboratory use to minimize the disposal of excess volumes of expired standards.

17.3 For information about pollution prevention that may be applied to laboratories and research institutions, consult *Less is Better: Laboratory Chemical Management for Waste Reduction* (Reference 7).

18.0 Waste Management

18.1 The laboratory is responsible for complying with all Federal, State, and local regulations governing waste management, particularly regarding management of hazardous waste, and to protect the air, water, and land by minimizing and controlling all releases from fume hoods and bench operations. Compliance also is required with any sewage discharge permits and regulations. An overview of requirements can be found in *Environmental Management Guide for Small Laboratories* (Reference 8).

18.2 Liquids, including aqueous samples, at pH < 2 or pH > 12.5 are hazardous and must be handled and disposed of as hazardous waste or neutralized and disposed of in accordance with all Federal, State, and local regulations

18.3 For further information on waste management, consult *The Waste Management Manual for Laboratory Personnel* and *Less is Better-Laboratory Chemical Management for Waste Reduction*, (Reference 9).

19.0 References

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20.0 Tables, Diagrams, Flowcharts, and Validation Data

Table 1. Names, Abbreviations, and CAS Registry Numbers for Target PFAS, Extracted Internal Standards, and Non-extracted Internal Standards[1]

Target Analyte Name	Abbreviation	CASRN
Perfluoroalkyl carboxylic acids		
Perfluorobutanoic acid	PFBA	375-22-4
Perfluoropentanoic acid	PFPeA	2706-90-3
Perfluorohexanoic acid	PFHxA	307-24-4
Perfluoroheptanoic acid	PFHpA	375-85-9
Perfluorooctanoic acid	PFOA	335-67-1
Perfluorononanoic acid	PFNA	375-95-1
Perfluorodecanoic acid	PFDA	335-76-2
Perfluoroundecanoic acid	PFUnA	2058-94-8
Perfluorododecanoic acid	PFDoA	307-55-1
Perfluorotridecanoic acid	PFTrDA	72629-94-8
Perfluorotetradecanoic acid	PFTeDA	376-06-7
Perfluoroalkyl sulfonic acids		
Acid Form		
Perfluorobutanesulfonic acid	PFBS	375-73-5
Perfluoropentanesulfonic acid	PFPeS	2706-91-4
Perfluorohexanesulfonic acid	PFHxS	355-46-4
Perfluoroheptanesulfonic acid	PFHpS	375-92-8
Perfluorooctanesulfonic acid	PFOS	1763-23-1
Perfluorononanesulfonic acid	PFNS	68259-12-1
Perfluorodecanesulfonic acid *	PFDS	335-77-3
Perfluorododecanesulfonic acid *	PFDoS	79780-39-5
Fluorotelomer sulfonic acids		
1*H*,1*H*, 2*H*, 2*H*-Perfluorohexane sulfonic acid	4:2FTS	757124-72-4
1*H*,1*H*, 2*H*, 2*H*-Perfluorooctane sulfonic acid	6:2FTS	27619-97-2
1*H*,1*H*, 2*H*, 2*H*-Perfluorodecane sulfonic acid	8:2FTS	39108-34-4
Perfluorooctane sulfonamides		
Perfluorooctanesulfonamide	PFOSA	754-91-6
N-methyl perfluorooctanesulfonamide	NMeFOSA	31506-32-8
N-ethyl perfluorooctanesulfonamide	NEtFOSA	4151-50-2
Perfluorooctane sulfonamidoacetic acids		
N-methyl perfluorooctanesulfonamidoacetic acid	NMeFOSAA	2355-31-9
N-ethyl perfluorooctanesulfonamidoacetic acid	NEtFOSAA	2991-50-6
Perfluorooctane sulfonamide ethanols		
N-methyl perfluorooctanesulfonamidoethanol	NMeFOSE	24448-09-7
N-ethyl perfluorooctanesulfonamidoethanol	NEtFOSE	1691-99-2
Per- and Polyfluoroether carboxylic acids		
Hexafluoropropylene oxide dimer acid	HFPO-DA	13252-13-6
4,8-Dioxa-3*H*-perfluorononanoic acid	ADONA	919005-14-4
Perfluoro-3-methoxypropanoic acid	PFMPA	377-73-1
Perfluoro-4-methoxybutanoic acid	PFMBA	863090-89-5
Nonafluoro-3,6-dioxaheptanoic acid	NFDHA	151772-58-6

Table 1. Names, Abbreviations, and CAS Registry Numbers for Target PFAS, Extracted Internal Standards, and Non-extracted Internal Standards[1]

Target Analyte Name	Abbreviation	CASRN
Ether sulfonic acids		
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid	9Cl-PF3ONS	756426-58-1
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid *	11Cl-PF3OUdS	763051-92-9
Perfluoro(2-ethoxyethane)sulfonic acid	PFEESA	113507-82-7
Fluorotelomer carboxylic acids		
3-Perfluoropropyl propanoic acid	3:3FTCA	356-02-5
2*H*,2*H*,3*H*,3*H*-Perfluorooctanoic acid	5:3FTCA	914637-49-3
3-Perfluoroheptyl propanoic acid	7:3FTCA	812-70-4
EIS Compounds		
Perfluoro-n-[$^{13}C_4$]butanoic acid	$^{13}C_4$-PFBA	NA
Perfluoro-n-[$^{13}C_5$]pentanoic acid	$^{13}C_5$-PFPeA	
Perfluoro-n-[1,2,3,4,6-$^{13}C_5$]hexanoic acid	$^{13}C_5$-PFHxA	
Perfluoro-n-[1,2,3,4-$^{13}C_4$]heptanoic acid	$^{13}C_4$-PFHpA	
Perfluoro-n-[$^{13}C_8$]octanoic acid	$^{13}C_8$-PFOA	
Perfluoro-n-[$^{13}C_9$]nonanoic acid	$^{13}C_9$-PFNA	
Perfluoro-n-[1,2,3,4,5,6-$^{13}C_6$]decanoic acid	$^{13}C_6$-PFDA	
Perfluoro-n-[1,2,3,4,5,6,7-$^{13}C_7$]undecanoic acid	$^{13}C_7$-PFUnA	
Perfluoro-n-[1,2-$^{13}C_2$]dodecanoic acid	$^{13}C_2$-PFDoA	
Perfluoro-n-[1,2-$^{13}C_2$]tetradecanoic acid	$^{13}C_2$-PFTeDA	
Perfluoro-1-[2,3,4-$^{13}C_3$]butanesulfonic acid	$^{13}C_3$-PFBS	
Perfluoro-1-[1,2,3-$^{13}C_3$]hexanesulfonic acid	$^{13}C_3$-PFHxS	
Perfluoro-1-[$^{13}C_8$]octanesulfonic acid	$^{13}C_8$-PFOS	
Perfluoro-1-[$^{13}C_8$]octanesulfonamide	$^{13}C_8$-PFOSA	
N-methyl-d_3-perfluoro-1-octanesulfonamidoacetic acid	D_3-NMeFOSAA	
N-ethyl-d_5-perfluoro-1-octanesulfonamidoacetic acid	D_5-NEtFOSAA	
1*H*,1*H*,2*H*,2*H*-Perfluoro-1-[1,2-$^{13}C_2$]hexane sulfonic acid	$^{13}C_2$-4:2FTS	
1*H*,1*H*,2*H*,2*H*-Perfluoro-1-[1,2-$^{13}C_2$]octane sulfonic acid	$^{13}C_2$-6:2FTS	
1*H*,1*H*,2*H*,2*H*-Perfluoro-1-[1,2-$^{13}C_2$]decane sulfonic acid	$^{13}C_2$-8:2FTS	
Tetrafluoro-2-heptafluoropropoxy-$^{13}C_3$-propanoic acid	$^{13}C_3$-HFPO-DA	
N-methyl-D_7-perfluorooctanesulfonamidoethanol	D_7-NMeFOSE	
N-ethyl-D_9-perfluorooctanesulfonamidoethanol	D_9-NEtFOSE	
N-ethyl-D_5-perfluoro-1-octanesulfonamide	D_5-NEtFOSA	
N-methyl-D_3-perfluoro-1-octanesulfonamide	D_3-NMeFOSA	
NIS Compounds		
Perfluoro-n-[2,3,4-$^{13}C_3$]butanoic acid	$^{13}C_3$-PFBA	NA
Perfluoro-n-[1,2,3,4-$^{13}C_4$]octanoic acid	$^{13}C_4$-PFOA	
Perfluoro-n-[1,2-$^{13}C_2$]decanoic acid	$^{13}C_2$-PFDA	
Perfluoro-n-[1,2,3,4-$^{13}C_4$]octanesulfonic acid	$^{13}C_4$-PFOS	
Perfluoro-n-[1,2,3,4,5-$^{13}C_5$] nonanoic acid	$^{13}C_5$-PFNA	
Perfluoro-n-[1,2-$^{13}C_2$]hexanoic acid	$^{13}C_2$-PFHxA	
Perfluoro-1-hexane[$^{18}O_2$]sulfonic acid	$^{18}O_2$-PFHxS	

[1] The target analyte names are for the acid and neutral forms of the analytes. See Table 2 for the names and Chemical Abstract Service Registry Numbers (CASRN) of the corresponding anion forms, where applicable.

NA = Not assigned a CAS Registry Number

* These analytes may not perform as well as others in some matrices (see Section 1.6): PFDS, PFDoS, and 11CLPF3OUdS in aqueous samples; PFDoS and 11CLPF3OUdS in biosolid samples; and PFDoS in tissue samples.

Table 2. Cross-reference of Abbreviations, Analyte Names, and CAS Registry Numbers for the Acid and Anion Forms of the Perfluoroalkyl Carboxylates and Perfluoroalkyl Sulfonates

Perfluoroalkyl carboxylic acids/anions				
Abbreviation	**Acid Name**	**CASRN**	**Anion Name**	**CASRN**
PFBA	Perfluorobutanoic acid	375-22-4	Perfluorobutanoate	45048-62-2
PFPeA	Perfluoropentanoic acid	2706-90-3	Perfluoropentanoate	45167-47-3
PFHxA	Perfluorohexanoic acid	307-24-4	Perfluorohexanoate	92612-52-7
PFHpA	Perfluoroheptanoic acid	375-85-9	Perflluoroheptanoate	120885-29-2
PFOA	Perfluorooctanoic acid	335-67-1	Pefluorooctanoate	45285-51-6
PFNA	Perfluorononanoic acid	375-95-1	Perfluorononanoate	72007-68-2
PFDA	Perfluorodecanoic acid	335-76-2	Perfluorodecanoate	73829-36-4
PFUnA	Perfluoroundecanoic acid	2058-94-8	Perfluoroundecanoate	196859-54-8
PFDoA	Perfluorododecanoic acid	307-55-1	Perfluorododecanoate	171978-95-3
PFTrDA	Perfluorotridecanoic acid	72629-94-8	Perfluorotridecanoate	862374-87-6
PFTeDA	Perfluorotetradecanoic acid	376-06-7	Perfluorotetradecanoate	365971-87-5
Perfluoroalkyl sulfonic acids/anions				
PFBS	Perfluorobutanesulfonic acid	375-73-5	Perfluorobutane sulfonate	45187-15-3
PFPeS	Perfluoropentanesulfonic acid	2706-91-4	Perfluoropentane sulfonate	175905-36-9
PFHxS	Perfluorohexanesulfonic acid	355-46-4	Perfluorohexane sulfonate	108427-53-8
PFHpS	Perfluoroheptanesulfonic acid	375-92-8	Perfluoroheptane sulfonate	146689-46-5
PFOS	Perfluorooctanesulfonic acid	1763-23-1	Perfluorooctane sulfonate	45298-90-6
PFNS	Perfluorononanesulfonic acid	68259-12-1	Perfluorononane sulfonate	474511-07-4
PFDS	Perfluorodecanesulfonic acid	335-77-3	Perfluorodecane sulfonate	126105-34-8
PFDoS	Perfluorododecanesulfonic acid	79780-39-5	Perfluorododecane sulfonate	343629-43-6

CASRN = Chemical Abstracts Service Registry Number

Table 3. Nominal Masses of Spike Added to Samples or Extracts

Standard Type	Amount Added (ng)[1]
EIS	
$^{13}C_4$-PFBA	40
$^{13}C_5$-PFPeA	20
$^{13}C_5$-PFHxA	10
$^{13}C_4$-PFHpA	10
$^{13}C_8$-PFOA	10
$^{13}C_9$-PFNA	5
$^{13}C_6$-PFDA	5
$^{13}C_7$-PFUnA	5
$^{13}C_2$-PFDoA	5
$^{13}C_2$-PFTeDA	5
$^{13}C_3$-PFBS	10
$^{13}C_3$-PFHxS	10
$^{13}C_8$-PFOS	10
$^{13}C_2$-4:2FTS	20
$^{13}C_2$-6:2FTS	20
$^{13}C_2$-8:2FTS	20
$^{13}C_8$-PFOSA	10
D_3-NMeFOSA	10
D_5-NEtFOSA	10
D_3-NMeFOSAA	20
D_5-NEtFOSAA	20
D_7-NMeFOSE	100
D_9-NEtFOSE	100
$^{13}C_3$-HFPO-DA	40
NIS	
$^{13}C_3$-PFBA	20
$^{13}C_2$-PFHxA	10
$^{13}C_4$-PFOA	10
$^{13}C_5$-PFNA	5
$^{13}C_2$-PFDA	5
$^{18}O_2$-PFHxS	10
$^{13}C_4$-PFOS	10

[1] The EIS amounts added to the samples in this table reflect the masses of each EIS that are present in each of the calibration standards, and the relative ratios of the target analytes and their EIS compounds are critical to the use of isotope dilution quantitation.

Table 4. Example Calibration Solutions (ng/mL) Based on Those Used in the Method Validation Studies

Compound	CS1 (LOQ)	CS2	CS3	CS4 (CV[1])	CS5	CS6	CS7[2]
Perfluoroalkyl carboxylic acids							
PFBA	0.8	2	5	10	20	50	250
PFPeA	0.4	1	2.5	5	10	25	125
PFHxA	0.2	0.5	1.25	2.5	5	12.5	62.5
PFHpA	0.2	0.5	1.25	2.5	5	12.5	62.5
PFOA	0.2	0.5	1.25	2.5	5	12.5	62.5
PFNA	0.2	0.5	1.25	2.5	5	12.5	62.5
PFDA	0.2	0.5	1.25	2.5	5	12.5	62.5
PFUnA	0.2	0.5	1.25	2.5	5	12.5	62.5
PFDoA	0.2	0.5	1.25	2.5	5	12.5	62.5
PFTrDA	0.2	0.5	1.25	2.5	5	12.5	62.5
PFTeDA	0.2	0.5	1.25	2.5	5	12.5	62.5
Perfluoroalkyl sulfonic acids							
PFBS	0.2	0.5	1.25	2.5	5	12.5	62.5
PFPeS	0.2	0.5	1.25	2.5	5	12.5	62.5
PFHxS	0.2	0.5	1.25	2.5	5	12.5	62.5
PFHpS	0.2	0.5	1.25	2.5	5	12.5	62.5
PFOS	0.2	0.5	1.25	2.5	5	12.5	62.5
PFNS	0.2	0.5	1.25	2.5	5	12.5	62.5
PFDS	0.2	0.5	1.25	2.5	5	12.5	62.5
PFDoS	0.2	0.5	1.25	2.5	5	12.5	62.5
Fluorotelomer sulfonic acids							
4:2FTS	0.8	2	5	10	20	50	NA
6:2FTS	0.8	2	5	10	20	50	NA
8:2FTS	0.8	2	5	10	20	50	NA
Perfluorooctane sulfonamides							
PFOSA	0.2	0.5	1.25	2.5	5	12.5	62.5
NMeFOSA	0.2	0.5	1.25	2.5	5	12.5	62.5
NEtFOSA	0.2	0.5	1.25	2.5	5	12.5	62.5
Perfluorooctane sulfonamidoacetic acids							
NMeFOSAA	0.2	0.5	1.25	2.5	5	12.5	62.5
NEtFOSAA	0.2	0.5	1.25	2.5	5	12.5	62.5
Perfluorooctane sulfonamide ethanols							
NMeFOSE	2	5	12.5	25	50	125	625
NEtFOSE	2	5	12.5	25	50	125	625
Per- and polyfluoroether carboxylic acids							
HFPO-DA	0.8	2	5	10	20	50	250
ADONA	0.8	2	5	10	20	50	250
PFMPA	0.4	1	2.5	5	10	25	125
PFMBA	0.4	1	2.5	5	10	25	125
NFDHA	0.4	1	2.5	5	10	25	125
Ether sulfonic acids							
9Cl-PF3ONS	0.8	2	5	10	20	50	250
11Cl-PF3OUdS	0.8	2	5	10	20	50	250
PFEESA	0.4	1	2.5	5	10	25	125

Table 4. Example Calibration Solutions (ng/mL) Based on Those Used in the Method Validation Studies

Compound	CS1 (LOQ)	CS2	CS3	CS4 (CV[1])	CS5	CS6	CS7[2]
Fluorotelomer carboxylic acids							
3:3FTCA	1.0	2.5	6.26	12.5	25	62.4	312
5:3FTCA	5.0	12.5	31.3	62.5	125	312	1560
7:3FTCA	5.0	12.5	31.3	62.5	125	312	1560
EIS Compounds							
$^{13}C_4$-PFBA	10	10	10	10	10	10	10
$^{13}C_5$-PFPeA	5	5	5	5	5	5	5
$^{13}C_5$-PFHxA	2.5	2.5	2.5	2.5	2.5	2.5	2.5
$^{13}C_4$-PFHpA	2.5	2.5	2.5	2.5	2.5	2.5	2.5
$^{13}C_8$-PFOA	2.5	2.5	2.5	2.5	2.5	2.5	2.5
$^{13}C_9$-PFNA	1.25	1.25	1.25	1.25	1.25	1.25	1.25
$^{13}C_6$-PFDA	1.25	1.25	1.25	1.25	1.25	1.25	1.25
$^{13}C_7$-PFUnA	1.25	1.25	1.25	1.25	1.25	1.25	1.25
$^{13}C_2$-PFDoA	1.25	1.25	1.25	1.25	1.25	1.25	1.25
$^{13}C_2$-PFTeDA	1.25	1.25	1.25	1.25	1.25	1.25	1.25
$^{13}C_3$-PFBS	2.5	2.5	2.5	2.5	2.5	2.5	2.5
$^{13}C_3$-PFHxS	2.5	2.5	2.5	2.5	2.5	2.5	2.5
$^{13}C_8$-PFOS	2.5	2.5	2.5	2.5	2.5	2.5	2.5
$^{13}C_2$-4:2FTS	5	5	5	5	5	5	5
$^{13}C_2$-6:2FTS	5	5	5	5	5	5	5
$^{13}C_2$-8:2FTS	5	5	5	5	5	5	5
$^{13}C_8$-PFOSA	2.5	2.5	2.5	2.5	2.5	2.5	2.5
D_3-NMeFOSA	2.5	2.5	2.5	2.5	2.5	2.5	2.5
D_5-NEtFOSA	2.5	2.5	2.5	2.5	2.5	2.5	2.5
D_3-NMeFOSAA	5	5	5	5	5	5	5
D_5-NEtFOSAA	5	5	5	5	5	5	5
D_7-NMeFOSE	25	25	25	25	25	25	25
D_9-NEtFOSE	25	25	25	25	25	25	25
$^{13}C_3$-HFPO-DA	10	10	10	10	10	10	10
NIS Compounds							
$^{13}C_3$-PFBA	5	5	5	5	5	5	5
$^{13}C_2$-PFHxA	2.5	2.5	2.5	2.5	2.5	2.5	2.5
$^{13}C_4$-PFOA	2.5	2.5	2.5	2.5	2.5	2.5	2.5
$^{13}C_5$-PFNA	1.25	1.25	1.25	1.25	1.25	1.25	1.25
$^{13}C_2$-PFDA	1.25	1.25	1.25	1.25	1.25	1.25	1.25
$^{18}O_2$-PFHxS	2.5	2.5	2.5	2.5	2.5	2.5	2.5
$^{13}C_4$-PFOS	2.5	2.5	2.5	2.5	2.5	2.5	2.5

[1] This calibration point is used as the calibration verification (CV)

[2] A minimum of six contiguous calibrations standards is required for linear models and a minimum of seven calibration standards is required for second-order models. Other calibration ranges and standard concentrations may be employed, provided that the conditions in Section 10.3, 10.3.2, and 10.3.3 are met.

Table 5. IPR/OPR/LLOPR Acceptance Limits for Target Analytes in Aqueous Matrices[1]

Target Analyte	IPR[2]		OPR/LLOPR Recovery (%)[2]
	Mean Recovery (%)	RSD (%)	
PFBA	70 - 135	21	70 - 140
PFPeA	70 - 135	23	65 - 135
PFHxA	70 - 135	24	70 - 145
PFHpA	70 - 135	28	70 - 150
PFOA	65 - 155	27	70 - 150
PFNA	70 - 140	28	70 - 150
PFDA	65 - 140	26	70 - 140
PFUnA	70 - 135	29	70 - 145
PFDoA	70 - 130	21	70 - 140
PFTrDA	60 - 145	29	65 - 140
PFTeDA	70 - 145	27	60 - 140
PFBS	70 - 140	23	60 - 145
PFPeS	70 - 135	25	65 - 140
PFHxS	70 - 135	27	65 - 145
PFHpS	70 - 140	30	70 - 150
PFOS	70 - 140	29	55 - 150
PFNS	70 - 135	29	65 - 145
PFDS	70 - 135	30	60 - 145
PFDoS	45 - 135	35	50 - 145
4:2FTS	70 - 135	27	70 - 145
6:2FTS	70 - 135	32	65 - 155
8:2FTS	70 - 140	33	60 - 150
PFOSA	70 - 135	22	70 - 145
NMeFOSA	70 - 135	30	60 - 150
NEtFOSA	70 - 130	26	65 - 145
NMeFOSAA	65 - 140	32	50 - 140
NEtFOSAA	70 - 135	28	70 - 145
NMeFOSE	70 - 135	29	70 - 145
NEtFOSE	70 - 130	21	70 - 135
HFPO-DA	70 - 135	23	70 - 140
ADONA	70 - 135	23	65 - 145
PFMPA	60 - 140	23	55 - 140
PFMBA	65 - 145	27	60 - 150
NFDHA	65 - 140	37	50 - 150
9Cl-PF3ONS	70 - 145	30	70 - 155
11Cl-PF3OUdS	50 - 150	35	55 - 160
PFEESA	70 - 135	25	70 - 140
3:3FTCA	70 - 130	23	65 - 130
5:3FTCA	70 - 130	24	70 - 135
7:3FTCA	55 - 130	34	50 - 145

[1] Limits apply to the IPR, OPR, and LLOPR analyses associated with all aqueous matrices, including wastewater, surface water, groundwater, and landfill leachates.

[2] The recovery and RSD limits apply to the target analyte results for IPR, OPR, and LLOPR samples associated with all aqueous matrices. Data were derived from the multi-laboratory validation study and are therefore the limits required for this method.

Table 6. Acceptance Limits for EIS and NIS Compounds in All Aqueous Matrices and Associated QC Samples		
	Aqueous Matrices Other Than Leachates[2]	Landfill Leachates[3]
EIS Compound[1]	Recovery (%)	Recovery (%)
$^{13}C_4$-PFBA	5[4] - 130	5[4] - 130
$^{13}C_5$-PFPeA	40 - 130	40 - 130
$^{13}C_5$-PFHxA	40 - 130	40 - 130
$^{13}C_4$-PFHpA	40 - 130	40 - 130
$^{13}C_8$-PFOA	40 - 130	40 - 130
$^{13}C_9$-PFNA	40 - 130	40 - 130
$^{13}C_6$-PFDA	40 - 130	40 - 130
$^{13}C_7$-PFUnA	30 - 130	40 - 130
$^{13}C_2$-PFDoA	10 - 130	35 – 130
$^{13}C_2$-PFTeDA	10 - 130	25 – 130
$^{13}C_3$-PFBS	40 - 135	40 - 130
$^{13}C_3$-PFHxS	40 - 130	40 - 130
$^{13}C_8$-PFOS	40 - 130	40 - 130
$^{13}C_2$-4:2FTS	40 - 200	40 – 220
$^{13}C_2$-6:2FTS	40 - 200	40 – 170
$^{13}C_2$-8:2FTS	40 - 300	40 – 145
$^{13}C_8$-PFOSA	40 - 130	40 – 130
D_3-NMeFOSA	10 - 130	40 – 130
D_5-NEtFOSA	10 - 130	35 - 130
D_3-NMeFOSAA	40 - 170	35 - 130
D_5-NEtFOSAA	25 - 135	30 - 130
D_7-NMeFOSE	10 - 130	20 - 130
D_9-NEtFOSE	10 - 130	20 - 130
$^{13}C_3$-HFPO-DA	40 - 130	40 - 130
$^{13}C_3$-PFBA	50 - 200	50 - 200
$^{13}C_2$-PFHxA		
$^{13}C_4$-PFOA		
$^{13}C_5$-PFNA		
$^{13}C_2$-PFDA		
$^{18}O_2$-PFHxS		
$^{13}C_4$-PFOS		

[1] The recovery limits for the EIS compounds were derived by EPA from the data from multi-laboratory validation study. To simplify laboratory operations, EPA has applied the same EIS recovery limits used for field sample analyses to the EIS recoveries in the method blank, IPR, OPR, and LLOPR samples. There are no IPR mean or RSD criteria for the EIS compounds.

[2] Limits apply to the EIS and NIS recoveries from samples of aqueous matrices, including wastewater, surface water, and groundwater, but **not** landfill leachates.

[3] Limits apply to the EIS and NIS recoveries from samples of landfill leachates, **not** other aqueous matrices.

[4] Recovery of $^{13}C_4$-PFBA can be problematic in some field samples. Although the lower limit for recovery for this EIS is set below 10%, laboratories should routinely track recovery of this EIS and take reasonable steps to ensure that recovery is at least 10% in the majority of samples.

Table 7. IPR/OPR/LLOPR Acceptance Limits for Target Analytes in Solid, Biosolid, and Tissue Matrices

Compound	Solid and Biosolid Matrices[1]			Tissue Matrix[1]		
	IPR			IPR		
	Mean Recovery (%)	RSD (%)	OPR/LLOPR Recovery (%)	Mean Recovery (%)	RSD (%)	OPR/LLOPR Recovery (%)
PFBA	70 - 140	17	70 - 140	70 - 135	20	60 - 140
PFPeA	70 - 140	26	60 - 150	70 - 130	20	60 - 145
PFHxA	70 - 135	23	65 - 140	70 - 140	20	60 - 160
PFHpA	70 - 140	21	65 - 145	70 - 140	20	60 - 145
PFOA	70 - 140	23	70 - 150	70 - 130	25	60 - 150
PFNA	65 - 145	24	70 - 155	70 - 140	20	60 - 145
PFDA	70 - 145	26	70 - 155	70 - 135	20	60 - 150
PFUnA	70 - 145	26	70 - 155	70 - 135	20	60 - 155
PFDoA	70 - 145	25	70 - 150	70 - 135	20	60 - 140
PFTrDA	55 - 160	26	65 - 150	55 - 160	20	60 - 150
PFTeDA	70 - 145	24	65 - 150	70 - 140	25	60 - 140
PFBS	60 - 145	25	65 - 145	70 - 145	20	60 - 150
PFPeS	65 - 140	29	55 - 160	70 - 150	20	60 - 145
PFHxS	65 - 145	28	60 - 150	70 - 140	25	60 - 155
PFHpS	70 - 140	27	65 - 155	70 - 145	20	60 - 140
PFOS	70 - 135	27	65 - 160	70 - 135	30	60 - 160
PFNS	70 - 140	27	55 - 140	60 - 130	20	45 - 140
PFDS	50 - 150	31	40 - 155	55 - 135	20	50 - 140
PFDoS	40 - 140	40	25 - 160	25 - 145	45	25 - 140
4:2FTS	70 - 135	27	60 - 150	65 - 140	30	55 - 150
6:2FTS	60 - 160	50	55 - 200	70 - 140	25	60 - 150
8:2FTS	70 - 140	27	70 - 150	70 - 150	25	60 - 170
PFOSA	70 - 140	19	70 - 140	70 - 140	20	60 - 150
NMeFOSA	65 - 145	26	70 - 155	70 - 140	30	60 - 160
NEtFOSA	70 - 135	19	70 - 140	70 - 140	40	60 - 150
NMeFOSAA	65 - 145	31	65 - 155	70 - 140	20	60 - 145
NEtFOSAA	60 - 150	31	65 - 165	70 - 140	25	60 - 145
NMeFOSE	70 - 140	19	70 - 140	60 - 150	20	40 - 180
NEtFOSE	70 - 135	17	70 - 135	70 - 145	40	60 - 205
HFPO-DA	70 - 140	25	70 - 145	70 - 140	25	60 - 145
ADONA	70 - 155	26	70 - 160	70 - 145	20	55 - 165
PFMPA	70 - 140	25	30 - 140	70 - 145	40	25 - 145
PFMBA	55 - 145	33	60 - 150	70 - 140	20	60 - 150
NFDHA	45 - 145	27	60 - 155	70 - 155	30	60 - 180
9Cl-PF3ONS	65 - 135	23	70 - 150	70 - 140	20	60 - 170
11Cl-PF3OUdS	50 - 135	31	45 - 160	65 - 140	20	50 - 170
PFEESA	70 - 140	20	70 - 140	70 - 145	25	50 - 150
3:3FTCA	45 - 155	32	45 - 130	55 - 130	25	30 - 140
5:3FTCA	70 - 135	28	60 - 130	70 - 145	20	60 - 160
7:3FTCA	70 - 145	39	60 - 150	70 - 155	20	60 - 200

[1] The recovery limits apply to the target analyte results for IPR, OPR, and LLOPR samples for solid, biosolids, and tissue matrices. Data were derived from the multi-laboratory validation study and are therefore the limits required for this method.

Table 8. Acceptance Limits for EIS and NIS Compounds in Soil-Sediment, Tissue, and Biosolid Matrices and Associated QC Samples			
	Soil/Sediment Samples[2]	**Tissue Samples[2]**	**Biosolid Samples[2]**
EIS Compound[1]	**Recovery (%)**	**Recovery (%)**	**Recovery (%)**
$^{13}C_4$-PFBA	8[3] - 130	5[3] - 130	5[3] - 130
$^{13}C_5$-PFPeA	35 - 130	10 - 185	35 - 130
$^{13}C_5$-PFHxA	40 - 130	25 - 170	40 – 130
$^{13}C_4$-PFHpA	40 - 130	25 - 150	40 – 130
$^{13}C_8$-PFOA	40 - 130	25 - 150	40 – 130
$^{13}C_9$-PFNA	40 - 130	35 - 185	40 – 145
$^{13}C_6$-PFDA	40 - 130	30 - 150	40 – 130
$^{13}C_7$-PFUnA	40 - 130	30 - 180	40 – 130
$^{13}C_2$-PFDoA	40 - 130	35 - 180	40 – 130
$^{13}C_2$-PFTeDA	20 - 130	20 - 160	10 - 160
$^{13}C_3$-PFBS	40 - 135	25 - 190	40 - 150
$^{13}C_3$-PFHxS	40 - 130	35 - 175	40 - 140
$^{13}C_8$-PFOS	40 - 130	40 - 160	40 - 130
$^{13}C_2$-4:2FTS	40 - 165	30 - 300	40 - 300
$^{13}C_2$-6:2FTS	40 - 215	35 - 300	40 - 300
$^{13}C_2$-8:2FTS	40 - 275	40 - 365	40 - 300
$^{13}C_8$-PFOSA	40 - 130	25 - 180	20 - 140
D_3-NMeFOSA	10 - 130	5[4] - 130	20 - 130
D_5-NEtFOSA	10 - 130	5[4]- 130	20 - 130
D_3-NMeFOSAA	40 - 135	30 - 250	30 – 150
D_5-NEtFOSAA	40 - 150	30 - 235	20 - 140
D_7-NMeFOSE	20 - 130	5[4] - 160	25 - 130
D_9-NEtFOSE	15 - 130	5[4] - 130	20 - 130
$^{13}C_3$-HFPO-DA	40 - 130	20 - 185	40 - 130
$^{13}C_3$-PFBA	50 - 200	50 - 200	50 - 200
$^{13}C_2$-PFHxA			
$^{13}C_4$-PFOA			
$^{13}C_5$-PFNA			
$^{13}C_2$-PFDA			
$^{18}O_2$-PFHxS			
$^{13}C_4$-PFOS			

[1] Limits apply to the EIS and NIS recoveries from samples of all solid, biosolid, and tissue matrices.

[2] The recovery limits for the EIS compounds were derived by EPA from the solid, tissue, and biosolids sample data from multi-laboratory validation study. To simplify laboratory operations, EPA has applied the same EIS recovery limits used for field sample analyses to the EIS recoveries in the method blank, IPR, OPR, and LLOPR samples. There are no IPR mean or RSD criteria for the EIS compounds.

[3] Recovery of $^{13}C_4$-PFBA, can be problematic in some soil, tissue, and biosolids samples. Although the lower limits for recovery for these EISs are set below 10%, laboratories should routinely track recoveries of these EISs and take reasonable steps to ensure that recoveries are at least 10% in the majority of samples.

[4] Recoveries of D_3-NMeFOSA, D_5-NEtFOSA, D_7-NMeFOSE, and D_9-NEtFOSE can be problematic in tissue samples. The 5% the lower limit for recovery for these EISs may not be achievable for all laboratories in tissue samples. Any result associated with an EIS recovery below 5% should be considered estimated.

Table 9. Pooled MDL and Ranges of LOQ Values for Aqueous, Solid, and Tissue Matrices Demonstrated in the Method Validation Studies[1]

	Aqueous (ng/L)		Solid (ng/g)		Tissue (ng/g)	
Compound	Pooled MDL_s[2]	Range of LOQs[3]	Pooled MDL_s[2]	Range of LOQs[3]	Pooled MDL_s[2]	Range of LOQs[3]
PFBA	0.79	4 - 16	0.15	0.64 - 1.6	0.208	1.6 – 4.0
PFPeA	0.54	2 - 8	0.07	0.32 - 0.8	0.155	0.8 – 1.0
PFHxA	0.46	1 - 4	0.06	0.16 - 0.4	0.111	0.4 - 0.5
PFHpA	0.37	1 - 4	0.05	0.16 - 0.4	0.099	0.4 - 0.5
PFOA	0.54	1 - 4	0.07	0.16 - 0.4	0.105	0.4 - 0.5
PFNA	0.45	1 - 4	0.14	0.16 - 1.3	0.119	0.4 - 0.5
PFDA	0.52	1 - 4	0.06	0.16 - 0.4	0.149	0.4 - 0.5
PFUnA	0.45	1 - 4	0.12	0.16 - 0.5	0.125	0.4 – 1.0
PFDoA	0.40	1 - 4	0.06	0.16 - 0.4	0.101	0.4 - 0.5
PFTrDA	0.46	1 - 4	0.07	0.16 - 0.4	0.142	0.4 - 0.5
PFTeDA	0.49	1 - 4	0.05	0.16 - 0.4	0.159	0.4 – 1.0
PFBS	0.37	1 - 4	0.05	0.16 - 0.4	0.097	0.4 - 0.5
PFPeS	0.50	1 - 4	0.08	0.16 - 0.4	0.076	0.4 - 0.5
PFHxS	0.54	1 - 4	0.08	0.16 - 0.4	0.081	0.4 - 0.5
PFHpS	0.50	1 - 4	0.07	0.16 - 0.4	0.119	0.4 - 0.5
PFOS	0.63	1 - 4	0.07	0.16 - 0.4	0.145	0.4 – 2.0
PFNS	0.47	1 - 4	0.07	0.16 - 0.4	0.108	0.4 - 0.5
PFDS	0.60	1 - 4	0.08	0.16 - 0.4	0.114	0.4 - 0.5
PFDoS	0.60	1 - 4	0.06	0.16 - 0.4	0.153	0.4 - 0.5
4:2FTS	1.69	4 - 15	0.20	0.64 - 1.5	0.369	1.6 – 2.0
6:2FTS	2.45	4 - 15	0.39	0.64 - 1.5	0.537	1.6 – 2.0
8:2FTS	2.50	4 - 15	0.31	0.64 - 1.5	0.378	1.6 – 2.0
PFOSA	0.32	1 - 4	0.04	0.16 - 0.4	0.069	0.4 - 0.5
NMeFOSA	0.43	1 - 4	0.07	0.16 - 0.4	0.162	0.4 - 0.5
NEtFOSA	0.45	1 - 4	0.07	0.16 - 0.4	0.163	0.4 – 1.0
NMeFOSAA	0.68	1 - 4	0.08	0.16 - 0.4	0.145	0.4 - 0.5
NEtFOSAA	0.59	1 - 4	0.08	0.16 - 0.4	0.148	0.4 - 0.5
NMeFOSE	3.81	10 - 40	0.36	1.6 – 4.0	0.832	4.0 – 5.0
NEtFOSE	4.84	10 - 40	0.35	1.6 - 4.0	1.77	4.0 – 5.0
HFPO-DA	0.51	2 - 8	0.25	0.64 - 1.6	0.339	1.6 - 2.1
ADONA	0.50	2 - 8	0.23	0.64 - 1.5	0.274	1.6 – 2.0
PFMPA	1.46	4 - 16	0.07	0.32 - 0.8	0.273	0.8 – 2.0
PFMBA	1.41	4 - 15	0.05	0.32 - 0.8	0.168	0.8 – 1.0
NFDHA	0.75	2 - 7	0.20	0.32 - 0.8	0.216	0.8 – 1.0
9Cl-PF3ONS	1.38	4 - 15	0.22	0.64 - 1.5	0.362	1.6 – 2.0
11Cl-PF3OUdS	1.67	4 - 15	0.18	0.64 - 1.5	0.352	1.6 – 2.0
PFEESA	1.17	2 - 8	0.08	0.32 - 0.7	0.123	0.8 – 1.0
3:3FTCA	2.47	5 - 20	0.23	0.80 - 5.0	0.716	2.0 – 4.0
5:3FTCA	9.59	25 - 100	0.86	4 - 10	2.38	10 - 20
7:3FTCA	8.71	25 - 100	0.87	4 - 10	2.02	10 - 12.5

[1] MDLs and LOQs for landfill leachates and biosolids were not determined directly in the multi-laboratory validation study. Given the smaller sample sizes analyzed for leachates and biosolids, the MDLs and LOQs for leachates and biosolids are likely to be 5 and 10 times higher than for other aqueous samples and solid samples, respectively. Laboratories analyzing leachates and/or biosolids must determine their own MDLs and LOQs for those matrices.

[2] The pooled MDL_s values and are derived from the multi-laboratory validation study using MDL data from eight laboratories for aqueous matrices, from ten laboratories for solid matrices, from seven laboratories for tissue matrices. These pooled MDL_s values are estimates of the sensitivity that should be achievable in a well-prepared laboratory. The actual MDL values (either MDL_s or MDL_b) generated in each laboratory should be used for data reporting and data quality assessments.

[3] The ranges of LOQ values represent the observed LOQs in the multi-laboratory validation study using data from eight laboratories for the aqueous matrices, nine laboratories for the solid matrices, and seven laboratories for tissue matrices. The actual LOQs generated in each laboratory should be used for data reporting and data quality assessments.

Table 10. Analyte Ions Monitored, Extracted Internal Standard, and Non-extracted Internal Standard Used for Quantification

Abbreviation	Example Retention Time [1]	Parent Ion Mass	Quantification Ion Mass	Confirmation Ion Mass[2]	Typical Ion Ratio	Quantification Reference Compound
Target Analytes						
PFBA	1.96	212.8	168.9	NA	NA	$^{13}C_4$-PFBA
PFPeA	4.18	263.0	219.0	68.9	NA	$^{13}C_5$-PFPeA
PFHxA	4.81	313.0	269.0	118.9	13	$^{13}C_5$-PFHxA
PFHpA	5.32	363.1	319.0	169.0	3.5	$^{13}C_4$-PFHpA
PFOA	6.16	413.0	369.0	169.0	3.0	$^{13}C_8$-PFOA
PFNA	6.99	463.0	419.0	219.0	4.9	$^{13}C_9$-PFNA
PFDA	7.47	512.9	469.0	219.0	5.5	$^{13}C_6$-PFDA
PFUnA	7.81	563.1	519.0	269.1	6.9	$^{13}C_7$-PFUnA
PFDoA	8.13	613.1	569.0	319.0	10	$^{13}C_2$-PFDoA
PFTrDA[3]	8.53	663.0	619.0	168.9	6.7	avg.$^{13}C_2$-PFTeDA and$^{13}C_2$-PFDoA
PFTeDA	8.96	713.1	669.0	168.9	6.0	$^{13}C_2$-PFTeDA
PFBS	4.79	298.7	79.9	98.8	2.1	$^{13}C_3$-PFBS
PFPeS	5.38	349.1	79.9	98.9	1.8	$^{13}C_3$-PFHxS
PFHxS	6.31	398.7	79.9	98.9	1.9	$^{13}C_3$-PFHxS
PFHpS	7.11	449.0	79.9	98.8	1.7	$^{13}C_8$-PFOS
PFOS	7.59	498.9	79.9	98.8	2.3	$^{13}C_8$-PFOS
PFNS	7.92	548.8	79.9	98.8	1.9	$^{13}C_8$-PFOS
PFDS	8.28	599.0	79.9	98.8	1.9	$^{13}C_8$-PFOS
PFDoS	9.14	699.1	79.9	98.8	1.9	$^{13}C_8$-PFOS
4:2FTS	4.67	327.1	307.0	80.9	1.7	$^{13}C_2$-4:2FTS
6:2FTS	5.81	427.1	407.0	80.9	1.9	$^{13}C_2$-6:2FTS
8:2FTS	7.28	527.1	507.0	80.8	3.0	$^{13}C_2$-8:2FTS
PFOSA	8.41	498.1	77.9	478.0	47	$^{13}C_8$-PFOSA
NMeFOSA	9.70	511.9	219.0	169.0	0.66	D_3-NMeFOSA
NEtFOSA	9.94	526.0	219.0	169.0	0.63	D_5-NEtFOSA
NMeFOSAA	7.51	570.1	419.0	483.0	2.0	D_3-NMeFOSAA
NEtFOSAA	7.65	584.2	419.1	526.0	1.2	D_5-N-EtFOSAA
NMeFOSE	9.57	616.1	58.9	NA	NA	D_7-NMeFOSE
NEtFOSE	9.85	630.0	58.9	NA	NA	D_9-NEtFOSE
HFPO-DA	4.97	284.9	168.9	184.9	1.95	$^{13}C_3$-HFPO-DA
ADONA	5.79	376.9	250.9	84.8	2.8	$^{13}C_3$-HFPO-DA
PFMPA	3.21	229.0	84.9	NA	NA	$^{13}C_5$-PFPeA
PFMBA	4.53	279.0	85.1	NA	NA	$^{13}C_5$-PFPeA
NFDHA	4.84	295.0	201.0	84.9	1.46	$^{13}C_5$-PFHxA
9Cl-PF3ONS	7.82	530.8	351.0	532.8→353.0	3.2	$^{13}C_3$-HFPO-DA
11Cl-PF3OUdS	8.62	630.9	450.9	632.9→452.9	3.0	$^{13}C_3$-HFPO-DA
PFEESA	5.08	314.8	134.9	82.9	9.22	$^{13}C_5$-PFHxA
3:3FTCA	3.89	241.0	177.0	117.0	1.70	$^{13}C_5$-PFPeA
5:3FTCA	5.14	341.0	237.1	217.0	1.16	$^{13}C_5$-PFHxA
7:3FTCA	6.76	441.0	316.9	336.9	0.69	$^{13}C_5$-PFHxA
EIS Compounds						
$^{13}C_4$-PFBA	1.95	216.8	171.9	NA		$^{13}C_3$-PFBA
$^{13}C_5$-PFPeA	4.18	268.3	223.0	NA		$^{13}C_2$-PFHxA
$^{13}C_5$-PFHxA	4.80	318.0	273.0	120.3		$^{13}C_2$-PFHxA
$^{13}C_4$-PFHpA	5.32	367.1	322.0	NA		$^{13}C_2$-PFHxA
$^{13}C_8$-PFOA	6.16	421.1	376.0	NA		$^{13}C_4$-PFOA
$^{13}C_9$-PFNA	6.99	472.1	427.0	NA		$^{13}C_5$-PFNA

Table 10. Analyte Ions Monitored, Extracted Internal Standard, and Non-extracted Internal Standard Used for Quantification

Abbreviation	Example Retention Time [1]	Parent Ion Mass	Quantification Ion Mass	Confirmation Ion Mass[2]	Typical Ion Ratio	Quantification Reference Compound
$^{13}C_6$-PFDA	7.47	519.1	474.1	NA		$^{13}C_2$-PFDA
$^{13}C_7$-PFUnA	7.81	570.0	525.1	NA		$^{13}C_2$-PFDA
$^{13}C_2$-PFDoA	8.13	615.1	570.0	NA		$^{13}C_2$-PFDA
$^{13}C_2$-PFTeDA	8.96	715.2	670.0	NA		$^{13}C_2$-PFDA
$^{13}C_3$-PFBS	4.78	302.1	79.9	98.9		$^{18}O_2$-PFHxS
$^{13}C_3$-PFHxS	6.30	402.1	79.9	98.9		$^{18}O_2$-PFHxS
$^{13}C_8$-PFOS	7.59	507.1	79.9	98.9		$^{13}C_4$-PFOS
$^{13}C_2$-4:2FTS	4.67	329.1	80.9	309.0		$^{18}O_2$-PFHxS
$^{13}C_2$-6:2FTS	5.82	429.1	80.9	409.0		$^{18}O_2$-PFHxS
$^{13}C_2$-8:2FTS	7.28	529.1	80.9	509.0		$^{18}O_2$-PFHxS
$^{13}C_8$-PFOSA	8.41	506.1	77.8	NA		$^{13}C_4$-PFOS
D_3-NMeFOSA	9.70	515.0	219.0	NA		$^{13}C_4$-PFOS
D_5-NEtFOSA	9.94	531.1	219.0	NA		$^{13}C_4$-PFOS
D_3-NMeFOSAA	7.51	573.2	419.0	NA		$^{13}C_4$-PFOS
D_5-NEtFOSAA	7.65	589.2	419.0	NA		$^{13}C_4$-PFOS
D_7-NMeFOSE	9.56	623.2	58.9	NA		$^{13}C_4$-PFOS
D_9-NEtFOSE	9.83	639.2	58.9	NA		$^{13}C_4$-PFOS
$^{13}C_3$-HFPO-DA	4.97	286.9	168.9	184.9		$^{13}C_2$-PFHxA
NIS Compounds						
$^{13}C_3$-PFBA	1.95	216.0	172.0	NA		NA
$^{13}C_2$-PFHxA	4.80	315.1	270.0	119.4		
$^{13}C_4$-PFOA	6.16	417.1	172.0	NA		
$^{13}C_5$-PFNA	6.99	468.0	423.0	NA		
$^{13}C_2$-PFDA	7.47	515.1	470.1	NA		
$^{18}O_2$-PFHxS	6.30	403.0	83.9	NA		
$^{13}C_4$-PFOS	7.59	502.8	79.9	98.9		

[1] Times shown are in decimal minute units. Example retention times are based on the instrument operating conditions and column specified in Section 10.2.

[2] Many of the EIS and NIS compounds do not produce useful confirmation ions under the instrumental operating parameters. Therefore, monitoring the confirmation ions for the EIS and NIS compounds is optional.

[3] For improved accuracy, PFTrDA is quantitated using the average areas of the labeled compounds $^{13}C_2$-PFTeDA and $^{13}C_2$-PFDoA. However, data systems from some LC/MS/MS vendors may not be able to utilize this approach at this time. In such cases, the laboratory should select the EIS with the stronger response to quantitate PFTrDA and use that EIS for all analyses.

NA = These analytes do not produce a confirmation ion mass or do not have a quantitation reference compound.

Table 11. Summary of Quality Control

Method Reference	Requirement	Specification and Frequency
Section 10.1	Mass Calibration	Annually and on as-needed basis
Section 10.1.7	Mass Calibration Verification	After mass calibration
Section 10.3	Initial Calibration (ICAL)	Minimum 6 calibration standards for linear model and 7 calibration standards for non-linear models.
Sections 10.2.2, 14.4	Retention Time (RT) window	After ICAL and at the beginning of analytical sequence
Sections 7.3.1, 9.4	Extracted Internal Standard (EIS) Analytes	All CAL standards, batch QC and field samples
Sections 7.3.2	Non-extracted Internal Standards (NIS)	All CAL standards, batch QC and field samples
Sections 7.3.4, 10.3.1, 13.3	Instrument Sensitivity Check (ISC)	At the beginning of each analytical sequence
Section 7.5, 10.3.5, 14.2	Bile Salt Interference Check	After an initial calibration and during each analytical sequence
Section 14.3	Calibration Verification (CV)	At the beginning of the analytical sequence (except for sample analyzed immediately after an initial calibration) and every 10 field sample injections
Section 14.5	Ongoing Precision Recovery (OPR)	One per preparation batch
Section 14.6	Instrument Blank	At the beginning of each analytical sequence, and after high standards and high concentration samples
Sections 9.1.3, 9.5, 14.7	Method Blank	One per preparation batch
Section 7.3.5, 14.8	Qualitative Identification Standards	At the beginning of each analytical sequence
Section 14.3.5, 15.1.3	Ion abundance ratio (IAR) check	Each analyte to be reported as detected from a field or QC sample
Section 11.0	Limit of Quantitation Verification (LLOPR)	One per preparation batch
Section 11.0	Matrix Spike (MS/MSD)	One per preparation batch (if required)

21.0 Glossary

These definitions and purposes are specific to this method but have been conformed to common usage to the extent possible.

21.1 Units of weight and measure and their abbreviations

21.1.1 Symbols

ºC	degrees Celsius
Da	Dalton (equivalent to "amu" below)
µg	microgram
µL	microliter
µm	micrometer
<	less than
≤	less than or equal
>	greater than
≥	greater than or equal
%	percent
±	plus or minus

21.1.2 Alphabetical abbreviations

amu	atomic mass unit (equivalent to Dalton)
cm	centimeter
g	gram
h	hour
L	liter
M	molar
mg	milligram
min	minute
mL	milliliter
mm	millimeter
cm	centimeter
m/z	mass-to-charge ratio
ng	nanogram
Q1	quantitation ion
Q2	confirmation ion
rpm	revolutions per minute
v/v	percent volume per volume

21.2 Definitions and acronyms (in alphabetical order)

Analyte – A PFAS compound included in this method. The analytes are listed in Table 1.

Calibration standard (CS) – A solution prepared from a secondary standard and/or stock solutions and used to calibrate the response of the LC-MS/MS instrument.

Calibration verification standard (CV) – The mid-point calibration standard (CS-4) that is used to verify calibration. See Table 4.

CFR – Code of Federal Regulations

Compound – One of many variants or configurations of a common chemical structure. Individual compounds are identified by the number of carbon atoms and functional group attached at the end of the chain.

Confirmation Ion – For the purpose of this method, the confirmation ion is produced by collisionally activated dissociation of a precursor ion to produce distinctive ions of smaller *m/z* than the precursor. It is used to confirm the identity of the analyte.

Class A glassware – Volumetric glassware that provides the highest accuracy. Class A volumetric glassware complies with the Class A tolerances defined in ASTM E694, must be permanently labeled as Class A, and is supplied with a serialized certificate of precision.

CWA – Clean Water Act

Extracted internal standard (EIS) – An isotopically labeled analog of a target analyte that is structurally identical to a native (unlabeled) analyte. The EIS compounds are added to the sample at the beginning of the sample preparation process and are used to quantify the native target analytes.

Extracted internal standard (EIS) quantification – The process of determining the concentration of the native target analyte by its comparing response to the response of a structurally related isotopically labeled analog that was added to the sample at the beginning of the sample preparation process.

LC – Liquid chromatograph or liquid chromatography

Instrument sensitivity check – solution used to check the sensitivity of the instrument. The solution contains the native compounds at the concentration of the LOQ.

Internal standard – A labeled compound used as a reference for quantitation of other labeled compounds and for quantitation of native PFAS compounds other than the compound of which it is a labeled analog. See Internal standard quantitation.

Internal standard quantitation – A means of determining the concentration of (1) a native compound by reference to a compound other than its labeled analog and (2) a labeled compound by reference to another labeled compound.

IPR – Initial precision and recovery; four aliquots of a reference matrix spiked with the analytes of interest and labeled compounds and analyzed to establish the ability of the laboratory to generate acceptable precision and recovery. An IPR is performed prior to the first time this method is used and any time the method or instrumentation is modified.

Isotope dilution (ID) quantitation – A means of determining a native compound by reference to the same compound in which one or more atoms has been isotopically enriched. The labeled PFAS are spiked into each sample and allow identification and correction of the concentration of the native compounds in the analytical process.

Isotopically labeled compound – An analog of a target analyte in the method which has been synthesized with one or more atoms in the structure replaced by a stable (non-radioactive) isotope of that atom. Common stable isotopes used are ^{13}C (Carbon-13) or Deuterium (D or ^{2}H). These labeled compounds do not occur in nature, so they can be used for isotope dilution quantification

or other method-specific purposes. These compounds are used as both extracted internal standards and non-extracted internal standards in this method.

Limit of Quantitation (LOQ) – The smallest concentration that produces a quantitative result with known and recorded precision and bias. The LOQ shall be set at or above the concentration of the lowest initial calibration standard (the lowest calibration standard must fall within the linear range).

Low-level OPR (LLOPR) – A version of the ongoing precision and recovery standard that is spiked at twice the concentration of the laboratory's LOQ and used as a routine check of instrument sensitivity.

Method blank – An aliquot of reagent water that is treated exactly as a sample including exposure to all glassware, equipment, solvents, reagents, internal standards, and labeled compounds that are used with samples. The method blank is used to determine if analytes or interferences are present in the laboratory environment, the reagents, or the apparatus.

Method Detection Limit (MDL) – The minimum measured concentration of a substance that can be reported with 99% confidence that the measured analyte concentration is distinguishable from method blank results (40 CFR 136, Appendix B).

MESA – Mining Enforcement and Safety Administration

Minimum level of quantitation (ML) – The lowest level at which the entire analytical system must give a recognizable signal and acceptable calibration point for the analyte. The ML represents the lowest concentration at which an analyte can be measured with a known level of confidence. It may be equivalent to the concentration of the lowest calibration standard, assuming that all method-specified sample weights, volumes, and cleanup procedures have been employed. Alternatively, the ML may be established by multiplying the MDL (pooled or unpooled, as appropriate) by 3.18 and rounding the result to the number nearest to 1, 2, or 5 x 10^n, where n is zero or an integer (see 68 FR 11770).

MS – Mass spectrometer or mass spectrometry

Matrix Spike/Matrix Spike Duplicate (MS/MSD) – Aliquots of field samples that have been fortified with a known concentration of target compounds, prior to sample preparation and extraction, and analyzed to measure the effect of matrix interferences. The use of MS/MSD samples is generally not required in isotope dilution methods because the labeled compounds added to every sample provide more performance data than spiking a single sample in each preparation batch.

Multiple reaction monitoring (MRM) – Also known as selected reaction monitoring (SRM). A type of mass spectrometry where a parent mass of the compound is fragmented through MS/MS and then specifically monitored for a single fragment ion.

Must – This action, activity, or procedural step is required.

NIOSH – The National Institute of Occupational Safety and Health

Non-extracted internal standard (NIS) –Labeled PFAS compounds spiked into the concentrated extract immediately prior to injection of an aliquot of the extract into the LC-MS/MS.

OPR – Ongoing precision and recovery standard (OPR); a method blank spiked with known quantities of analytes. The OPR is analyzed exactly like a sample. Its purpose is to assure that the results produced by the laboratory remain within the limits specified in this method for precision and recovery.

PFAS – Per- and Polyfluoroalkyl substances –A group of man-made fluorinated compounds, many of which are hydrophobic and lipophobic, manufactured and used in a variety of industries globally. These compounds are persistent in the environment as well as in the human body. This method analyzes for the PFAS listed in Table 1.

Precursor Ion – For the purpose of this method, the precursor ion is the deprotonated molecule ([M-H]-) of the method analyte. In MS/MS, the precursor ion is mass selected and fragmented by collisionally activated dissociation to produce distinctive product ions of smaller *m/z*. Also called a parent ion.

Product Ion – For the purpose of this method, a product ion is a charged fragment ion that is formed as the product of collisionally activated dissociation of a particular precursor ion. Also called a transition or transition ion.

Quantification Ion – For the purpose of this method, the quantification ion is produced by collisionally activated dissociation of a precursor ion to produce distinctive ions of smaller m/z than the precursor. It is used to quantify (determine the concentration) of the analyte. It is usually, but not always, the most intense of the ions produced by the dissociation of the precursor ion.

Reagent water – Water demonstrated to be free from the analytes of interest and potentially interfering substances at the method detection limit for the analyte.

Relative centrifugal force (RCF) – Refers to the force applied to a material that is centrifuged. It is a function of the speed of rotation of the centrifuge (i.e., revolutions per minute or rpm) and the radius of the centrifuge head. It can be calculated from an rpm setting using the formula:

$$RCF = rpm^2 \times 1.118\,x\,10^{-5} \times radius$$

Relative standard deviation (RSD) – The standard deviation multiplied by 100 and divided by the mean. Also termed "coefficient of variation."

Relative Standard Error (RSE) – The standard error of the mean divided by the mean and multiplied by 100.

RF – Response factor. See Section 10.3.3.2.

RR – Relative response. See Section 10.3.3.2.

RT – Retention time**;** the time it takes for an analyte or labeled compound to elute off the HPLC/UPLC column

Should – This action, activity, or procedural step is suggested but not required.

Signal-to-noise ratio (S/N) – The height of the signal as measured from the mean (average) of the noise to the peak maximum divided by the mean height of the noise.

SPE – Solid-phase extraction; a technique in which an analyte is extracted from an aqueous solution, or a solid/tissue extract by passage over or through a material capable of reversibly adsorbing the analyte. Also termed liquid-solid extraction.

Stock solution – A solution containing an analyte that is prepared using a reference material traceable to EPA, NIST, or a source that will attest to the purity and authenticity of the reference material.

Appendix A - Sample Pre-screening Instructions

Samples that are known or suspected to contain high levels of analytes may be pre-screened using the following procedure. These are example procedures using smaller sample aliquots spiked with EIS and NIS and no clean up procedures. Other pre-screening procedures may be used. The results of the pre-screening should be used by the analyst to assess the need for sample or extract dilutions necessary to keep the target analytes within the calibration range of the instrument. The results may also be used to reduce the risk of prevent gross contamination of the instrument when dealing with unfamiliar sources of samples.

Aqueous Samples

1. Weight out 10 (±0.1) g of sample into a 50-mL centrifuge tube.
2. Add 50 µL of EIS and NIS to the sample and vortex to mix.
3. Filter 1 mL of the sample through 0.2-µm membrane filter into a microvial. Sample is ready for instrumental analysis.

Solid and Tissue Samples

1. Weigh 1.0 (±0.1) g sample into 50-mL polypropylene centrifuge tubes.
2. Add 20 mL of 0.3% methanolic ammonium hydroxide (Section 7.1.7.1). Vortex and mix on a shaker table (or equivalent) for 10 min. Allow to settle and/or centrifuge to produce a clear extract.
3. Filter using a SINGLE StEP® filter vial:
   a. Add 20 µL of EIS to a clean SINGLE StEP® filter vial (chamber).
   b. Add 400 µL of clear extract from step 2 (e.g., by adding extract until it reaches the fill line), carefully vortex to mix.
   c. Use filter/plunger part and filter.
4. Transfer 30 µL of filtrate to a ~300-µL polypropylene micro-vial and dilute to 300 µL with 0.3% methanolic ammonium hydroxide (Section 7.1.7.1). Add NIS to the filtrate.
5. The extract is now a 10x dilution.
6. Sample is ready for instrumental analysis.

Calculate results using the equivalent sample weight computed as follows:

$$Equivalent\ Weight = Sample\ weight\ (g) \times \frac{0.4\ mL}{20\ mL}$$

Note that the EIS concentration in the diluted portion is 0.5x the level in the regular analysis of solid samples.

Appendix B - Aqueous Sample Subsampling Instructions

Warning: Because some target analytes may be stratified within the sample (e.g., AFFF-contaminated media, surfactants), or adhere to the walls of the sample container, subsampling may only be done on a project-specific basis. Subsampling has been shown to increase uncertainty in PFAS analysis, especially on foaming samples.

If a reduced sample size is required, transfer a weighed subsample using the following subsampling procedure to a 60-mL HDPE bottle and dilute to approximately 60 mL using reagent water. This container is now considered the "sample bottle."

1. Gently invert sample 3-4 times being careful to avoid foam formation and subsample immediately (do not let stand).

2. If foam forms and more than 5 mL is required – pour sample, avoiding any foam.

3. If foaming forms and a volume less than 5 mL is required – pipette from ½ cm below the foam.

4. If no foam forms – pour or pipette based on volume required.