

TN-0158

Optimized Total Organic Fluorine Methods Using Strata™ PFAS SPE Cartridges for a More Comprehensive Measurement of PFAS in Environmental Samples

Alexandria L.B. Forster¹, Ying Zhang, PhD^{1,2}, Danielle C. Westerman, PhD¹, Susan D. Richardson, PhD¹, Richard Jack, PhD³, and Bryan Tackett, PhD³

¹Department of Chemistry and Biochemistry, University of South Carolina, 631 Sumter Street, Columbia, SC 29208, USA

²Department of Environmental Science and Engineering, Nankai University, No. 38 Tongyan Road, Jinnan District, Tianjin, 300350, China

³Phenomenex, Inc., 411 Madrid Ave., Torrance, CA 90501 USA



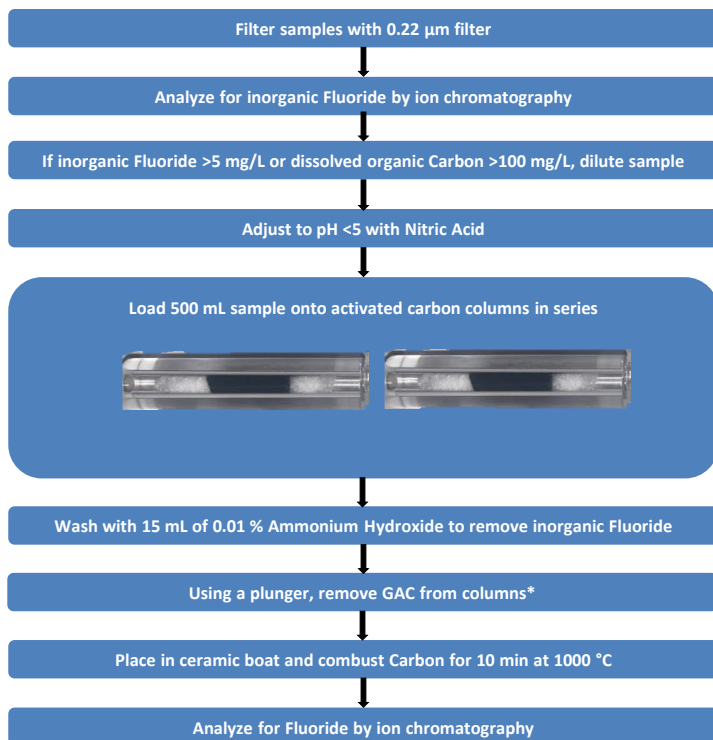
Introduction

Per- and Polyfluoroalkyl Substances (PFAS) are present in all environmental matrices, including water, soil, air, and living organisms. Due to the persistent nature of these compounds, as well as their ability to be easily transported in the environment, there is a significant push to regulate them. Liquid chromatography coupled with mass spectrometry (LC-MS) has been the most often used technique for measuring PFAS in various matrices but is limited to the standards, analytical methods available, and the limited number of PFAS compounds analyzed. Since it has been estimated that there are over 6000 possible PFAS compounds, most organic Fluorine present in the sample is missed. By measuring Total Organic Fluorine (TOF) content, a more comprehensive account of PFAS contamination can be determined. This approach measures organofluorine compounds from PFAS and non-PFAS fluorinated compounds such as pesticides and pharmaceuticals that can be retained on granular activated Carbon (GAC). The result is reported as the concentration of fluoride (F⁻) in the sample. The EPA has published Method EPA 1621 *Screening Method for the Determination of Adsorbable Organic Fluorine (AOF) in Aqueous Matrices by Combustion Ion Chromatography (CIC)* with the goal of establishing a

validated method for use in Clean Water Act applications. Within EPA 1621, it is mentioned that short-chain (less than 4 carbons) organofluorine compounds are poorly retained on GAC.

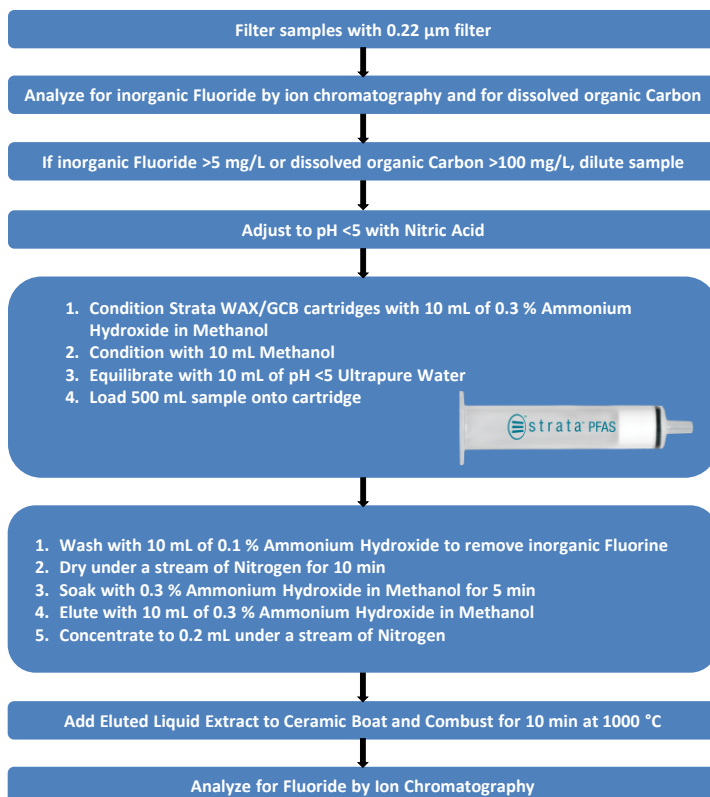
To more comprehensively capture organic Fluorine, Combustion Ion Chromatography (CIC) can be used because this technique measures total organic Fluorine present in a sample. This CIC method involves sample extraction, concentration, combustion, collection of generated gasses in an aqueous absorbing solution, and analysis of resulting anions by ion chromatography. This method converts organic Fluorine into inorganic Fluoride which is measured by ion chromatography. However, CIC is limited in its ability to distinguish between organic and inorganic Fluorine/Fluoride, so analyte extraction methods must be optimized. For TOF, previous extraction methods include Extractable Organic Fluorine (EOF) and Adsorbable Organic Fluorine (AOF), which differ in how the samples are extracted. EOF uses Solid Phase Extraction (SPE) with a solid stationary phase while AOF uses an activated Carbon column. In this technical note, we report a new TOF method with improved recovery, detection limits, and quantity of PFAS studied (43 total) by implementing the Strata PFAS SPE cartridge.

AOF Method



*EOF does not require the laborious extrusion needed to remove the GAC prior to combustion. This makes EOF scalable for higher throughput laboratories as EOF can readily be automated.

EOF Method



Results and Discussion

Both AOF and EOF methods can be used to quantify TOF. Compared to AOF, EOF extractions have higher overall recoveries and lower LODs and LOQs (**Table 1**). Both SPE extraction methods allow for the removal of inorganic Fluoride which is crucial for the use of CIC as a PFAS screening technique. The lower LOD and LOQ using Strata™ PFAS is due to the use of the WAX layer that allows for better recoveries since this approach relies on acidic pKas of many PFAS compounds. As shown in **Table 1**, there is a significant time savings between the methods. EOF does not require the laborious extrusion needed to remove the GAC prior to combustion. This makes EOF scalable for higher throughput laboratories as EOF can readily be automated.

As shown in **Figures 1 and 2**, AOF recoveries in river water and ultrapure water ranged from 55–98 % to 46–112 %. Trends between compounds show a slight decrease in river water compared to ultrapure water, likely due to other organics outcompeting PFAS for sorption sites on the AC. Branched ether compounds, such as PMPA (C4), HPFO-DA (C6), and PFECAG (C7) yielded somewhat lower recoveries (46, 89, and 87 %, respectively) than linear ethers, PEPA (C4), PFO4DA (C6), and PFO5DA (C7) with the same number of carbons (65, 89, and 92 %, respectively). Perfluorocarboxylic acids (PFCAs) and perfluorosulfonic acids (PFSAs) such as PFBA (C4), PFBS (C4), PFHxA (C6), and PFHpA (C7) generally yielded higher recoveries (64, 90, 92, 92 %, respectively) when compared to ethers of similar chain length. While in general, shorter-chain PFAS compounds yielded lower recoveries compared to longer-chain PFAS, no consistent trend was observed. An LOD of 0.3 µg/L and an LOQ of 1.0 µg/L can be achieved with a 500 mL sample. This LOD value is well below those required by EPA Method (2.4 µg/L).

The efficiency of the final EOF method was evaluated using 39 individual PFAS standards and 39-PFAS mix (as 50 µg/L Fluorine) in ultrapure and river water (DOC of 2.4 mg/L). Two zwitterionic and two neutral PFAS compounds were also evaluated individually (data not shown) for a total of 43. As observed for AOF, recoveries for EOF also decreased slightly in river water (66–98 %) compared to ultrapure water (72–99 %), and shorter-chain PFAS generally yielded lower recoveries compared to longer-chain PFAS, but no consistent trend was observed. Branched ether compound PMPA (C4) yielded a lower recovery (87 %) than its linear ether, PFCA, and PFSA counterparts PEPA (95 %), PFBA (88 %), and PFBS (94 %); however, branched ether compounds HPFO-DA (C6) and PFECAG (C7) yielded higher recoveries (91 and 89 %, respectively) than their linear ether, PFCA, and PFSA counterparts PFO4DA (91 %), PFHxA (89 %), PFO5DA (86 %), and PFHpA (88 %). When compared to the AOF trends, the difference in the higher recoveries of longer-chain PFAS could be explained by the extra GCB layer for extraction. An LOD and LOQ of 0.2 and 0.5 µg/L can be achieved, respectively, with a 500 mL sample.

When comparing the PFAS recoveries between the two methods as shown in **Figures 1 and 2**, several compounds had low recoveries (below 70 %) for the AOF method but were >80 % for the EOF method. These include PFPrA, PFBA, PFO4DA, Hydro EVE, DFSA, Hydro PS Acid, R-PSDA.

Table 1. Comparison of AOF and EOF Methods.

	AOF (500 mL Sample Volume)	EOF (500 mL Sample Volume)
Mean Recovery in Ultrapure Water	79 %	91 %
Mean Recovery in River Water	72 %	87 %
Inorganic Fluoride Removed	98 %	≥99 %
LOD (µg/L)	0.3	0.2
LOQ (µg/L)	1.0	0.5
Full Analysis Time (one sample in triplicate)	~11 hours	~5 hours



Figure 1. Mean Organic Fluorine Recovery of 39 Individual PFAS Standards Spiked into Ultrapure Water.

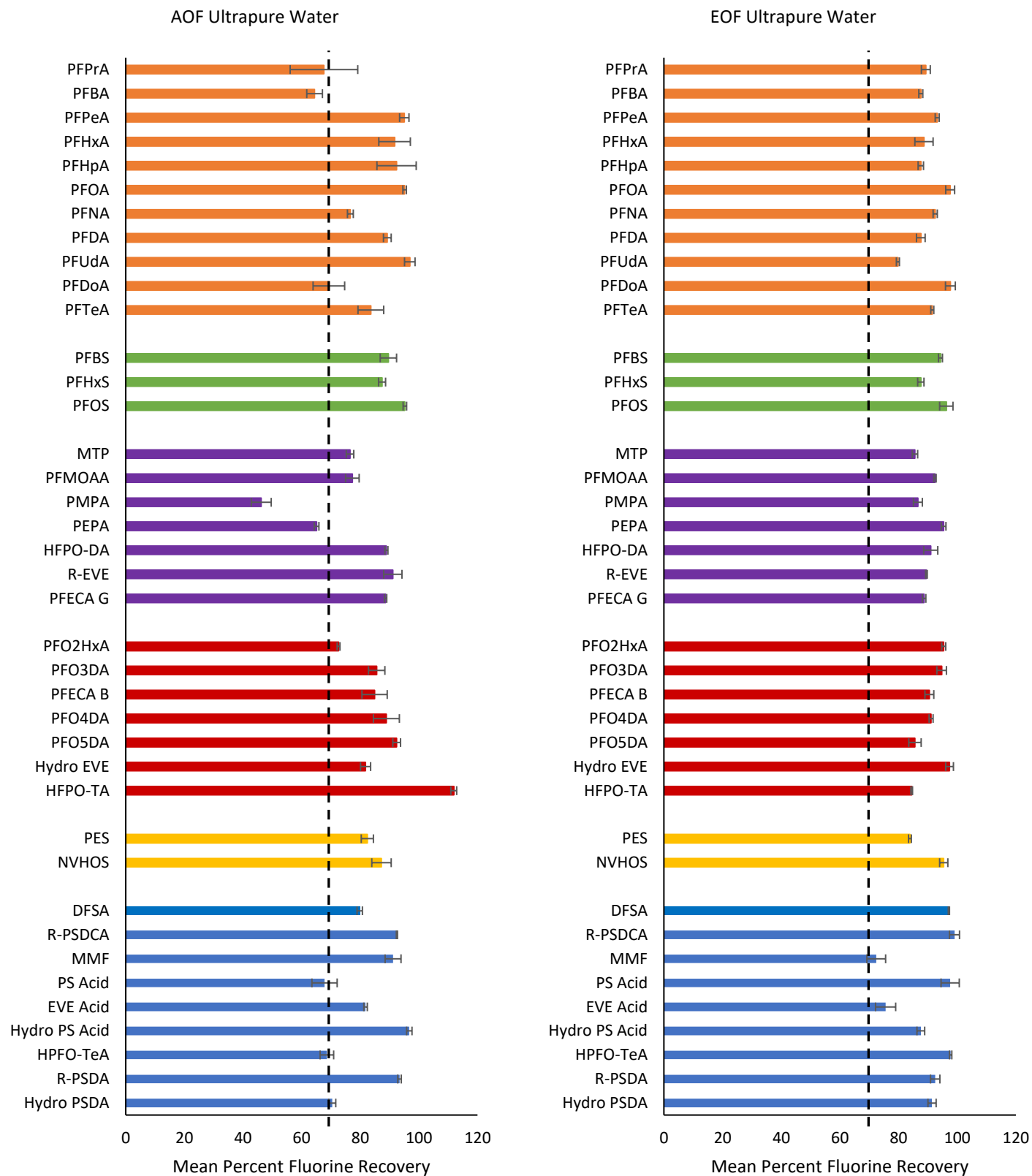
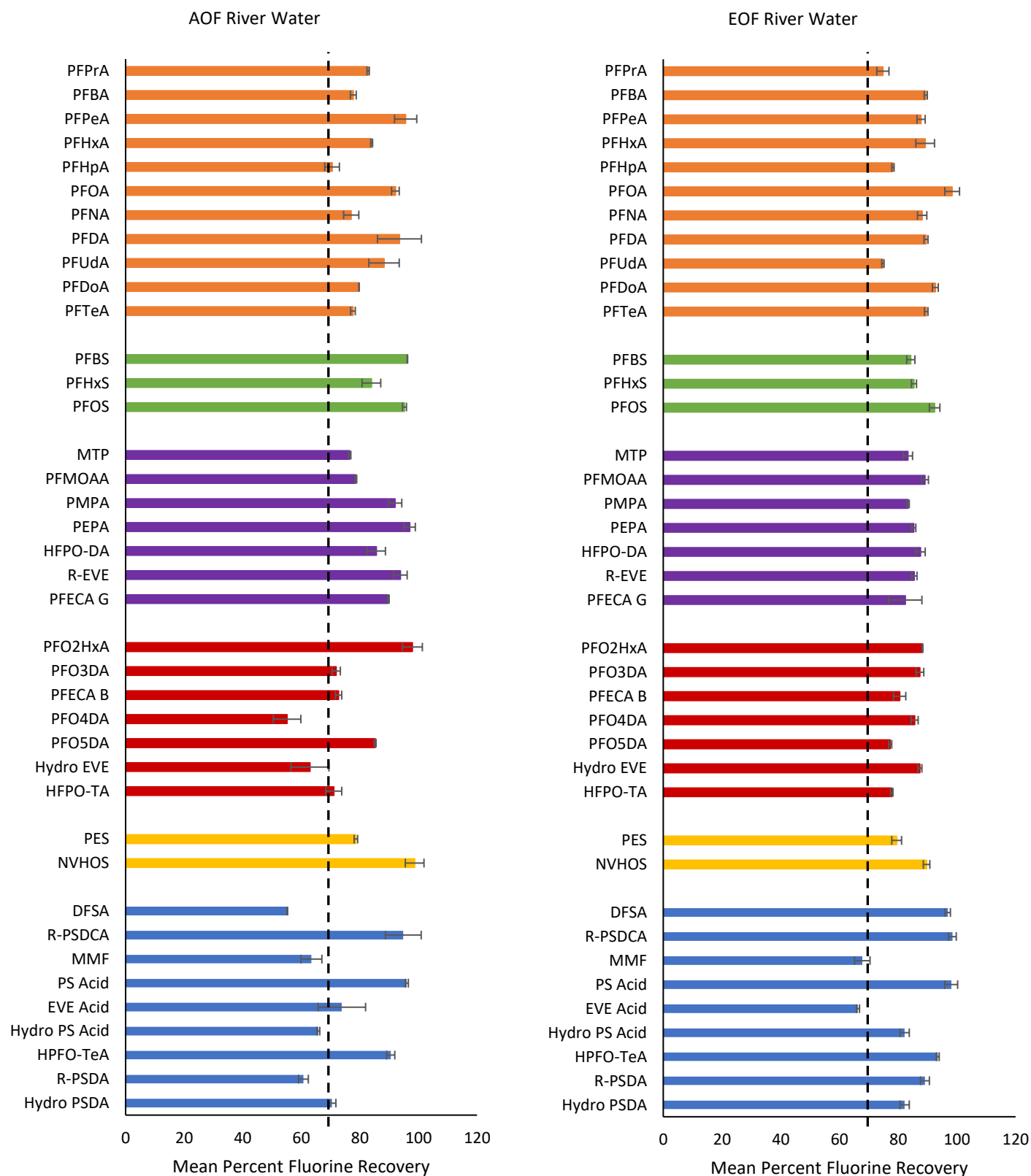


Figure 2. Mean Organic Fluorine Recovery of 39 Individual PFAS Standards Spiked into River Water.



Conclusions

Our results demonstrate the development of two new sensitive methods (AOF and EOF) to quantify TOF in river water. Compared to previous methods, we achieved higher recoveries for a larger mix of 43 PFAS compounds, and our AOF method utilizes commercial pre-packed ACs rather than manual packing in a clean room. Our EOF method also utilizes a new type of SPE cartridge, Strata™ PFAS, which combines benefits of a WAX phase with GCB to more efficiently extract a wide range of PFAS classes with varying size and polarity. Larger samples (up to 1200 mL) can be used with larger Strata PFAS cartridges to achieve 0.1 µg/L LOD and 0.3 µg/L LOQ (data not shown). Another benefit of EOF is that a sample of SPE eluent can be saved for future LC-MS/MS analysis to identify specific PFAS compounds in samples with high TOF.

References

- Office of Science and Technology. (2024, January). [Method 1621: Determination of Adsorbable Organic Fluorine \(AOF\) in Aqueous Matrices by Combustion Ion Chromatography \(CIC\)](#). (EPA 821-R-24-002). Environmental Protection Agency. Office of Water.

Strata PFAS Ordering Information

Strata		
Sorbent Mass	Part Number	Unit
200 mg / 50 mg (WAX/GCB)	CS0-9207	6 mL (30/box)
250 mg / 50 mg (WAX/GCB)	CS0-9215	6 mL (200/box)
250 mg / 100 mg (GCB/WAX)	CS0-9217	6 mL (30/box)
500 mg / 50 mg (WAX/GCB)	CS0-9208	6 mL (200/box)
50 mg / 200 mg (GCB/WAX)	CS0-9214	6 mL (30/box)

Other Recommended Products for Your PFAS Methods

Description	Part No.
Luna™ Omega Column 3 µm PS C18 50 x 3 mm	00B-4758-Y0
Kinetex™ EVO Column 5 µm C18 100 x 2.1 mm	00D-4633-AN
Strata SDB-L 500 mg/6mL tubes, 30/pk	8B-S014-HCH
Verex™ Vial, 9 mm Screw, PP, 1.7 mL, 1000/pk	AR0-39P0-13
Verex Vial, 9 mm Screw, PP, 300 µL, 1000/pk	AR0-39P2-13
Verex Vial, 9 mm Screw, PP, 700 µL, 1000/pk	AR0-39P1-13
SecurityCAP™ mobile phase filter for PFAS testing, 6-month capacity, ¼ in-28 thread	AC2-0961-P
SecurityCAP mobile phase starter kit for PFAS testing, 3-port GL45 caps and 6-month safety filter	AC2-4345-P
SecurityCAP mobile phase starter kit for PFAS testing, 2-port GL45 caps and 6-month safety filter	AC2-4245-P

Columns and vials available in multiple sizes. Contact Phenomenex for details.

PFAS CRM Native Standards. All analytes at the same concentration in acid form for easy calculation and dilution.

Product	Part	Volume	Concentration
EPA 533 mix	AL0-101838	1 mL	2 µg/mL in Methanol
EPA 537.1 mix	AL0-101839	1mL	2 µg/mL in Methanol
EPA 533 + 537.1 mix	AL0-101840	1 mL	2 µg/mL in Methanol

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auinfo@phenomenex.com

Austria

t: +43 (0)1-319-1301
anfrage@phenomenex.com

Belgium

t: +32 (0)2 503 4015 (French)
t: +32 (0)2 511 8666 (Dutch)
beinfo@phenomenex.com

Canada

t: +1 (800) 543-3681
info@phenomenex.com

China

t: +86 400-606-8099
cninfo@phenomenex.com

Czech Republic

t: +420 272 017 077
cz-info@phenomenex.com

Denmark

t: +45 4824 8048
nordicinfo@phenomenex.com

Finland

t: +358 (0)9 4789 0063
nordicinfo@phenomenex.com

France

t: +33 (0)1 30 09 21 10
franceinfo@phenomenex.com

Germany

t: +49 (0)6021-58830-0
anfrage@phenomenex.com

Hong Kong

t: +852 6012 8162
hkinfo@phenomenex.com

India

t: +91 (0)40-3012 2400
indiainfo@phenomenex.com

Indonesia

t: +62 21 3952 5747
indoinfo@phenomenex.com

Ireland

t: +353 (0)1 247 5405
eireinfo@phenomenex.com

Italy

t: +39 051 6327511
italiainfo@phenomenex.com

Japan

t: +81 (0) 120-149-262
jpinfo@phenomenex.com

Luxembourg

t: +31 (0)30-2418700
nlinfo@phenomenex.com

Mexico

t: 01-800-844-5226
tecnicomx@phenomenex.com

The Netherlands

t: +31 (0)30-2418700
nlinfo@phenomenex.com

New Zealand

t: +64 (0)9-4780951
nzinfo@phenomenex.com

Norway

t: +47 810 02 005
nordicinfo@phenomenex.com

Poland

t: +48 22 51 02 180
pl-info@phenomenex.com

Portugal

t: +351 221 450 488
ptinfo@phenomenex.com

Singapore

t: 800-852-3944 (toll free)
t: 6559 4052 (office main line)
sginfo@phenomenex.com

Slovakia

t: +420 272 017 077
sk-info@phenomenex.com

Spain

t: +34 91-413-8613
espinfo@phenomenex.com

Sweden

t: +46 (0)8 611 6950
nordicinfo@phenomenex.com

Switzerland

t: +41 (0)61 692 20 20
swissinfo@phenomenex.com

Taiwan

t: +886 (0) 0801-49-1246
twinfo@phenomenex.com

Thailand

t: +66 (0) 2 566 0287
thaiinfo@phenomenex.com

United Kingdom

t: +44 (0)1625-501367
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