APPLICATION NOTE

Liquid Chromatography/Mass Spectrometry

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Improved Throughput for the Analysis of Perfluoroalkyl and Polyfluoroalkyl Substances in Drinking Water by EPA Method 533

Introduction

Per- and polyfluoroalkyl substances (PFAS) are a group of man-made chemicals that have been used in a wide variety of industries around the world since the 1940s.[1,2] This includes equipment used to package and process foodstuffs, commercial household products like nonstick cookware and cleaning products, and industrial goods such as automotive lubricants and electronics, among numerous of other applications.[3-6] Perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS) are the two most extensively produced and studied of these chemicals. Originally considered biologically inactive, more in-depth research has revealed their toxicity to humans and wildlife alike. Furthermore, many of these chemicals are incredibly stable in the environment and the human body, meaning they are resistant to breaking down and can accumulate over time.[7,8]

Growing health concerns regarding PFAS and their prevalence in consumer goods and the environment indicates a critical need to perform existing and upcoming regulatory methods efficiently and reliably on commercially available instrumentation. The United States Environmental Protection Agency (EPA) continues to update their Method 537.1 for analysis of PFAS in drinking water;[9] however, EPA Method 533,[10] a more inclusive method aimed at monitoring multiple short-chain PFAS that are difficult to measure by Method 537.1 is becoming more prevalent. EPA Method 533 is utilized for the determination of selected PFAS in drinking water by isotope dilution anion exchange solid phase extraction (SPE) and liquid chromatography/mass spectrometry (LC/MS/MS). Other published methods, including provisional EPA Methods 8327 and 1633, may be utilized for analysis of PFAS in more diverse matrices and sample types. This application note will focus on the validation of EPA Method 533, as well as the development of an improved version of this methodology using the PerkinElmer QSight LX50 Ultra High-Performance Liquid Chromatography (UHPLC) System coupled with the PerkinElmer QSight 210 Triple Quadrupole Mass Spectrometer. The results demonstrate that all the PFAS analytes listed in EPA Method 533 can be determined reliably by the QSight 210 LC/MS/MS system, with good recovery and precision at low limits of quantification (LLOQs).

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Experimental

Materials and Reagents

The mixed primary PFAS standards, isotope performance standards, and isotope dilution standards were obtained from Wellington Laboratories, listed in Table 1. The LC/MS grade methanol (MeOH) and LC/MS grade water (reagent water) were purchased from VWR. Ammonium acetate solution, ammonium acetate crystals, sodium phosphate monobasic, and sodium phosphate dibasic were purchased from Sigma Aldrich. Ammonium Hydroxide was purchased from Fisher Scientific.

The PerkinElmer SPE manifold system used for the extraction of all water samples was modified to allow for the extraction of large volume samples with the addition of linear low-density polyethylene tubing (LLDPE) obtained from Freelin-Wade, and SPE tube adaptors obtained from Sigma Aldrich. Strata X-AW 33 µm Weak Anion Exchange SPE cartridges (0.5 g, 6-mL) were obtained from Phenomenex. The 250-mL high density polyethylene (HDPE) bottles used for preparation and extraction of all blanks, spiked blanks, field samples and QC samples were obtained from Sigma Aldrich. The nitrogen evaporation system with heated water bath used for the concentration of final extracts was obtained from Organomation Associates, Inc.

PerkinElmer low volume, 300-µL polyethylene (PE) vials were used in the HPLC autosampler, and the polyethylene vial caps were obtained from Sigma Aldrich. Polyethylene vials and caps are required to prevent adsorption of PFAS compounds on glass vials and to eliminate PFAS materials commonly used in HPLC vial septa.

Hardware/Software

A PerkinElmer QSight 210 Triple Quadrupole LC/MS/MS was used for the chromatographic separation of the analytes, with subsequent detection achieved with electrospray ionization (ESI). The LX50 Autosampler was modified by replacing all polytetrafluoroethylene (PTFE) based tubing with polyether ether ketone (PEEK) tubing to reduce or eliminate any contamination from PFAS compounds introduced by the PTFE tubing. In addition, a PEEK needle was installed in the autosampler. All instrument control, data acquisition, and data processing were performed using PerkinElmer Simplicity™ 3Q Software.

Table 1: Target analytes, isotope performance and dilution standards, and acronyms of PFAS compounds.

Native Analytes	Acronym
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid	11Cl-PF3OUdS
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid	9Cl-PF3ONS
4,8-Dioxa-3*H*-perfluorononanoic acid	ADONA
Hexafluoropropylene oxide dimer acid	HFPO-DA
Nonafluoro-3,6-dioxaheptanoic acid	NFDHA
Perfluorobutanoic acid	PFBA
Perfluorobutanesulfonic acid	PFBS
1*H*,1*H*, 2*H*, 2*H*-Perfluorodecane sulfonic acid	8:2FTS
Perfluorodecanoic acid	PFDA
Perfluorododecanoic acid	PFDoA
Perfluoro(2-ethoxyethane)sulfonic acid	PFEESA
Perfluoroheptanesulfonic acid	PFHpS
Perfluoroheptanoic acid	PFHpA
1*H*,1*H*, 2*H*, 2*H*-Perfluorohexane sulfonic acid	4:2FTS
Perfluorohexanesulfonic acid	PFHxS
Perfluorohexanoic acid	PFHxA
Perfluoro-3-methoxypropanoic acid	PFMPA
Perfluoro-4-methoxybutanoic acid	PFMBA
Perfluorononanoic acid	PFNA
1*H*,1*H*, 2*H*, 2*H*-Perfluorooctane sulfonic acid	6:2FTS
Perfluorooctanesulfonic acid	PFOS
Perfluorooctanoic acid	PFOA
Perfluoropentanoic acid	PFPeA
Perfluoropentanesulfonic acid	PFPeS
Perfluoroundecanoic acid	PFUnA
Isotope Performance Standards	**Acronym**
Perfluoro-*n*-[2,3,4-$^{13}C_3$]butanoic acid	$^{13}C_3$-PFBA
Perfluoro-[1,2-$^{13}C_2$]octanoic acid	$^{13}C_2$-PFOA
Sodium perfluoro-1-[1,2,3,4-$^{13}C_4$]octanesulfonate	$^{13}C_4$-PFOS
Isotope Performance Standards	**Acronym**
Perfluoro-*n*-[1,2,3,4-$^{13}C_4$]butanoic acid	$^{13}C_4$-PFBA
Perfluoro-*n*-[1,2,3,4,5-$^{13}C_5$]pentanoic acid	$^{13}C_5$-PFPeA
Sodium perfluoro-1-[2,3,4-$^{13}C_3$]butanesulfonate	$^{13}C_3$-PFBS
Sodium 1*H*,1*H*,2*H*,2H-perfluoro-1-[1,2-$^{13}C_2$] hexane sulfonate	$^{13}C_2$-4:2FTS
Perfluoro-*n*-[1,2,3,4,6-$^{13}C_5$]hexanoic acid	$^{13}C_5$-PFHxA
2,3,3,3-Tetrafluoro-2-(1,1,2,2,3,3,3-heptafluoropropoxy-$^{13}C_3$-propanoic acid	$^{13}C_3$-HFPO-DA
Perfluoro-*n*-[1,2,3,4-$^{13}C_4$]heptanoic acid	$^{13}C_4$-PFHpA
Sodium perfluoro-1-[1,2,3-$^{13}C_3$]hexanesulfonate	$^{13}C_3$-PFHxS
Sodium 1*H*,1*H*,2*H*,2*H*-perfluoro-1-[1,2-$^{13}C_2$]-octane sulfonate	$^{13}C_2$-6:2FTS
Perfluoro-*n*-[$^{13}C_8$]octanoic acid	$^{13}C_8$-PFOA
Perfluoro-*n*-[$^{13}C_9$]nonanoic acid	$^{13}C_9$-PFNA
Sodium perfluoro-[$^{13}C_8$]octanesulfonate	$^{13}C_8$-PFOS
Sodium 1*H*,1*H*,2*H*,2*H*-perfluoro-1-[1,2-$^{13}C_2$]-decane sulfonate	$^{13}C_2$-8:2FTS
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

Method

LC Conditions and MS Parameters

The LC method and MS source parameters are shown in Table 2. A pair of C18 columns were used in this method. A delay column (Brownlee SPP C18 Column, 50 x 3.0mm, 2.7 µm) was installed in-line between the LX50 pump and the autosampler to trap and delay possible interferent PFAS arising from the LC pump and solvent reservoirs. The analytical column (Brownlee SPP C18 Column, 75 x 4.6 mm, 2.7 µm) was used to separate the PFAS and any other interfering components. A guard column (Brownlee SPP C18 Column, 5mm x 4.6mm, 2.7 µm) was also utilized. The LC gradient program was modified from the program recommended in EPA Method 533, as allowed in the method, to speed up the chromatographic analysis, as shown in Table 3.

For maximum sensitivity, the MS source parameters, which include the gas flows, temperature, and position settings, were optimized. The compound dependent parameters such as collision energy (CE), entrance voltage (EV), and the collision cell lens voltage (CCL2), were optimized for the target compounds as shown in Table 4.

Table 2: LC Method and MS Source Conditions.

LC Conditions	
Analytical Column	Brownlee SPP C18 Column, 75 x 4.6 mm, 2.7 µm (PN: N9308415)
Guard Column	Brownlee SPP C18 Column, 5 mm x 4.6 mm, 2.7 µm (PN: N9308532)
Delay Column	Brownlee SPP C18 Column, 50 x 3.0 mm, 2.7 µm (PN: N9308408)
Mobile Phase A	10 mM ammonium acetate in water
Mobile Phase B	Methanol
Flow Rate	0.8 mL/min
Column Oven Temperature (°C)	40
Auto Sampler Temperature (°C)	15
Injection Volume	10
Needle Wash 1	25% acetonitrile in methanol
Needle Wash 2	50% water in methanol
MS Source Conditions	
Electrospray Voltage	-3500
Drying Gas	110
Nebulizer Gas	400
Source Temperature (°C)	350
HSID Temperature (°C)	280
Detection Mode	Time Managed MRM

Table 3: LC Gradient Program.

Step #	Time (min)	Mobile Phase A (%)	Mobile Phase B (%)
1	0.00	95	5
2	0.70	95	5
3	1.00	55	45
4	7.00	2	98
5	8.00	2	98
6	8.10	95	5
7	10.00	95	5

Calibration Standards Preparation

The analyte mixture purchased from Wellington was used as received for the primary dilution standard (PDS), as per section 7.17.4 of EPA Method 533. The PDS was diluted in 80% MeOH and 20% reagent water to prepare eight calibration standards, as per Section 7.17.5 of EPA Method 533. Isotope Performance Standards (IPS) and Isotope Dilution Standards (IDS) were added at a constant volume to each calibration standard. Analyte concentrations in the calibration standards ranged from ~5 to 25,000 ng/L. Calibration standards were transferred to low volume polyethylene vials and caps for UHPLC analysis. The broad range calibration standards were used to determine method linearity and instrument limits of detection (LOD), but a reduced range and number of calibrants at a higher minimum level can be utilized in general practice. The EPA method only requires a minimum of five calibration levels.

Laboratory Reagent Blank and Laboratory Fortified Blank Preparation

All laboratory reagent blanks (LRB) and laboratory fortified blanks (LFB) were prepared in 250 mL polyethylene bottles by placing ~0.25 g of ammonium acetate crystals into each bottle and adding 250 mL of reagent water. A constant volume of IDS was added to all LRBs and LFBs to monitor extraction efficiency based on recoveries. The PDS was also used as the analyte fortification solution by spiking into LFBs at varying amounts to evaluate and validate analyte recoveries, as well as determine the method detection limits (DL), minimum reporting levels (MRL) and lowest concentration minimum reporting levels (LCMRL). All LRBs and LFBs were extracted and concentrated by the SPE sample preparation method, as defined and required in section 11.4 of EPA Method 533. Final extracts were spiked with a constant amount of IPS prior to transferring an aliquot to vials with caps for analysis by LC/MS. LRBs were analyzed daily on the LC/MS system to ensure the adequate reduction or absence of PFAS interferences. LRBs were considered acceptable if the analyte concentrations were less than 1/3 the proposed MRL, in accordance with section 9.2.1 of EPA Method 533.

Table 4: Optimized MRM Parameters for the PFAS analytes, and isotope performance and dilution standards.

Acronym	Precursor Ion	Product Ion	RT (min)	CE[a]	EV[b]	CCL2[c]	Quantifier/ Qualifier	Type
$^{13}C_3$-PFBA	216	172	2.81	14	-4	40	Quantifier	IPS
$^{13}C_4$-PFBA	217	172	2.81	14	-4	40	Quantifier	IDS
PFBA	213	169	2.82	13	-9	36	Quantifier	Analyte
PFMPA	229	85	3.05	30	-10	70	Quantifier	Analyte
$^{13}C_5$-PFPeA	268	223	3.48	12	-12	45	Quantifier	IDS
PFPeA	263	219	3.48	15	-8	80	Quantifier	Analyte
$^{13}C_3$PFBS-1	302	80	3.57	67	-28	80	Quantifier	IDS
$^{13}C_3$PFBS-2	302	99	3.57	41	-28	80	Qualifier	IDS
PFBS-1	299	80	3.70	65	-40	240	Quantifier	Analyte
PFBS-2	299	99	3.86	40	-40	240	Qualifier	Analyte
PFMBA	279	85	4.07	30	-10	55	Quantifier	Analyte
PFEESA	315	135	4.12	30	-30	75	Quantifier	Analyte
NFDHA	201	85	4.12	30	-10	30	Quantifier	Analyte
$^{13}C_2$-4:2FTS-1	329	81	4.18	53	-36	60	Quantifier	IDS
$^{13}C_2$-4:2FTS-2	329	309	4.18	29	-36	60	Qualifier	IDS
4:2FTS-1	327	81	4.23	38	-4	65	Quantifier	Analyte
4:2FTS-2	327	307	4.37	25	-2	65	Qualifier	Analyte
$^{13}C_5$-PFHxA	318	273	4.37	12	-4	52	Quantifier	IDS
PFHxA-1	313	269	4.80	17	-10	55	Quantifier	Analyte
PFHxA-2	313	119	4.80	31	-10	50	Qualifier	IDS
PFPeS-1	349	80	4.81	73	-6	100	Quantifier	Analyte
PFPeS-2	349	99	4.81	45	-6	90	Qualifier	Analyte
$^{13}C_3$-HFPO-DA-1	287	169	4.87	12	-3	44	Quantifier	IDS
$^{13}C_3$-HFPO-DA-2	287	185	5.32	15	-3	52	Qualifier	IDS
HFPO-DA-1	285	169	5.32	14	-4	40	Quantifier	Analyte
HFPO-DA-2	285	185	5.32	29	-4	53	Qualifier	Analyte
$^{13}C_4$-PFHpA	367	322	5.33	17	-6	75	Quantifier	IDS
PFHpA-1	363	319	5.33	16	-10	56	Quantifier	Analyte
PFHpA-2	363	169	5.33	21	-10	65	Qualifier	Analyte
$^{13}C_3$-PFHxS-1	402	80	5.77	84	-8	100	Quantifier	IDS
$^{13}C_3$-PFHxS-2	402	99	5.77	47	-8	100	Qualifier	IDS
PFHxS-1	399	80	5.77	85	-45	120	Quantifier	Analyte
PFHxS-2	399	99	5.79	49	-45	87	Qualifier	Analyte
ADONA-1	377	251	5.79	17	-10	62	Quantifier	Analyte
ADONA-2	377	85	5.98	64	-10	88	Qualifier	Analyte
$^{13}C_2$-6:2FTS-1	429	409	6.18	33	-16	124	Quantifier	IDS
$^{13}C_2$-6:2FTS-2	429	81	6.18	43	-16	124	Qualifier	IDS
6:2FTS-1	427	81	6.18	65	-8	80	Quantifier	Analyte
6:2FTS-2	427	407	6.18	65	-8	30	Qualifier	Analyte
$^{13}C_2$-PFOA	415	370	6.51	15	-5	76	Quantifier	IPS
$^{13}C_8$-PFOA	421	376	6.51	16	-4	84	Quantifier	IDS

Table 4: Optimized MRM Parameters for the PFAS analytes, and isotope performance and dilution standards continued...

Acronym	Precursor Ion	Product Ion	RT (min)	CE[a]	EV[b]	CCL2[c]	Quantifier/ Qualifier	Type
PFOS-1	499	80	5.97	100	-50	170	Quantifier	Analyte
PFOS-2	499	99	5.97	55	-50	170	Qualifier	Analyte
PFHpS-1	449	80	6.63	86	-18	90	Quantifier	Analyte
PFHpS-2	449	99	6.79	52	0	80	Qualifier	Analyte
PFNA-1	463	419	6.79	20	-10	75	Quantifier	Analyte
PFNA-2	463	219	2.81	29	-10	90	Qualifier	Analyte
$^{13}C_4$-PFOS	503	80	2.81	105	-45	125	Quantifier	IPS
$^{13}C_8$-PFOS-1	507	80	2.82	107	-22	140	Quantifier	IDS
$^{13}C_8$-PFOS-2	507	99	3.05	60	-22	140	Qualifier	IDS
PFOS-1	499	80	3.48	100	-50	170	Quantifier	Analyte
PFOS-2	499	99	3.48	55	-50	170	Qualifier	Analyte
9Cl-PFONS-1	533	351	3.57	35	-30	110	Quantifier	Analyte
9Cl-PFONS-2	533	83	3.57	35	-30	98	Qualifier	Analyte
$^{13}C_2$-8:2FTS-1	529	81	3.70	76	-40	115	Quantifier	IDS
$^{13}C_2$-8:2FTS-2	529	509	3.86	35	-40	115	Qualifier	IDS
8:2FTS-1	527	81	4.07	70	-30	100	Quantifier	Analyte
8:2FTS-2	527	507	4.12	25	-30	90	Qualifier	Analyte
$^{13}C_6$-PFDA	519	474	4.12	17	0	88	Quantifier	IDS
PFDA-1	513	469	4.18	21	-10	90	Quantifier	Analyte
PFDA-2	513	219	4.18	28	-10	96	Qualifier	Analyte
$^{13}C_7$-PFUnA	570	525	4.23	21	-4	87	Quantifier	IDS
PFUnA-1	563	519	4.37	19	-10	96	Quantifier	Analyte
PFUnA-2	563	270	4.37	30	-10	85	Qualifier	Analyte
11Cl-PF3OUdS-1	631	451	4.80	39	-40	170	Quantifier	Analyte
11Cl-PF3OUdS-2	631	199	4.80	32	-40	148	Qualifier	Analyte
$^{13}C_2$-PFDoA	615	570	4.81	17	-14	104	Quantifier	IDS
PFDoA-1	613	569	4.81	17	-10	104	Quantifier	Analyte
PFDoA-2	613	319	4.87	27	-10	100	Qualifier	Analyte
$^{13}C_9$PFNA	472	427	5.32	20	-10	75	Quantifier	IDS

a. CE = Collision Cell Energy
b. EV = Entrance Voltage
c. CCL2 = Collision Cell Lens 2 voltage

Field Samples, Field Reagent Blanks and Laboratory Fortified Sample Matrix

All field duplicate (FD) samples, laboratory fortified sample matrix samples (LFSM), and field reagent blanks (FRB) were collected in a 250 mL polyethylene bottle containing a ~0.25 g of ammonium acetate crystals, in accordance with section 8 of EPA Method 533. The FD and LFSM samples were collected at the source by opening the tap for 3-5 minutes and then collecting the sample from the flowing system. FRB were prepared by placing 250 mL of reagent water, plus ammonium acetate, in the sample bottle in the laboratory. The FRB was then taken to the sampling site and transferred to a clean sample bottle. The purpose of the FRB was to ensure that no contamination was introduced by the sample collection process. All FD, LFSM and FRB were stored at <10 °C until extraction. A constant amount of IDS was added to all FDs, LFSM and FRB prior to extraction. A constant amount of analyte fortification solution (i.e., PDS) was added to all LFSM prior to extraction. Final extracts were spiked with IPS prior to transferring an aliquot to vials for analysis by the LC/MS/MS system.

Solid Phase Extraction and Sample Concentration

A manual SPE vacuum manifold system was used for all extractions. The SPE system was equipped with LLDPE transfer lines, SPE tube adaptors and PTFE-free manifold valves to eliminate PFAS contamination introduced from the SPE system. Extractions were performed in strict accordance with the procedure defined in section 11.4 in EPA Method 533, as required by the method. Weak Anion Exchange SPE 6 mL tubes containing 0.5 g of sorbent were utilized. The SPE cartridges were conditioned with 10 mL of methanol followed by 10 mL of aqueous 0.1 M phosphate buffer (pH 7). Samples were introduced on the cartridges at a rate of 5 mL/min, followed by 10 mL aliquot of 1 g/L ammonium acetate used to rinse the bottles. Air was pulled through the cartridges for five minutes at high vacuum (15-20 in. Hg) to dry the cartridges. PFAS analytes were eluted from the cartridges by rinsing the bottles with two 5 mL aliquots of methanol with 2% ammonium hydroxide (v/v) and then pulled through the extraction system.

The methanol extracts were collected in 15 mL polyethylene tubes. The extracts were then evaporated to dryness under a gentle stream of nitrogen while heating in a water bath at 60 °C. Samples were reconstituted with 1 mL of 80:20% (v/v) methanol/water, and the appropriate amount of IPS was added. A small aliquot was transferred to a polyethylene vial for final LC/MS analysis.

Results and Discussion

Remediation of PFAS Background Contamination

One of the major challenges associated with trace analysis of PFAS is the contamination of blanks, samples and QC samples arising from the reagents, SPE apparatus, sample collection materials, volumetric ware, vials, the LC/MS/MS system, and the lab environment. Many of these interferences can originate from the materials that are used in construction of volumetric ware, pipettes, syringes, tubing, and vials, as well as from PTFE parts in the LC/MS/MS system. In order to eliminate or reduce these interferences from the LC/MS/MS System, a delay column was placed between the mobile phase mixer in the pump and the sample valve in the autosampler to trap and delay any PFAS compounds arising from the pump and mobile phase solvents. By doing so, the PFAS chromatographic peaks in the sample are well separated from the incoming PFAS contaminant peaks from the pump system. The standard LX50 autosampler also contains PTFE tubing both internally and to the wash solution reservoirs that contribute to PFAS contamination. This contamination was remediated by replacing all PTFE tubing in the autosampler with PEEK tubing. All the materials used in this study were tested prior to running samples to check for PFAS contamination through the injection of blank samples. Through these experiments, it was confirmed that all the supplies used were free of PFAS contamination.

LC and MS/MS Methods

The QSight MS/MS MRM parameters were optimized for each analyte, IDS, and IPS by direct infusion experiments using a syringe pump. Once precursor and product masses were determined, the entrance voltage (EV), collision cell energy (CE) and collision cell lens 2 voltage (CCL2) were optimized for each compound using the autotune feature in Simplicity 3Q. The optimized MRM parameters are shown in Table 4. MRM experiments were established for precursor/product ion transitions for each analyte, IDS, and IPS. Where possible, two mass transitions were chosen for the analytes to serve as quantifier and qualifier ions. Once the retention times for each analyte were established, a time-managed MRM MS/MS method was used with optimized time windows and dwell times so that there were at least 10 scans across each analyte peak.

The LC gradient method was optimized to provide good separation of the analytes, minimize run time, and optimize peak symmetry. A high efficiency superficially porous particle (SPP) type column was chosen to provide narrow peaks and short run times. The original chromatographic method described in EPA 533 had a 35-minute runtime, while the method presented herein reduces the injection-to-injection run time to 10 minutes. The total ion chromatogram (TIC) is shown in Figure 1. In the initial demonstration of the LC method capability, the baseline separation of the branched vs. linear isomers was established for PFHxS, PFOS, and PFOA, as shown in Figure 2.

Analyte	Peak #	RT (min)	IDS Ref #	IPS Ref #
$^{13}C_3$-PFBA (IPS #1)	1	2.81	-	-
$^{13}C_4$-PFBA (IDS #1)	1	2.81	-	1
PFBA	1	2.82	1	1
PFMPA	2	3.05	1	1
$^{13}C_5$-PFPeA (IDS #2)	3	3.48	-	1
PFPeA	3	3.48	2	1
$^{13}C_3$PFBS (IDS #3)	4	3.57	-	3
PFBS	4	3.57	3	3
PFMBA	5	3.70	2	1
PFEESA	6	3.86	3	3
NFDHA	7	4.07	5	2
$^{13}C_2$-4:2FTS (IDS #4)	8	4.12	-	3
4:2FTS	8	4.12	4	3
$^{13}C_5$-PFHxA (IDS #5)	9	4.18	-	2
PFHxA	9	4.18	5	2
PFPeS	10	4.23	8	3
$^{13}C_3$-HFPO-DA (IDS #6)	11	4.37	-	2
HFPO-DA	11	4.37	6	2
$^{13}C_4$-PFHpA (IDS #7)	12	4.80	-	2
PFHpA	12	4.80	7	2
$^{13}C_3$-PFHxS (IDS #8)	12	4.81	-	3
PFHxS	12	4.81	8	3
ADONA	13	4.87	7	2
6:2FTS	14	5.32	9	3
$^{13}C_2$-6:2FTS (IDS #9)	14	5.32	-	3
PFHpS	14	5.32	11	3
$^{13}C_2$-PFOA (IPS #2)	14	5.33	-	-
$^{13}C_8$-PFOA (IDS #10)	14	5.33	-	2
PFOA	14	5.33	10	2
$^{13}C_4$-PFOS (IPS #3)	15	5.77	-	-
$^{13}C_8$-PFOS (IDS #11)	15	5.77	-	3
PFOS	15	5.77	11	3
PFNA	15	5.79	12	2
$^{13}C_9$PFNA (IDS #12)	15	5.79	-	2
9Cl-PFONS	16	5.98	11	3
$^{13}C_2$-8:2FTS (IDS #14)	17	6.18	-	3
8:2FTS	17	6.18	14	3
$^{13}C_6$-PFDA (IDS #13)	17	6.18	-	2
PFDA	17	6.18	13	2
PFUnA	18	6.51	15	2
$^{13}C_7$-PFUnA (IDS #15)	18	6.51	-	2
11Cl-PF3OUdS	19	6.63	11	3
$^{13}C_2$-PFDoA (IDS #16)	20	6.79	-	2
PFDoA	20	6.79	16	2

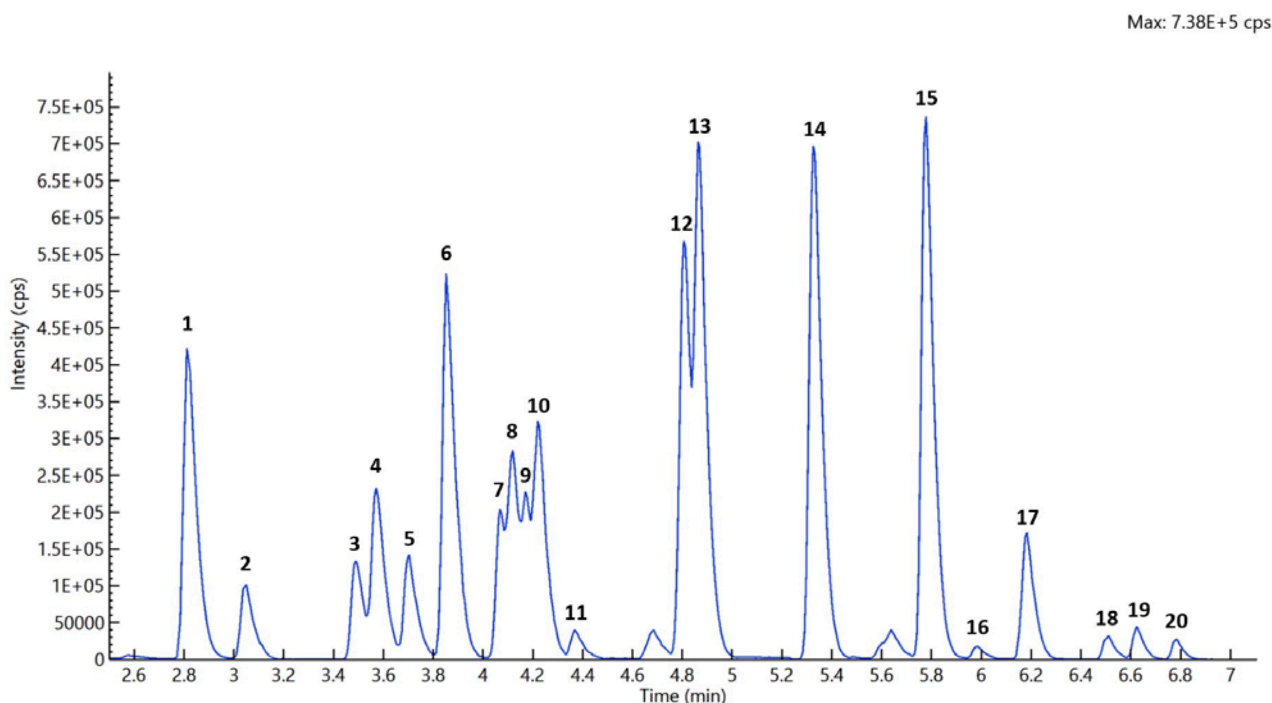

Figure 1: Total ion chromatogram of an 80 ng/L extracted LFB sample containing all method analytes and standards.

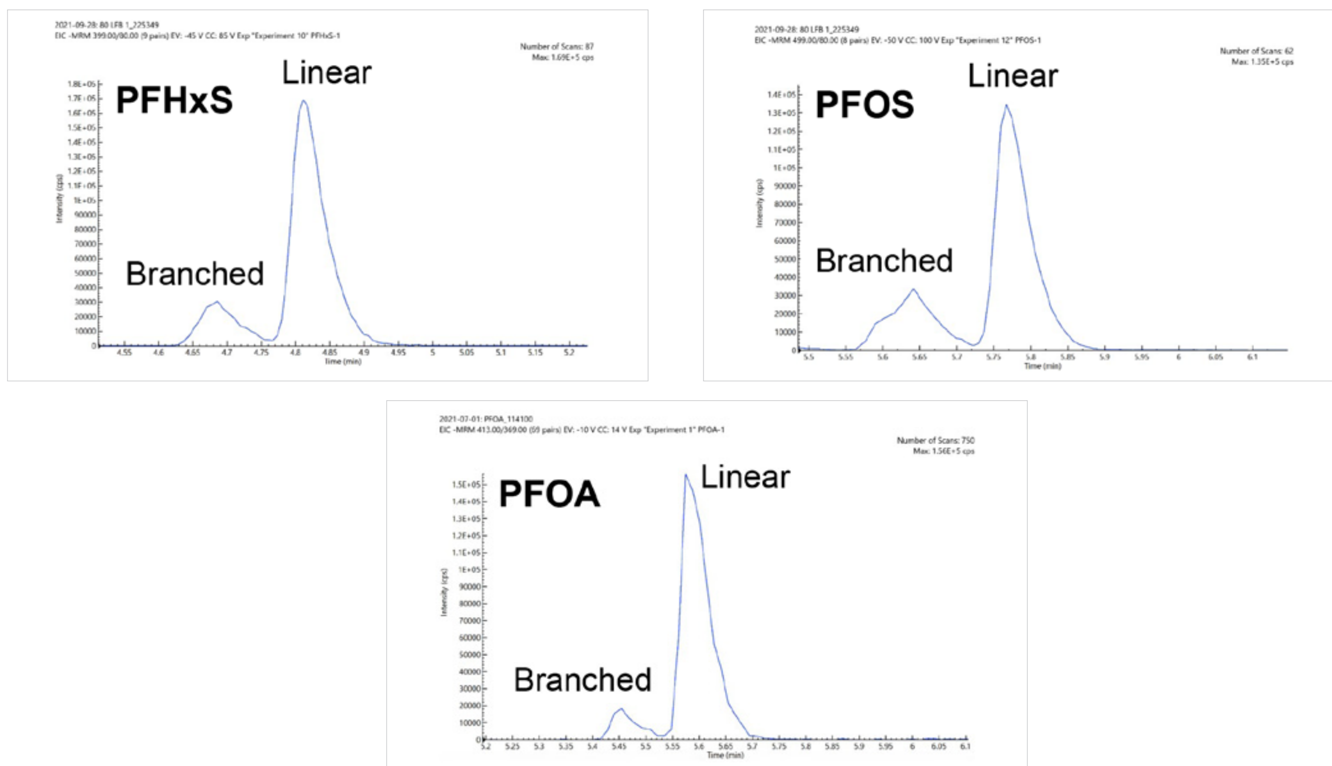

Figure 2: MRM chromatograms of PFHxS, PFOS and PFOA showing the baseline separation of linear and branched chain isomers.

Linearity, Instrument Limits of Quantitation and Instrument Limits of Detection

Calibration curves were used to assess linearity, instrument limits of detection (LOD) and limits of quantitation (LOQ) for all PFAS targets and surrogates. Eight-point calibration curves were constructed using a non-weighted linear regression with the intercept forced through zero in the concentration range of ~5 – 25,000 ng/L from three replicates at each level. Excellent linearity was achieved over the studied range of concentrations with correlation coefficient values (R^2) greater than 0.99 for all the analytes, as shown in Table 5. Figure 3 shows representative calibration curves for triplicate injections of analytes PFOA, PFOS, PFPeA and PFHxA.

The instrument LOD and LOQ for each target analyte were determined at the lowest detectable standard on the calibration curve (ng/L) extrapolated to give a signal-to-noise ratio (S/N) of 3 for LOD and an extrapolated S/N equal to 10 for the LOQ. Table 6 is a summary of the instrument and method LOD and LOQ.

Table 5: Instrument and Method Calibration Ranges and Linearity (R^2) for eight-point calibration curves of all EPA Method 533 analytes.

Compound	Instrument Calibration Range (ng/L)[a]	Method Calibration Range (ng/L)[b]	R^2 [c]
PFBA	5-25000	0.02-100	0.9906
PFMPA	20-25000	0.08-100	0.9980
PFPeA	20-25000	0.08-100	0.9953
PFBS	5-25000	0.02-100	0.9916
PFMBA	5-25000	0.02-100	0.9950
PFEESA	5-25000	0.02-100	0.9927
NFDHA	5-25000	0.02-100	0.9964
4:2FTS	80-23000	0.3-90	0.9935
PFHxA	20-25000	0.08-100	0.9953
PFPeS	5-25000	0.02-100	0.9954
HFPO-DA	390-25000	1.5-100	0.9946
PFHpA	5-25000	0.02-100	0.9927
PFHxS	5-25000	0.02-100	0.9927
ADONA	5-25000	0.02-100	0.9941
6:2FTS	80-23000	0.3-90	0.9957
PFHpS	5-25000	0.02-100	0.9936
PFOA	5-25000	0.02-100	0.9931
PFOS	5-25000	0.02-100	0.9962
PFNA	90-25000	0.3-100	0.9951
9Cl-PF3ONS	360-23000	1.5-90	0.9920
PFDA	90-25000	0.3-100	0.9963
8:2FTS	80-23000	0.3-90	0.9963
PFUnA	90-25000	0.3-100	0.9942
11Cl-PF3OUdS	10-23000	0.07-90	0.9933
PFDoA	90-25000	0.3-100	0.9939

a. Instrument calibration range is the actual concentration range of calibration standards used to determine calibration curves.

b. Method calibration range is determined by multiplying the instrument calibration range by 1/250 to account for the SPE sample preparation/concentration.

c. R^2 values are the average of triplicate calibration curves.

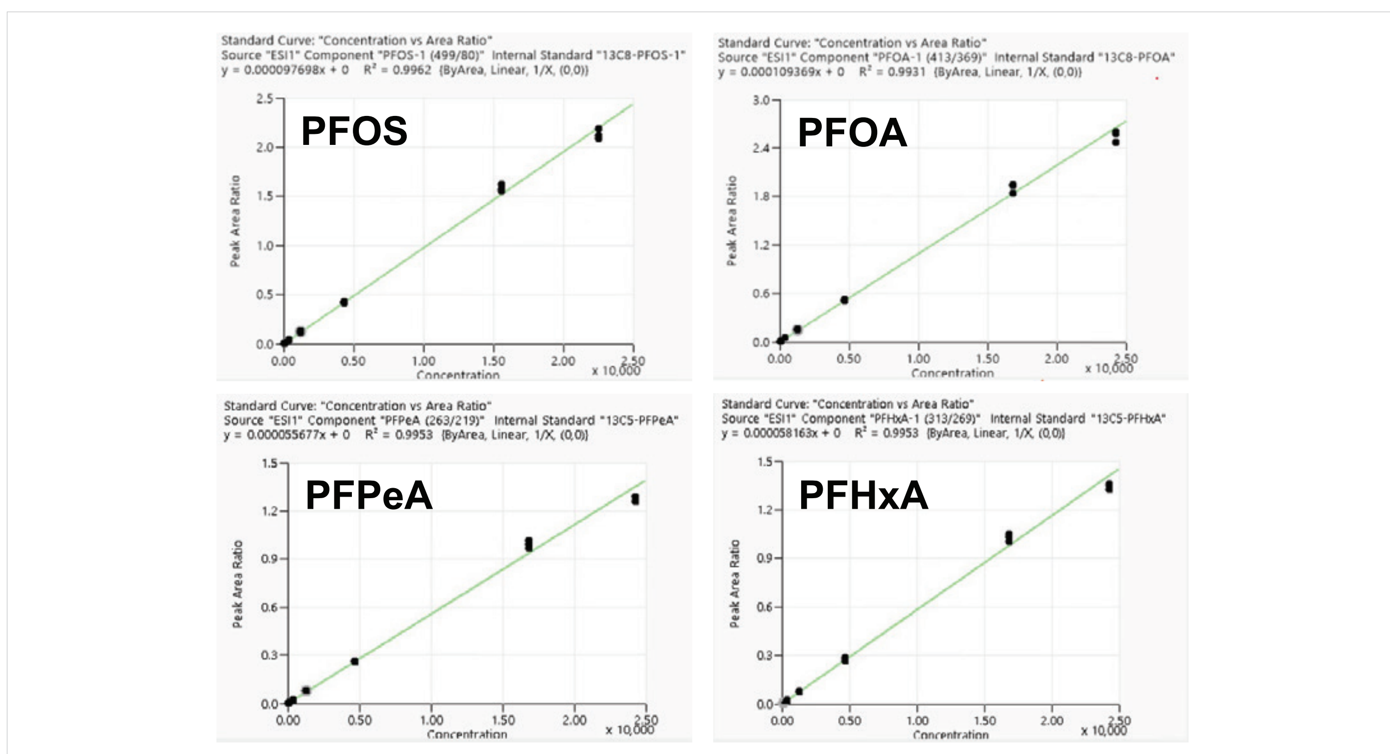

Figure 3: Triplicate injection calibration curves for representative analytes PFOS, PFOA, PFPeA, and PFHxA.

Table 6: Instrument and method limits of detection (LOD) and limits of quantitation (LOQ) for all target analytes in EPA Method 533.

Analyte	Instrument (ng/L)[a]		Method (ng/L)[b]	
	LOD	LOQ	LOD	LOQ
PFBA	1.7	5.9	0.007	0.024
PFMPA	6.2	21.0	0.025	0.084
PFPeA	4.1	14.0	0.016	0.056
PFBS	2.5	8.3	0.010	0.033
PFMBA	1.6	5.5	0.006	0.022
PFEESA	1.5	5.0	0.006	0.020
NFDHA	2.1	7.0	0.008	0.028
4:2FTS	30.0	101.0	0.120	0.404
PFHxA	40.0	130.0	0.160	0.520
PFPeS	2.0	7.8	0.008	0.031
HFPO-DA	200.0	700.0	0.800	2.800
PFHpA	3.0	9.0	0.012	0.036
PFHxS	2.0	5.8	0.008	0.023
ADONA	2.0	5.0	0.008	0.020
6:2FTS	30.0	110.0	0.120	0.440
PFHpS	2.0	5.0	0.008	0.020
PFOA	2.0	5.4	0.008	0.022
PFOS	2.0	5.6	0.008	0.022
PFNA	30.0	98.0	0.120	0.392
9Cl-PF3ONS	200.0	610.0	0.800	2.440
PFDA	30.0	97.0	0.120	0.388
8:2FTS	30.0	110.0	0.120	0.440
PFUnA	50.0	150.0	0.200	0.600
11Cl-PF3OUdS	4.0	13.0	0.016	0.052
PFDoA	50.0	150.0	0.200	0.600

a. Instrument LOD/LOQ was determined using the signal-to-noise ratio (S/N) of the peak from the lowest detectable calibration standard (5-18 ng/L) and extrapolating to the concentration at which the S/N = 3 or 10 for LOD or LOQ, respectively. This is an estimate to demonstrate expected LOD/LOQ and can vary from lab to lab.

b. Method LOD/LOQ is calculated by multiplying the Instrument LOD/LOQ by 1/250 to account for the 250 to 1 sample concentration from the SPE extraction. LOD/LOQ cannot be used as MRLs but provide an estimate of instrument sensitivity.

Table 7: PFAS analyte recovery data for LFB of reagent water spiked at 1, 10, & 80 ng/L. Seven replicate samples were extracted at each fortification level.

Analyte	~1 ng/L				~10 ng/L				~80 ng/L			
	Fortified Conc. (ng/L)	Average Recovery (ng/L)	%RSD	% Average Recovery	Fortified Conc. (ng/L)	Average Recovery (ng/L)	%RSD	% Average Recovery	Fortified Conc. (ng/L)	Average Recovery (ng/L)	%RSD	% Average Recovery
PFBA	1	1.1	8	106	10	10.7	10	107	80	89.7	8	112
PFMPA	1	1.0	9	97	10	10.7	9	102	80	89.8	8	112
PFPeA	1	1.2	6	115	10	10.6	7	106	80	89.4	8	112
PFMBA	1	1.1	9	111	10	10.8	11	107	80	89.1	7	100
NFDHA	1	1.2	8	120	10	10.7	9	107	80	87.2	8	109
PFHxA	1	1.1	8	115	10	11.1	10	111	80	91.8	9	115
HFPO-DA	1	N/A	N/A	0	10	10	7	100	80	89.1	11	111
PFHpA	1	1.2	7	115	10	10.8	11	108	80	89.9	8	112
PFOA	1	1.2	8	115	10	10.9	10	109	80	90.2	8	113
PFNA	1	1.1	9	112	10	10.8	9	108	80	89.9	8	112
PFDA	1	1.0	9	105	10	11.4	13	114	80	91.7	8	115
PFunA	1	1.0	6	102	10	11.1	12	111	80	91.6	8	115
PFDoA	1	1.0	7	105	10	10.6	10	106	80	87.8	9	110
PFBS	0.89	1.1	8	113	8.88	10.7	10	108	71.04	80.4	8	101
PFEESA	0.89	1.1	7	114	8.92	10.4	10	104	71.36	81.5	9	102
4:2FTS	0.94	1.9	11	119	9.38	10.6	9	106	75.04	85.7	8	107
PFPeS	0.94	1.1	8	115	9.4	10.8	11	108	75.2	82.5	7	103
PFHxS	0.91	1.3	5	126	9.13	10.6	11	103	73.01	71.6	9	90
ADONA	0.95	1.1	6	108	9.46	10.5	7	103	75.68	83.2	7	104
6:2FTS	0.95	1.2	7	117	9.52	10.5	8	105	76.16	85.5	8	107
PFHpS	0.95	1.1	10	110	9.54	10.2	10	102	76.32	86.6	8	108
PFOS	0.93	1.1	10	108	9.28	10.6	4	104	74.24	65.3	8	82
9Cl-PF3ONS	0.93	N/A	N/A	0	9.34	9.8	11	98	74.72	79.2	7	99
8:2FTS	0.96	1.1	7	107	9.6	11	5	104	76.8	86.7	8	108
11Cl-PF3OUdS	0.94	1.2	7	124	9.44	10.6	16	106	75.52	81.3	7	102

Table 8: PFAS isotope dilution standard recovery data for LFB of reagent water spiked at 1, 10, & 80 ng/L. Seven replicate samples were extracted at each fortification level.

Analyte	~1 ng/L				~10 ng/L				~80 ng/L			
	Fortified Conc. (ng/L)	Average Recovery (ng/L)	%RSD	% Average Recovery	Fortified Conc. (ng/L)	Average Recovery (ng/L)	%RSD	% Average Recovery	Fortified Conc. (ng/L)	Average Recovery (ng/L)	%RSD	% Average Recovery
$^{13}C_4$-PFBA	40	25.1	9	63	40	34	10	85	40	29	9	71
$^{13}C_5$-PFPeA	40	24.03	10	60	40	35	10	89	40	30	8	74
$^{13}C_5$-PFHxA	40	38.8	2	97	40	36	10	90	40	30	8	75
$^{13}C_3$-HFPO-DA	40	38.2	7	96	40	33	12	82	40	28	13	70
$^{13}C_4$-PFHpA	40	39.3	4	98	40	37	12	92	40	31	9	77
$^{13}C_8$-PFOA	40	39.7	4	99	40	38	10	96	40	33	8	81
$^{13}C_9$-PFNA	40	33.77	3	84	40	37	11	92	40	32	7	80
$^{13}C_6$-PFDA	40	42.2	5	105	40	37	11	93	40	31	9	77
$^{13}C_7$-PFUnA	40	72	6	180	40	38	13	96	40	32	11	79
$^{13}C_2$-PFDoA	40	70.6	5	177	40	34	11	85	40	30	10	74
$^{13}C_3$-PFBS	40	41.5	3	104	40	37	10	93	40	31	9	78
$^{13}C_8$-PFOS	40	40.8	4	102	40	39	10	98	40	33	8	83
$^{13}C_3$-PFHxS	40	41.7	4	104	40	39	9	97	40	33	8	82
$^{13}C_2$-8:2FTS	160	280	4	175	160	169	10	106	160	139	7	87
$^{13}C_2$-4:2FTS	160	266.8	6	167	160	192	10	120	160	150	8	94
$^{13}C_2$-6:2FTS	160	219.1	8	137	160	189	10	118	160	156	7	98

Determination of Method DL, MRL and LCMRL

The method DL were determined as described in EPA Method 537.1 since EPA Method 533 does not discuss DL determination, while MRL and LCMRL were determined as described in EPA Method 533. Seven replicate reagent water samples were fortified (LFB) with method analytes at five different concentrations, representing the proposed MRL (1 ng/L), as well as low (4 ng/L), mid (10 ng/L and 20 ng/L) and high (80 ng/L) concentrations to evaluate method recoveries. A constant volume of IDS was also added to each LFB, as described in section 9.2.3 of EPA Method 533. Each of these LFB were then carried through the full sample preparation method including SPE, evaporation, reconstitution and IPS addition. Aliquots of each LFB replicate were then transferred to polypropylene vials and analyzed on the LC/MS/MS system to determine analyte and IDS recoveries. The recoveries of all analytes at all fortification levels fell well within the required 70-130% recoveries, as shown in Table 7. At the 1 ng/L fortification level, HFPO-DA and 9Cl-PF3ONS were not detected. The recovery RSDs were below 15% for all fortification levels. For the isotope dilution standards, recoveries fell between the required 50-200% as stated in section 9.2.5 of EPA Method 533 and shown in Table 8.

The method DL, MRL and LCMRL were calculated and validated using the seven replicate LFB fortified at five levels ranging from 1 to 80 ng/L using the statistical analysis methods described in EPA Methods 533 and 537.1. Table 9 summarizes the statistical analysis and determinations of DL, MRL and LCMRL in this study.

The method detection limits are not a specific requirement of EPA Method 533 but may be required by other regulatory bodies for compliance monitoring. The DL are the minimum concentrations of analytes that can be measured, identified, and determined with a 99% confidence that the analyte concentration is greater than zero. This is a statistical determination of precision, and accurate quantitation is not expected at this level.[10] The detection limits in this study were determined from seven replicate LFB fortified at ~4 ng/L and calculated as described in section 9.8.2 of EPA 537.1.

The single laboratory LCMRL are the lowest concentration for which future recoveries are expected, with 99% confidence, to be between 50 and 150% recovery. This value is not required to be determined by EPA but provides good guidance on the expected method performance on a particular instrument in a specific laboratory. The LCMRL were determined in this study to demonstrate method and instrument performance.

To determine the LCMRL, seven replicate LFB at five fortification levels were carried through the full sample preparation method including SPE, evaporation, reconstitution and IPS addition. Aliquots of the final samples were transferred to polypropylene vials and analyzed by LC/MS/MS to determine analyte

concentrations. The concentrations were then analyzed using the LCMRL calculator[11] provided by EPA, using the statistical procedures described by Winslow, et. al., 2004.[12] The LCMRL in this study are generally consistent with or lower than those reported in EPA Method 533, demonstrating that this instrument is well suited for the analysis of PFAS compounds in drinking water using EPA Method 533.

The MRL were determined by fortifying, extracting, and analyzing ten replicate LFB at proposed MRL concentrations ranging from 1-4 ng/L. Calculations were then performed for the mean and the standard deviation to determine the half range for prediction interval of results (HRPIR). It was then confirmed that the upper and lower limits for the predicted interval for results (PIR) met the upper and lower recovery limits described in section 9.1.4 of EPA Method 533. The upper PIR recovery limit must be ≤ 150% and the lower PIR recovery limit must be ≥ 50%. The experimentally determined MRLs from this study are summarized in the last column of Table 9. These values are provided to reflect MRL values one can expect when performing EPA 533 using the QSight 210 LC/MS/MS System. The MRL demonstrated here are well below any state or federal action limits for regulated PFAS contaminants in drinking water.

Table 9: Method detection limits (DL), minimum reporting levels (MRL) and lowest concentration minimum reporting limits (LCMRL) determined experimentally on the QSight 210 LC/MS/MS system. Experimental values are compared to reference values of LCMRL reported in EPA Method 533.

Analyte	Experimental DL (ng/L)[a]	Calculated LCMRL (ng/L)[b]	EPA 533 LCMRL (ng/L)[c]	Experimental MRL (ng/L)[d]
PFBA	1.5	2.1	13	1
PFMPA	1.3	1.9	3.8	1
PFPeA	1.1	1.3	3.9	1
PFMBA	2.1	3	3.7	1
NFDHA	1	1.7	16	1
PFHxA	1.2	1.4	5.3	1
HFPO-DA	1.9	2.2	3.7	4
PFHpA	0.8	1.1	2.6	1
PFOA	1.1	2.1	3.4	1
PFNA	1.3	1.3	4.8	1
PFDA	1.1	4.8	2.3	1
PFunA	1.2	1.7	2.7	1
PFDoA	1.1	2	2.2	1
PFBS	0.9	1.2	3.5	0.88
PFEESA	1	1.1	2.6	0.89
4:2FTS	2	7.1	4.7	0.94
PFPeS	1	2.3	6.3	0.94
PFHxS	1.1	4.3	3.7	0.91
ADONA	0.6	1	3.4	0.95
6:2FTS	1	1.1	14	0.95
PFHpS	0.6	1.1	5.1	0.95
PFOS	1.2	1.5	4.4	0.93
9Cl-PF3ONS	1.2	1.9	1.4	3.74
8:2FTS	1.6	2.6	9.1	0.96
11Cl-PF3OUdS	1.1	5.2	1.6	0.94

a. Experimental DL was determined from ten LFB replicates fortified at ~4 ng/L measured over three days and calculated according to section 9.2.8 in EPA Method 537.1.
b. Experimental LCMRLs were determined from ten replicates each at five fortification levels ranging from ~1 – 80 ng/L using the EPA LCMRL Calculator.[11]
c. Reference LCMRL values from EPA Method 533 (Table 7).
d. Experimental MRLs were determined from seven LFBs fortified at concentrations ranging from ~1 to 4.0 ng/L according to section 9.1.4 of EPA Method 533 using the Half Range prediction interval method with confirmed upper and lower Prediction Interval Results (PIR) ≤150% and ≥50%, respectively.

Field Sample Analysis

Field samples of tap water were collected from three different sources in the Baltimore Metro Area and are designated S1, S2, and S3. Public drinking water in all three locations are sourced from groundwater. Four field samples and one FRB were collected at each location. Prior to extraction, all samples were spiked with a constant amount of IDS and two field samples were fortified with method analytes at a concentration of ~10 ng/L, resulting in two FD samples, two LFSM samples, and one FRB from each sampling location. All samples from a single location were then carried through SPE extraction, evaporation, and reconstitution. The reconstituted samples were then spiked with IPS and an aliquot was transferred to a polypropylene vial for LC/MS/MS analysis.

The FRB were evaluated to confirm that there was no contamination from sampling, and that all analytes were either not present or at <1/3 of the MRL concentrations, as required by EPA Method 533, indicating that the field sampling process was free of contamination.

Table 10 summarizes the results for all samples. All samples contained PFBA, PFPeA, 4:2 FTS, and PFHxA levels above the MRL of the method, but still below any state or federal regulatory action limit. The samples collected in locations S2 and S3 contained PFBS, PFHpA, PFHxS, PFOA, and PFOS above the method MRL, and the samples from S3 also contained PFDA above the MRL. All other analytes were either not detected or below the MRL, as indicated by <MRL in the table. The LFSM % recoveries were all within the method requirements of ≥70% and ≤130%. The RPD values for the LFSM are a measure of the percent difference between the two replicates and are required to be ≤ 30%. All analytes are well below the RPD requirement. All calculations were performed according to the method definitions.

Table 10: Average analyte field duplicate (FD) sample concentrations, average laboratory fortified sample matrix (LFSM) recoveries and LFSM relative percent difference (RPD) data for duplicate (2x) FD and LFSM from each sampling location..

Analyte	Average FD Conc (ng/L)			Average LFSM % Recovery[a]			LFSM RPD[b]		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
PFBA	1.04	1.99	1.97	100	116	121	2	7	0.2
PFMPA	<MRL	<MRL	<MRL	98	117	113	12	7	3
PFPeA	1.19	2.01	2.40	114	130	126	2	7	9
PFBS	<MRL	2.11	2.30	96	116	120	2	8	14
PFMBA	<MRL	<MRL	<MRL	95	115	118	8	9	10
PFEESA	<MRL	<MRL	<MRL	104	125	130	0.5	11	10
NFDHA	<MRL	<MRL	<MRL	93	116	121	6	7	6
4:2 FTS	1.47	1.70	1.10	95	121	129	3	4	20
PFHxA	1.41	3.10	3.53	111	125	130	0.1	9	13
PFPeS	<MRL	<MRL	<MRL	96	117	121	0.3	12	5
HFPO-DA	<MRL	<MRL	<MRL	113	125	124	2	24	20
PFHpA	<MRL	1.71	2.95	103	119	115	2	12	6
PFHxS	<MRL	1.80	2.32	82	90	122	14	13	5
ADONA	<MRL	<MRL	<MRL	96	113	119	1	10	14
PFOA	<MRL	2.15	2.23	98	109	119	0.4	10	13
6:2FTS	<MRL	<MRL	<MRL	87	103	111	3	11	5
PFHpS	<MRL	<MRL	<MRL	94	115	120	2	7	14
PFNA	<MRL	<MRL	<MRL	103	122	127	5	14	4
PFOS	<MRL	4.10	3.65	97	107	124	0.1	11	11
9Cl-PFONS	<MRL	<MRL	<MRL	112	127	130	2	5	22
PFDA	<MRL	<MRL	1.58	95	128	99	12	16	16
8:2FTS	<MRL	<MRL	<MRL	102	118	120	11	21	5
PFUnA	<MRL	<MRL	<MRL	79	96	103	9	15	3
11Cl-PF3OUdS	<MRL	<MRL	<MRL	118	113	127	2	12	10
PFDoA	<MRL	<MRL	<MRL	109	120	129	7	5	6

a. LFSM percent recovery calculated according to section 9.2.6.1 of EPA Method 533.
b. Relative percent difference (RPD) for duplicate LFSMs calculated according to section 9.2.7.3 of EPA Method 533.

Conclusion

This application note reports the improvement and validation of an LC/MS/MS method for the determination of PFAS analytes and isotopically labelled standards in drinking water listed in the US EPA Method 533 using the PerkinElmer QSight LX50 UHPLC System, coupled with the PerkinElmer QSight 210 LC/MS/MS. These validation studies demonstrate that excellent linearity was achieved for all PFAS analytes and isotopic standards, R^2 greater than 0.99, PFBA R^2 is 0.9906. The instrument LOD and LOQ verify that the QSight 210 LC/MS/MS has ample sensitivity required to quantify the PFAS analytes listed in US EPA Method 533. Instrument modifications and the incorporation of a delay column are required to eliminate and reduce background PFAS contaminants and have been verified to be effective by the analysis of blanks.

An improved chromatographic method was previously developed for EPA Method 537.1 to decrease LC/MS/MS runtimes to 10 minutes, as compared to the method described in EPA Method 537.1 with a runtime of 37 minutes and that described in EPA Method 533 with a runtime of 35 minutes; an over 71% decrease in LC/MS/MS runtime for EPA 533. MRM experiments were optimized for all analytes and isotopically labelled standards on the QSight 210 MSMS, including quantifier and qualifier MRMs for all ions of interest. A time-managed MRM mass spectrometer method has also been optimized to maximize dwell time for improved sensitivity, while maintaining more than 10 data points across each chromatographic peak. Recoveries for all analytes fall well within the ≥70% and ≤130% requirements of the method for LFB fortified at levels ranging from 1 to 80 ng/L, and recoveries for all isotope dilution standards similarly falls between the 50-200% requirements. The SPE extraction in this study was carried out on a manual SPE manifold system that was modified to eliminate any components constructed of PTFE to minimize or eliminate PFAS contamination. Method MRL were not reported in EPA Method 533 but were previously established and validated again here to meet or fall below those reported in EPA Method 537.1 for similar analytes. They could be improved further by incorporating an automated or robotic SPE extraction system and these systems will be evaluated in future studies.

Municipal drinking water samples from three sampling sites were quantified and validated recoveries and repeatability fell within the method requirements. Overall, this validation study shows that the LX50 UHPLC System coupled to the QSight 210 LC/MS/MS is an excellent analytical instrument for the application of EPA Method 533 with ample sensitivity to measure all analytes. Additionally, a singular method, including use of the same columns and mobile phases, was validated for analysis of all analytes from both EPA Methods 533 and 537.1 without the need to physically alter the system or consumables other than to utilize a different SPE cartridge and preparation method as specified by each methodology. This will drastically improve throughput in labs needing to analyze drinking water for either EPA method.

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