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Characterization of PFAS in Surface Water, Sediment and Fish in the Pennsylvania Coastal Zone

Technical Report No. 2025-4

CRMP Project # 22.PD.12

NOAA Award # NA22NOS4190149

Prepared by Jeremy L. Conkle, Ph.D.

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Pennsylvania Coastal Resources Management Program

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DELAWARE RIVER BASIN COMMISSION

Water Quality Assessment

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AUTHORSHIP

This project was overseen and undertaken by Jeremy Landon Conkle, Ph.D., Senior Chemist/Toxicologist at the Delaware River Basin Commission (DRBC), with the field assistance from Elaine Panuccio, Senior Water Resource Scientist, and Jacob Bransky, Senior Aquatic Biologist, to collect water and sediment or catch fish.

SUGGESTED CITATION

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EXECUTIVE SUMMARY

The Pennsylvania Coastal Zone includes tidal waters of the Delaware River and its tributaries that stretch from Morrisville to Chester, Pa. Much of this area is marked by high population densities and heavy industrialization, including petrochemical facilities, which are linked to per- and polyfluoroalkyl substances (PFAS) pollution. This technical report presents the results from a study conducted by the Delaware River Basin Commission (DRBC), documenting the presence of PFAS in surface water, sediment, and fish within this important ecosystem.

PFAS are synthetic chemicals found in various industrial and consumer products, including firefighting foams, cookware, and food packaging. Their persistence in the environment raises concerns about their bioaccumulation and toxicological effects on wildlife, ecosystems, and human health. This report is the latest effort by DRBC to examine and understand PFAS contamination from numerous sources, such as wastewater treatment plants, landfills, industrial outfalls, and runoff, which is crucial for protecting water resources that are essential for ecological and public health.

In this study, DRBC sampled water, sediment, and fish from tributaries and the main stem of the Delaware River. PFAS are present in each environmental media sampled, and different suites of PFAS accumulate in each of those media. The findings indicate that these contaminants are not only prevalent in the river system but may be approaching levels of concern for fish consumption.

These efforts contribute to DRBC's broader plans to identify knowledge gaps, examine presence and trends, and determine PFAS sources. By enhancing our understanding of PFAS occurrence and distribution, this report contributes to future DRBC efforts to mitigate contamination and safeguard the health of the environment and the communities dependent on the shared water resources of the Delaware River Basin.

LIST OF ACRONYMS/ABBREVIATIONS

AFFF	Aqueous film-forming foams
DRBC	Delaware River Basin Commission
EPA	U.S. Environmental Protection Agency
HDPE	High-density polyethylene
K_{OC}	Organic carbon partitioning coefficient
NYSDEC	New York State Department of Environmental Conservation
PACZM	Pennsylvania Coastal Zone Management
PDE	Partnership for the Delaware Estuary
BIL	Bipartisan Infrastructure Law
RfD	Reference dose
SPE-WAX	Solid phase extraction with weak anion exchange
TOP	Total oxidizable precursor
Σ_{PFAS}	Summed PFAS

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1. INTRODUCTION

Per- and polyfluoroalkyl substances (PFAS) are found in a wide range of industrial and consumer products, including stain-repellent textiles, aqueous film-forming foams (AFFF), paper products, toilet paper, and food wrappers. These materials can directly expose humans to PFAS, while environmental contamination occurs through industrial outfalls, municipal wastewater treatment, firefighting activities involving AFFF, stormwater runoff, and landfill leachate. Once in the environment, PFAS can affect wildlife and humans through direct exposure (e.g., drinking water) and indirect routes (e.g., consuming contaminated organisms). Due to their widespread presence and persistence, PFAS have been linked to serious health effects such as liver damage, high cholesterol, thyroid disease, reduced vaccine response, asthma, decreased fertility, pregnancy-induced hypertension, low birth weight, and developmental issues in children, among others.

This diverse group of over 13,000 chemicals exhibits varying degrees of persistence, toxicity, and bioaccumulation in the environment.[2] Studying such a broad class of chemicals is challenging, but quantifying PFAS occurrence and bioaccumulation in urban environments is critical for protecting water resources essential to ecosystem and human health. The Delaware River has a long history of PFAS pollution, stemming from early research and the manufacturing of PFAS compounds by chemical companies in the Basin. Consequently, various PFAS compounds are consistently detected in the surface waters, sediment, and aquatic organisms of the Delaware River Basin, raising concerns about recreation and the sustainable use of this vital resource.

The Delaware River Basin Commission (DRBC, or "the Commission") has studied PFAS in the Delaware River Basin since 2004, with expanded sampling efforts beginning in 2020. The Commission is developing a PFAS Roadmap to synthesize existing data, identify knowledge gaps, and pinpoint potential sources. Data from this study will contribute to the broader dataset supporting these efforts.

2. METHODS

Understanding the occurrence and bioaccumulation of PFAS in urban areas is important for protecting water resources. Main stem sites were selected near Delaware Estuary Water Quality Monitoring Program ("Boat Run") stations with historic water quality data[3] and at locations suitable for fish collection (Figure 1 and Table 1). Additionally, multiple sample matrices were collected at both main stem and tributary sites in the Delaware Estuary, focusing on the Pennsylvania Coastal Zone between Morrisville, Pa. and Chester, Pa. Surface water and sediment were sampled at 17 sites in late summer 2023, and composite fish samples were collected for two species in fall 2023 and spring 2024. Select Pennsylvania tributaries were sampled near their confluence with the Delaware River. Main stem samples were collected from a boat, while tributary samples were collected from bridges, boats, or by wading. Site names are based on proximity to nearby municipalities or landmarks.

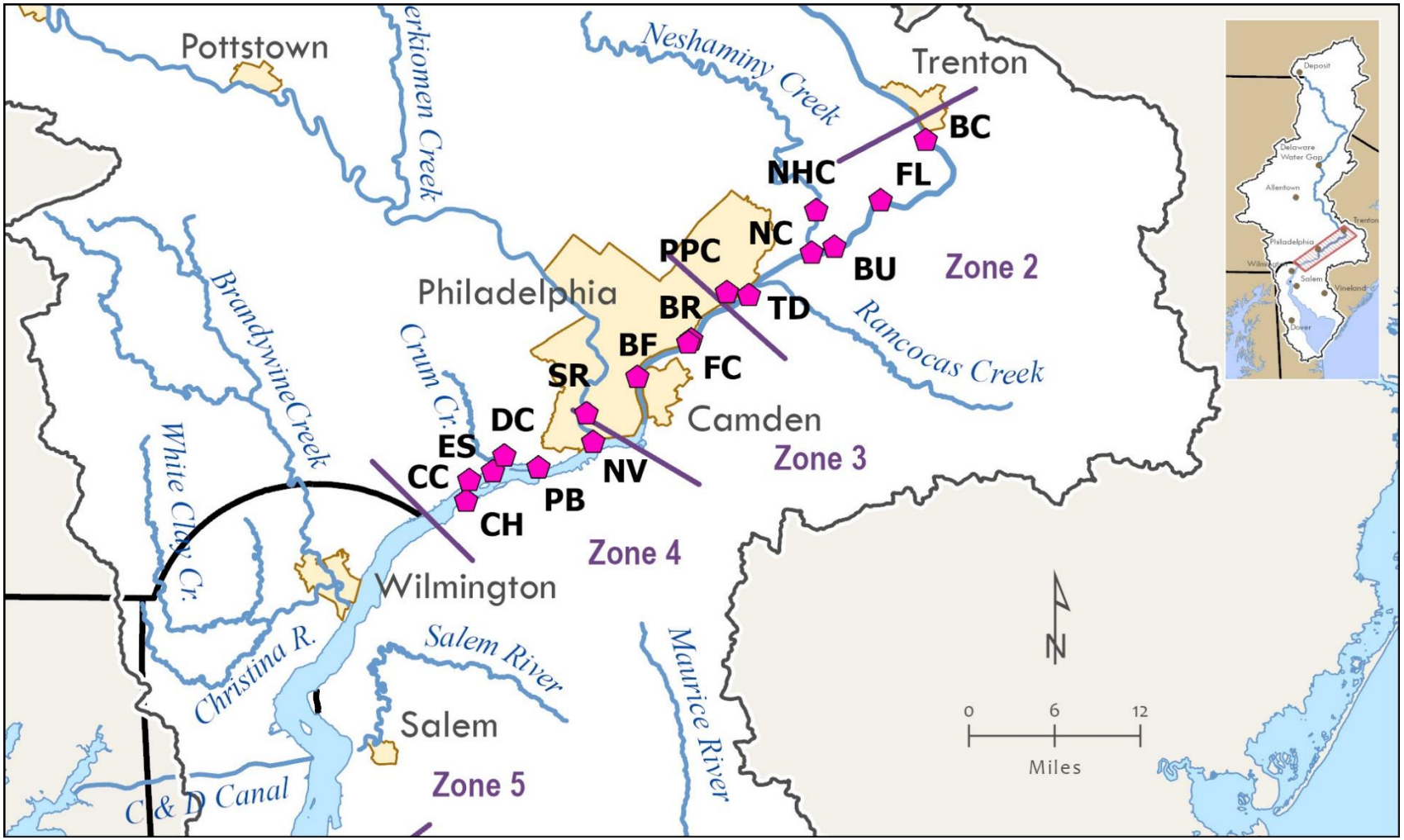

Figure 1. Delaware River and tributary sampling locations.

Table 1. Summary of PFAS sampling site information in the Delaware River and its tributaries. Total Oxidizable Precursor (TOP) analysis samples were collected at select sites alongside water and sediment sampling. Latitude and longitude are provided for surface water, sediment, and fish tissue collection; sites with coordinates in the fish tissue columns indicate locations where fish were collected.

			Water and Sediment			Fish	
Name	**ID**	**River Mile**	**Latitude**	**Longitude**	**TOP Analysis**	**Latitude**	**Longitude**
Main Stem Sites							
Biles Channel	BC	131.4	40.190	-74.758	Yes	40.184	-74.758
Florence	FL	122.4	40.129	-74.818	Yes	40.131	-74.813
Burlington Bristol Bridge	BU	117.8	40.082	-74.879	Yes		
Torresdale	TD	110.2	40.033	-74.992	Yes	40.033	-74.992
Betsy Ross	BR	104.7	39.988	-75.068	Yes		
Ben Franklin Bridge	BF	100.0	39.950	-75.139	Yes		
Navy Yard	NV	92.5	39.884	-75.197	Yes		
Philadelphia Airport	PB	90.5	39.858	-75.269	Yes		
Eddystone	ES	85.0	39.854	-75.329	Yes	39.855	-75.328
Chester	CH	82.0	39.824	-75.364	Yes	39.825	-75.365
Tributary Sites							
Neshaminy Creek (head of tide)	NHC		40.119	-74.903			
Neshaminy Creek	NC		40.076	-74.909	Yes		
Pennypack Creek (head of tide Frankford Ave)	PPC		40.036	-75.021			
Frankford Creek	FC		39.985	-75.072	Yes		
Schuylkill River	SR		39.913	-75.206	Yes	39.911	-75.214
Darby Creek	DC		39.870	-75.314			
Chester Creek	CC		39.845	-75.360			

2.1 Surface Water Sampling

Targeted surface water and Total Oxidizable Precursor (TOP) Assay samples were collected for PFAS analysis on August 30th, September 6th, and September 19th at the sites listed in Table 1. Sample collection followed the NY State Department of Environmental Conservation (NYSDEC) PFAS protocols for surface waters.[4] Surface water grab samples for targeted analysis were collected in two 500 ml high-density polyethylene (HDPE) bottles (one as a backup), while TOP Assay samples consisted of a single 60 ml HDPE bottle. Samples were kept on ice in coolers at 4 ± 2 ˚C during transport and then frozen prior to shipping to the laboratory. SGS AXYS laboratory provided PFAS-free water for field blanks, which were prepared on site by transferring the water into empty sample bottles. Field duplicates were collected as additional samples at select locations. At each site, in-field measurements of specific conductivity, water temperature, dissolved oxygen, turbidity, and pH were recorded.

2.2 Sediment Sampling

Surface sediment samples were collected on August 30th, September 6th, and September 19th following the NYSDEC PFAS protocols for sediment.[4] Sediment samples were collected using a decontaminated Ponar stainless-steel grab or stainless-steel spoon. Samples were placed in a large, decontaminated stainless-steel bowl, homogenized with a pre-washed stainless-steel spoon, and transferred to 250 ml HDPE jars. Samples were stored in a cooler on ice at 4 ± 2 ˚C during transport and then frozen prior to shipping to the laboratory. A backup field duplicate was collected at each site. SGS AXYS PFAS-free water was used as an equipment rinsate blank.

2.3 Fish Collection

Fish collection followed NYSDEC protocols[4] at the six sites listed in Table 1. Two tidal species—white perch (*Morone americana)* and channel catfish (*Ictalurus punctatus)*—were collected using hook and line in October 2023 and May 2024. However, due to difficulties landing fish at some locations, both species were only caught at the Chester and Eddystone sites; only one species was collected at the remaining four sites. Each fish was wrapped in aluminum foil provided by SGS AXYS upon collection. Fish of the same species from each site were grouped into a single bag and stored at -20˚C prior to shipment and processing at the analytical laboratory. At the contracted analytical lab, fillets were prepared for each species: white perch fillets included the skin, while channel catfish fillets did not. A composite sample of three fillets from fish of similar length and weight was prepared for each species at each site.

2.4 PFAS Analysis

Surface water, surficial sediment, and fish fillets were analyzed by SGS AXYS Method MLA-110 (equivalent to EPA Method 1633) for 40 PFAS analytes (Table 2). Samples were spiked with isotopically labeled surrogate standards, cleaned using SPE-WAX cartridges, and analyzed by LC-

Table 2. Targeted PFAS analytes.

Analyte		Group		CAS #
Full Name	**Abbreviation**	**Full Name**	**Abbreviation**	
11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (*replacement*)	11Cl-PF3OUdS	Ether Sulfonic Acids	ESA	2196242-82-5
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (*replacement*)	9Cl-PF3ONS	Ether Sulfonic Acids	ESA	1621485-21-9
Perfluoro(2-ethoxyethane)sulfonic acid	PFEESA	Ether Sulfonic Acids	ESA	113507-82-7
2H,2H,3H,3H-Perfluorooctanoate (*precursor*)	5:3 FTCA	Fluorotelomer Carboxylic Acids	FTCA	1799325-94-2
4,4,5,5,6,6,6-Heptafluorohexanoate (*precursor*)	3:3 FTCA	Fluorotelomer Carboxylic Acids	FTCA	1169706-83-5
4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-Pentadecafluorodec-2-enoic acid (*precursor*)	7:3 FTCA	Fluorotelomer Carboxylic Acids	FTCA	755-03-3
4:2 fluorotelomersulfonic acid (*precursor*)	4:2 FTS	Fluorotelomer Sulfonic Acids	FTSA	414911-30-1
6:2 fluorotelomersulfonic acid (*precursor*)	6:2 FTS	Fluorotelomer Sulfonic Acids	FTSA	425670-75-3
8:2 fluorotelomersulfonic acid (*precursor*)	8:2 FTS	Fluorotelomer Sulfonic Acids	FTSA	481071-78-7
4,8-dioxa-3H-perfluorononanoate (*replacement*)	ADONA	Per- and Polyfluoroether Carboxylic Acids	PFECA	2127366-90-7
Hexafluoropropylene oxide dimer acid (*replacement*)	HFPO-DA	Per- and Polyfluoroether Carboxylic Acids	PFECA	13252-13-6
Perfluoro(4-methoxybutanoic) acid	PFMBA	Per- and Polyfluoroether Carboxylic Acids	PFECA	863090-89-5
Perfluoro-3-methoxypropanoic acid	PFMPA	Perfluoroalkyl Carboxylic Acids	PFCA	377-73-1
Perfluoro-3,6-dioxaheptanoic acid	NFDHA	Perfluoroalkyl Carboxylic Acids	PFCA	151772-58-6
Perfluorobutanoate	PFBA	Perfluoroalkyl Carboxylic Acids	PFCA	45048-62-2
Perfluorodecanoate	PFDA	Perfluoroalkyl Carboxylic Acids	PFCA	73829-36-4
Perfluorododecanoate	PFDoA	Perfluoroalkyl Carboxylic Acids	PFCA	171978-95-3
Perfluoroheptanoate	PFHpA	Perfluoroalkyl Carboxylic Acids	PFCA	120885-29-2
Perfluorohexanoate	PFHxA	Perfluoroalkyl Carboxylic Acids	PFCA	92612-52-7
Perfluorononanoate	PFNA	Perfluoroalkyl Carboxylic Acids	PFCA	72007-68-2
Perfluorooctanoic acid	PFOA	Perfluoroalkyl Carboxylic Acids	PFCA	45285-51-6
Perfluoropentanoate	PFPeA	Perfluoroalkyl Carboxylic Acids	PFCA	45167-47-3
Perfluorotetradecanoate	PFTeDA	Perfluoroalkyl Carboxylic Acids	PFCA	365971-87-5

Perfluorotridecanoate	PFTrDA	Perfluoroalkyl Carboxylic Acids	PFCA	862374-87-6
Perfluoroundecanoate	PFUnA	Perfluoroalkyl Carboxylic Acids	PFCA	196859-54-8
Perfluorobutanesulfonate	PFBS	Perfluoroalkyl Sulfonic Acids	PFSA	45187-15-3
Perfluorodecanesulfonate	PFDS	Perfluoroalkyl Sulfonic Acids	PFSA	126105-34-8
Perfluorododecanesulfonate	PFDoS	Perfluoroalkyl Sulfonic Acids	PFSA	343629-43-6
Perfluoroheptanesulfonate	PFHpS	Perfluoroalkyl Sulfonic Acids	PFSA	146689-46-5
Perfluorohexanesulfonic acid	PFHxS	Perfluoroalkyl Sulfonic Acids	PFSA	108427-53-8
Perfluorononanesulfonate	PFNS	Perfluoroalkyl Sulfonic Acids	PFSA	68259-12-1
Perfluorooctanesulfonate	PFOS	Perfluoroalkyl Sulfonic Acids	PFSA	45298-90-6
Perfluoropentanesulfonate	PFPeS	Perfluoroalkyl Sulfonic Acids	PFSA	175905-36-9
N-Ethyl perfluorooctane sulfonamido ethanol (*precursor*)	N-EtFOSE	Perfluorooctane Sulfonamide Ethanols	FOSE	1691-99-2
N-Methylperfluorooctane sulfonamido ethanol (*precursor*)	N-MeFOSE	Perfluorooctane Sulfonamide Ethanols	FOSE	24448-09-7
N-Ethylperfluorooctane-1-sulfonamide (*precursor*)	N-EtFOSA	Perfluorooctane Sulfonamides	FOSA	4151-50-2
N-Methyl perfluorooctane sulfonamide (*precursor*)	N-MeFOSA	Perfluorooctane Sulfonamides	FOSA	31506-32-8
Perfluorooctanesulfonamide (*precursor*)	PFOSA	Perfluorooctane Sulfonamides	FOSA	754-91-6
N-ethyl perfluorooctanesulfonamidoacetic acid (*precursor*)	EtFOSAA	Perfluorooctane Sulfonamidoacetic Acids	FOSAA	2991-50-6
N-methyl perfluorooctanesulfonamidoacetic acid (*precursor*)	MeFOSAA	Perfluorooctane Sulfonamidoacetic Acids	FOSAA	2355-31-9

MS/MS. Final concentrations were determined using isotope dilution/internal standard quantification against extracted calibration standards in water.

TOP Assay analysis was performed using SGS AXYS method MLA-111. Aqueous samples (up to 60 ml) were spiked with isotopically labeled surrogates and oxidized using base and heat-activated persulfate. After cooling, samples were pH adjusted, and subsequent extraction and analysis followed Method MLA-110 procedures.

2.5 Data Interpretations and Limitations

Data reported by the contract analytical lab was flagged if there were any potential issues. One of the most common is the "J" flag for a detected compound at levels below the limits of quantification. However, no J-flagged results are presented in this report, nor will they be uploaded to the water quality portal. No lab or field blank contamination was found in the water or sediment samples. In a lab blank, N-Ethyl perfluorooctane sulfonamido ethanol (N-EtFOSE), which is a volatile PFAS compound, was detected at 1.62 ng g^{-1}. N-EtFOSE was also detected in all three channel catfish and two of the five white perch samples. Its concentrations in samples ranged from 3.66 to 12.30 ng g^{-1}, which are 2.3 to 5.7 times higher than the blank contamination concentration. For samples where N-EtFOSE concentrations were <3x (<4.86 ng g^{-1}) the 1.62 ng g^{-1} detected in the laboratory blank, their results are excluded from the discussion below. However, all results, even if greater than 3x the amount in the lab blank, presented for N-EtFOSE are qualified, meaning there is greater uncertainty with the N-EtFOSE values quantified in fish tissue samples compared to those for other PFAS analytes.

This experimental design—a single sampling of sediment and water at each site—provides a snapshot of PFAS concentrations at a specific point in time and may not reflect long-term conditions. This limitation is particularly true for surface water, which can exhibit high variability over both short and long timescales. However, sediment is typically less temporally variable. While this design limits DRBC's ability to draw broad conclusions from this one study, it was informed by and implemented with the knowledge of data from previous years and will inform future research. These works are generating the spatial and temporal dataset that will enable DRBC to assess PFAS trends, hotspots, and long-term patterns more robustly in the Delaware River Basin.

3. Results and Discussion

3.1 Surface Water – Delaware River Tributaries

Tributaries are dynamic systems influenced by diverse land uses, such as industry, agriculture, and residential development, which can affect PFAS concentrations and compounds in surface water. The sampling locations within each tributary are subject to tidal influence, which can both dilute baseflow PFAS concentrations and introduce additional PFAS from the main stem of the Delaware

River. To reduce tidal dilution and better capture tributary-specific PFAS levels, samples in this study were collected at or near low tide. In contrast, sampling during the 2021 PACZM[5] study was not coordinated with tidal cycles, and although some samples were collected at low tide, this makes direct comparisons between the studies more complex.

Surface water was collected from seven sites across six Pa. Delaware River tributaries in late summer 2023. PFAS was detected in every sample, with an average of 7.9 ± 2.5 detections per sample out of the 40 targeted analytes. Chester Creek (n = 11) had the most detections, while Frankford Creek had the fewest (n = 3). Three compounds—PFHxA, PFOS, and PFOA—were quantifiable at all seven sites. Four other compounds—PFBS, PFHpA, PFNA, and PFPeA—were detected at six sites. In total, 11 PFAS compounds were quantifiable in this study's tributary surface water samples, compared to eight in the 2021 PACZM study.[5] The eight compounds—PFBS, PFHpA, PFHxS, PFHxA, PFNA, PFOS, PFOA, and PFPeA—were dominant in both PACZM-funded studies, while three additional compounds (PFBA, PFDA, and PFUnA) were newly detected in this study, though only at four or fewer sites.

In October 2023, a DRBC study funded by the Partnership for the Delaware Estuary (PDE BIL) also collected surface water from five of the same tributaries (NHC, PPC, FC, SR, and CC).[6] That study found a similar number of quantifiable compounds per site (ranging from seven to nine), and the same eight dominant PFAS compounds were observed. The consistent detection of the same core group of compounds across three studies suggests a stable PFAS signature in these tributaries. Minor differences in compound detection are likely due to tidal dilution and laboratory detection limits rather than true absence.

The tributary summed PFAS (Σ_{PFAS}) concentration, representing the total of all quantifiable compounds in a sample, ranged from 7.72 ng L^{-1} in Frankford Creek to 140.16 ng L^{-1} in Chester Creek, with an overall average of 57.09 ± 42.64 ng L^{-1} (Figure 2). The Chester Creek concentration of 140.16 ng L^{-1} notably skews the average, as it is approximately 66 ng L^{-1} higher than the next highest concentration, observed in Neshaminy Creek head of tide (NHC; 73.28 ng L^{-1}).

Overall, Σ_{PFAS} values in this study were higher than those observed in the first PACZM study, which ranged from 8.72 at Neshaminy Creek (NC) to 55.26 ng L^{-1} at Neshaminy Creek head of tide. In this study, NHC and NC exhibited the second and third highest Σ_{PFAS}, respectively. This result aligns with expectations, as Neshaminy Creek is impacted by legacy PFAS contamination from the former Naval Air Station Joint Reserve Base Willow Grove.[7] It is somewhat surprising that NC had a much lower Σ_{PFAS} of 8.72 ng L^{-1} in the previous PACZM study compared to 66.28 ng L^{-1} in this study. However, tidal conditions likely explain this discrepancy: high tide occurred around 2:15 p.m. on May 24, 2021, and the NC sample was collected shortly after, at 3:00 p.m. This timing suggests significant dilution. In contrast, the upstream NHC value was collected at low tide on November 8, 2021, at 11:30 a.m.

The highest Σ_{PFAS} concentration in this study—140.16 ng L^{-1} at the mouth of Chester Creek—was consistent with the PDE BIL study, which measured 103.38 ng L^{-1} at the same location. By comparison, the previous PACZM study reported a lower value of 45.98 ng L^{-1} at Chester Creek,

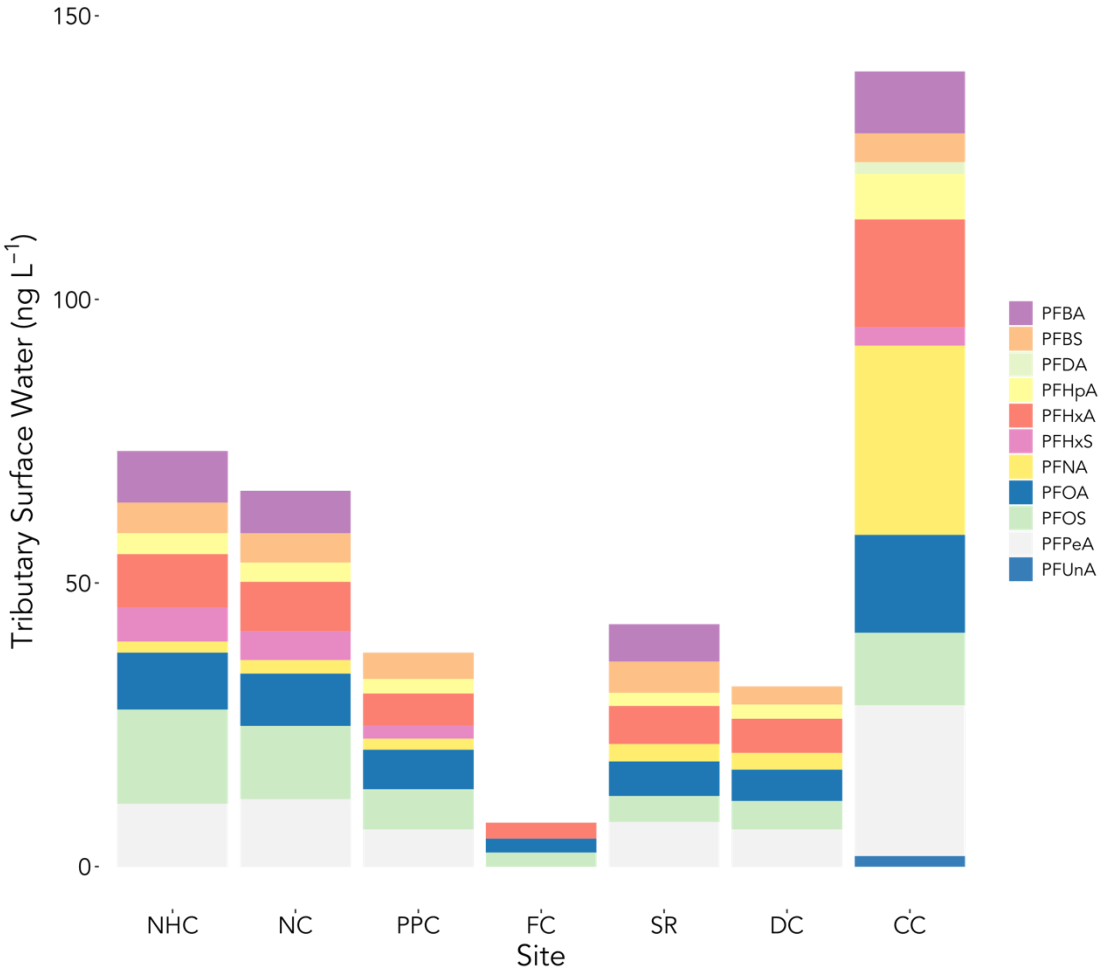

Figure 2. Tributary surface water PFAS concentrations ordered by river mile at the confluence with the Delaware River main stem.

again, possibly due to tidal dilution, as sampling occurred approximately two hours into a rising tide on May 27, 2021.

Another noteworthy result is the Σ_{PFAS} for Frankford Creek. In this study, the sample had a value of 7.72 ng L^{-1} with three compounds detected. This result is similar to the previous PACZM study, which measured 11.11 ng L^{-1} from four compounds.[5] Both samples had nearly identical PFAS compound profiles. However, they were collected under different tidal conditions: the previous PACZM study sample was taken within an hour before a high tide, while this study's sample was collected less than 30 minutes after a low tide. Despite these differences, the concentrations were comparable, suggesting that tidal dilution may not have been the sole factor influencing PFAS concentrations at this site. Both samples were collected at the same location, approximately 0.2 km (0.12 miles)

upstream from the mouth of Frankford Creek (Figure 3). This location is likely heavily influenced by Delaware River water, regardless of the approximate six-foot tidal range.

This hypothesis of the river's dilution influence is further supported by data from the recent PDE BIL study, where DRBC sampled Frankford Creek ~3 km (1.9 miles) upstream. Although this site remains under tidal influence, it is farther from the Delaware River's direct impact, especially at low tide, when the sample was collected. The Frankford Creek yielded a Σ_{PFAS} concentration of 64.35 ng L^{-1} with 9 compounds detected.[6] This concentration is ~five to six times higher than the results in either PACZM study. Notably, the compounds detected in both PACZM samples were also found in the PDE BIL sample, representing four of the highest concentrations. This indicates that river dilution likely suppressed concentrations at the more downstream PACZM site, even at or near low tide.

These findings suggest that future tidal tributary sampling efforts should aim to collect water at low tide and farther upstream from the confluence with the main stem. This would minimize the influence of main stem river water while still capturing contributions from major PFAS sources, or other target pollutants, within the watershed.

Figure 3. View of Frankford Creek's confluence with the Delaware River from a DRBC boat. This picture was taken within 0.1 miles of the Frankford Creek sampling site in this study.

3.2 Surface Water – Delaware River Main Stem

Surface water was collected at or near low tide from 10 main stem Delaware River sites between river mile 132 (Biles Channel) and 82 (Chester) in late summer 2023. PFAS was detected in all samples, with an average of 4.0 ± 1.6 detections per sample out of the 40 target analytes. Biles Channel had the fewest detections (n = 2), while the Navy Yard site had the most (n = 7). Across the main stem, PFHxA and PFOA were quantified at all 10 sampling sites, and PFOS was quantified at nine sites. No other compound was detected in more than four samples.

This pattern aligns with results from DRBC's 2021 PACZM study[5], in which PFOS and PFOA were quantifiable at all 10 mainstem sites, and PFHxA at eight. While that study found 10 compounds in

the main stem, this study identified seven, each of which was also found in 2021. These results suggest a consistent group of dominant PFAS compounds in the river since at least 2021.

The Σ_{PFAS} concentrations in the main stem ranged from 3.92 ng L^{-1} at Biles Channel to 25.28 ng L^{-1} at the Navy Yard (Figure 4). Except for Frankford Creek (discussed above), all tributary samples had higher Σ_{PFAS} concentrations than mainstem sites. This is expected given the lower flow volumes of tributaries, resulting in less dilution, which amplifies PFAS concentrations relative to the larger Delaware River or active or passive sources of PFAS that exist in tributary watersheds.

The Navy Yard sample exhibited the highest Σ_{PFAS} concentration and the most detections. This sampling site is located at the mouth of the Schuylkill River, the largest tributary in the Delaware River Basin. Conversely, Biles Channel, the most upstream site, likely experiences less cumulative impact from population density and industrial activity. Chester, located downstream, had the second highest mainstem Σ_{PFAS} (21.58 ng L^{-1}). As shown in Figure 4, Σ_{PFAS} generally increased modestly from upstream to downstream, as seen in other DRBC PFAS studies.[8] The exception remains the

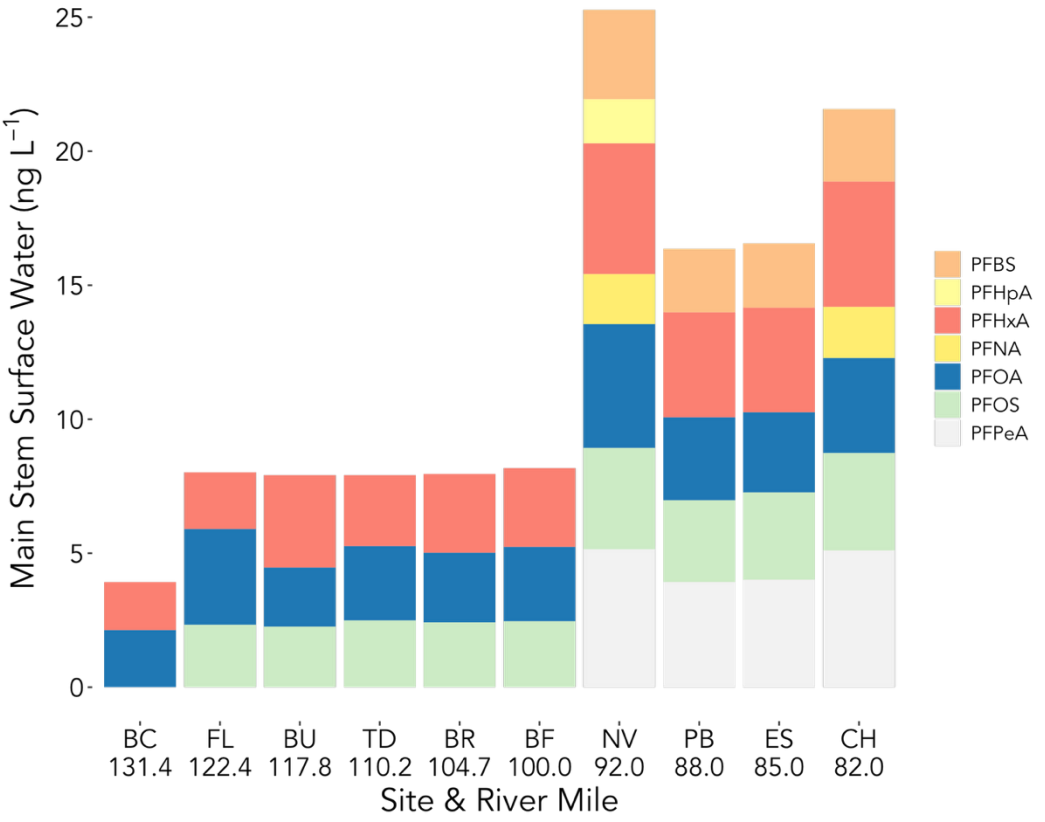

Figure 4. Delaware River main stem surface water PFAS concentrations ordered by decreasing river mile.

Navy Yard site, where influence from the Schuylkill River likely accounts for the relatively elevated concentration.

Compared to the tributaries, main stem samples consistently had fewer quantifiable compounds and lower Σ_{PFAS} concentrations. This is expected due to the main stem's higher water volume—orders of magnitude higher than its tributaries—and corresponding dilution capacity. While some compounds present in the tributaries (PFBA, PFDA, PFHxS, and PFUnA) were not quantified in the main stem, it is likely that they were still in the main stem, but below instrument detection limits.

Before the Navy Yard site, three PFAS compounds were consistently quantified at main stem locations: PFOA, PFOS, and PFHxA. These compounds have long been among the most frequently detected in the Delaware River Basin—quantified in approximately 90%, 85%, and 77% of Delaware River Basin surface water samples in the National Water Quality Portal, respectively, since 2007. In this study, PFHxA was found in all samples, and combined, these three compounds accounted for 53–100% of Σ_{PFAS} in the main stem and 41–100% in the tributaries.

PFPeA was detected in seven of the eight tributary samples, with Frankford Creek as the exception. However, it was not quantifiable in the main stem until the Navy Yard site, where it contributed 20–24% of the Σ_{PFAS} in each sample downstream. Given its widespread presence in tributaries, PFPeA was likely present upstream of the Navy Yard in the main stem, but below instrument detection limits. Its increase downstream suggests additional inputs, likely from the Schuylkill River and other sources.

The origin of PFPeA in surface waters remains unclear. It is used in a range of consumer products, including food wrappers, personal care products (lotions, creams, and concealers), cosmetics, fabrics, and more.[9] Based on these broad uses, its presence in this stretch of the river could stem from industrial or commercial discharges or municipal wastewater effluent.

3.3 Surface Water – Delaware River Main Stem: Total Oxidizable Precursor Analysis

As of April 2025, the USEPA CompTox database identifies more than 13,000 compounds that meet the definition of PFAS in the U.S.[2] However, USEPA Method 1633 targets just 40 of these compounds, leaving thousands of potential PFAS, many of which are precursors or intermediates used in commercial products,[10] undetected in routine monitoring. To account for some of these missing compounds, the Total Oxidizable Precursor (TOP) assay was developed. This method involves oxidizing a water sample prior to extraction, converting some PFAS precursors and intermediates into detectable perfluoroalkyl carboxylic acids (PFCAs) and sulfonic acids (PFSA), the compounds targeted in Method 1633. When a TOP assay is conducted alongside a standard grab sample, differences in PFAS concentrations can indicate the presence of oxidizable precursors.[10]

In this study, TOP assay analysis was performed on samples from 13 sites (Table 1). Surprisingly, no PFAS were detected in any of the TOP assay samples. This likely reflects limitations in instrument

sensitivity rather than the true absence of precursors. Standard surface water grab samples extract and concentrate 500 mL of water prior to analysis, meanwhile, TOP assay samples are limited to 60 mL—an order of magnitude difference in sample volume. As a result, PFAS compounds and their precursors were likely below detection limits after oxidation and analysis.

Although no precursors were quantified through the TOP assay in this study, this result does not necessarily indicate their absence in surface waters. Rather, it highlights the importance of developing more sensitive methods or using larger sample volumes to better evaluate the environmental presence of PFAS beyond the 40 targeted compounds using USEPA Method 1633.

3.4 Sediment – Delaware River Tributaries

Quantifiable concentrations of PFAS were found at all seven tributary sites, with seven unique compounds identified (Figure 5). All sites except for the Neshaminy Creek head of tide (NHC) and Chester Creek had five or six quantifiable compounds. The five most frequently detected were PFUnA (7 sites), PFDA (5), PFTrDA (5), PFOS (6), and EtFOSAA (4). The first three are perfluoroalkyl carboxylic acids (PFCAs), while PFOS is a perfluoroalkyl sulfonic acid (PFSA), and EtFOSAA is a precursor compound categorized as a perfluorooctane sulfonamidoacetic acid (FOSAA).

Fewer PFAS compounds were detected in sediment compared to surface water, likely due to the more complex nature of the sediment matrix, which results in higher detection limits. However, when detected, PFAS compounds in sediment (reported in μg kg^{-1}) were three orders of magnitude higher than in water (reported in ng L^{-1}). The average Σ_{PFAS} in tributary sediment was 1.43 ± 0.75 μg kg^{-1}, ranging from 0.15 μg kg^{-1} in Chester Creek to 2.33 μg kg^{-1} in Frankford Creek. This contrasts with the surface water results, where Chester Creek had the highest Σ_{PFAS} and Frankford Creek the lowest.

This inverse relationship may be explained by the difference in compound properties. Unlike "traditional" organic pollutants (e.g., PCBs and organochlorine pesticides), PFAS compound partitioning between sediment and water is typically more complex.[11] The PFAS compounds found in the sediments of Frankford Creek and Chester Creek generally have lower water solubility and higher Log K_{OC} values than those quantified in the corresponding water samples.[11] This suggests that different suites of PFAS compounds are entering these tributaries, potentially from distinct sources or pathways.

In the previous PACZM study, no PFAS were detected in Frankford Creek sediment samples. While PFAS concentrations in sediment samples should not be impacted by the timing of sampling, both PACZM sediment samples were collected at low tide from nearly identical locations. The contrasting results between both studies demonstrate the spatial heterogeneity of PFAS in sediment, even over short distances at nearly the same location.

Of the seven PFAS compounds detected in tributary sediment and 11 detected in tributary surface waters, only two were found in both media: PFUnA and PFOS. Notably, these compounds also have the highest Log K_{OC} values and lowest solubilities among those detected in tributary surface waters,[11] supporting their greater affinity for sediment.

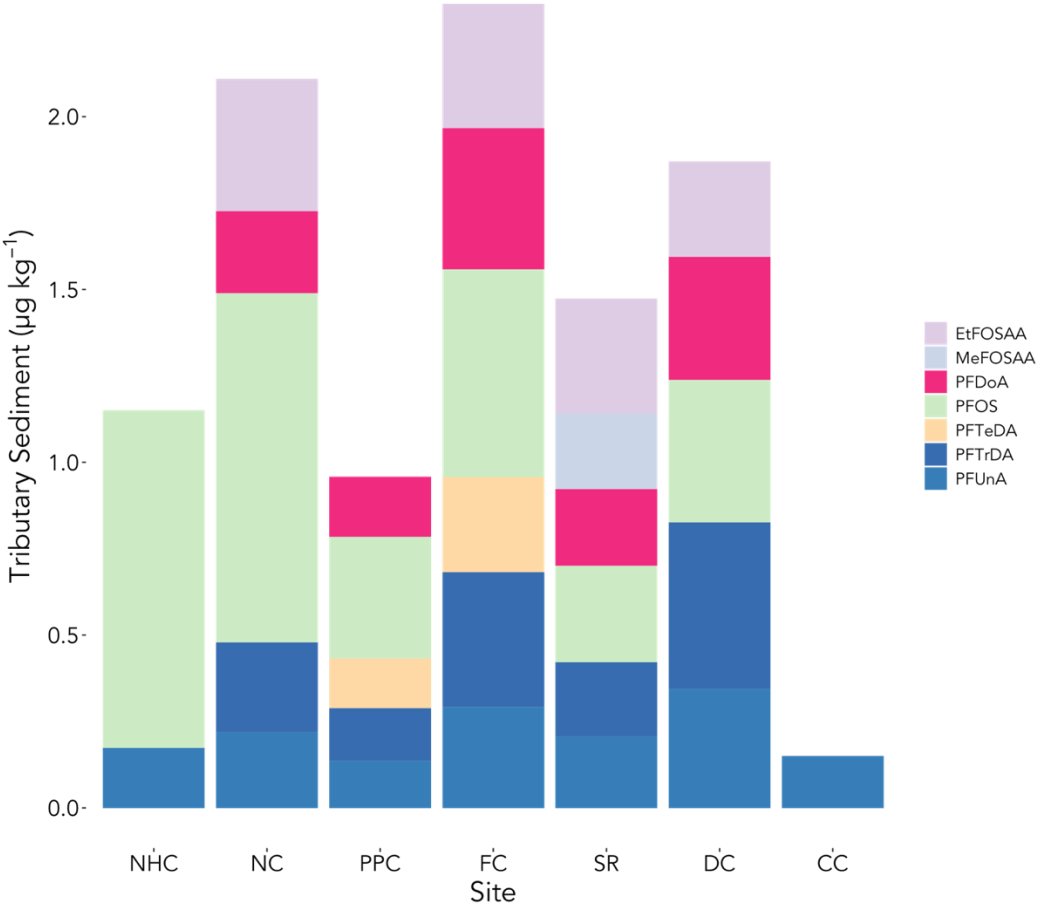

Figure 5. Delaware River tributary sediment PFAS concentrations ordered by river mile for each tributary's confluence with the river's mainstem.

These findings highlight the importance of sampling across multiple environmental media. Reliance on a single matrix (e.g., only surface water) can lead to an incomplete understanding of PFAS distribution, sources, and behavior. Comprehensive assessments of PFAS presence, fate, and transport in the Delaware River Basin must include a variety of media to accurately characterize contamination patterns.

3.5 Sediment – Delaware River Main Stem

Quantifiable PFAS concentrations were found at eight of the 10 sites sampled, with both the Navy Yard and Biles Channel having all compounds below detection limits (Figure 6). The number of PFAS detections per site ranged from 0 to 6, with an average of 2.70 ± 2.21. The Ben Franklin Bridge (n = 5), Philadelphia Airport (5), and Eddystone (6) sites had the most detections. PFOS and EtFOSAA were

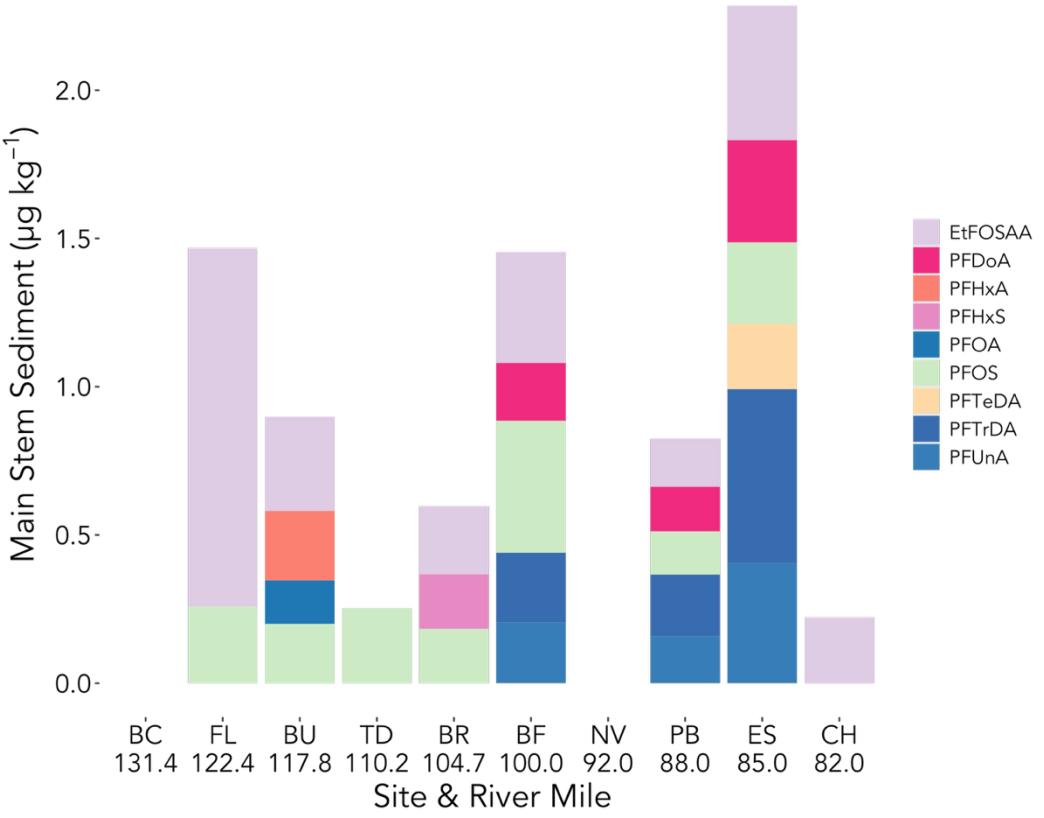

Figure 6. Mainstem Delaware River sediment PFAS concentrations ordered by river mile.

the most frequently quantified compounds, each found in seven of the 10 samples. No other compound was found at more than three sites.

PFOS was also the most commonly quantified compound in both main stem surface water and sediment samples. Notably, PFUnA and PFTrDA began appearing in sediment samples at the Ben Franklin Bridge site and peaked in concentration at the Eddystone site. Both compounds are used in a variety of consumer and industrial products, including food packaging, cosmetics, personal care products, clothing, and paints. Given these broad uses, their increased presence along and downstream of densely populated urban areas is logical.

The Σ_{PFAS} concentration in main stem sediment ranged from below detection to 2.29 µg kg^{-1}, with an average of 0.80 ± 0.75 µg kg^{-1}. The highest values were at the Eddystone (2.29 µg kg^{-1}), Florence Bend (1.47 µg kg^{-1}), and Ben Franklin Bridge (1.45 µg kg^{-1}). The two sites with the highest surface water Σ_{PFAS}, Navy Yard and Chester, had some of the lowest sediment concentrations. At the Navy Yard, all PFAS compounds were below detection, and at Chester, only EtFOSAA was quantifiable in sediment.

3.6 Channel Catfish

Channel catfish are the most abundant catfish species in North America and are commonly found throughout the Delaware River. As opportunistic predators, adult channel catfish consume a wide range of prey, including smaller fish, crustaceans, reptiles, amphibians, and even small birds or mammals. Due to this position, they are expected to accumulate PFAS through contaminated prey. Although, since they are omnivores, channel catfish PFAS concentrations should be lower than those of a top carnivore at the highest trophic level.

While the daily range of a channel catfish in the Delaware River is not well documented, studies in other river systems suggest they have a home range of 1.25 to 3 miles per day.[12,13] These distances could be longer in response to seasonal or hydrologic conditions.[14] Based on these traits, channel catfish are a useful bioindicator for PFAS presence within a few miles of where they are caught, and for assessing potential human exposure, as they are frequently consumed by local anglers.

Catfish were targeted at six sites but were only successfully caught in the Schuylkill River and at the Eddystone and Chester sites in the main stem of the Delaware River. Nine PFAS compounds were quantifiable in catfish fillet tissues (Figure 7a), with eight found in each composite sample. The fluorotelomer carboxylic acid precursor 5:3 FTCA, was found in the Schuylkill River fish. Across all catfish samples, Σ_{PFAS} was dominated by three precursor compounds: 5:3 FTCA, 7:3 FTCA, and N-EtFOSA. The remaining six PFAS compounds accounted for only 7–12% of the Σ_{PFAS} in the catfish tissue (Figure 7b). While data for 7:3 FTCA will remain in this report, fish tissues contain a biological interferent, which can result in false-positive detections.[15] Therefore, all results for 7:3 FTCA in fish tissues should be interpreted cautiously, which also applies to the previous PACZM and other studies where this compound was detected in fish tissues within the Delaware River Basin.

The detection of N-EtFOSE value is questionable due to its presence in the associated lab blank. However, all detections observed in channel catfish were >3x the lab blank concentration. The presence of N-EtFOSE is also suspect since it does not bioaccumulate because of its rapid transformation to PFOS in vertebrates under most conditions.[16] The only situation where N-EtFOSE might be found in fish would be near a major source, leading to continuous chemical exposure. In that scenario, the concentration of PFOS in the fish would also be high due to ongoing transformation from N-EtFOSE to PFOS. Therefore, N-EtFOSE in channel catfish could be valid due to a nearby source, a result of lab contamination, or, similar to 7:3 FTCA, a false positive caused by an as-yet-unidentified interferent.

The dominance of 5:3 FTCA and 7:3 FTCA mirrors results from the previous PACZM study. However, those 7:3 FTCA results should be carefully considered as it is now known to have an analytical interference in fish tissues. While N-EtFOSE was also detected in those samples, its concentrations were notably lower.[5] In a 2022 study by DRBC, 7:3 FTCA was again dominant in catfish collected at the Eddystone site, although 5:3 FTCA and N-EtFOSE were not detected at that site.[8] Despite some variation in compound profiles, the Σ_{PFAS} concentrations in the catfish at Eddystone have remained relatively consistent (~80 ng g^{-1}) across samples collected in 2021, 2022, and 2023. In contrast, the

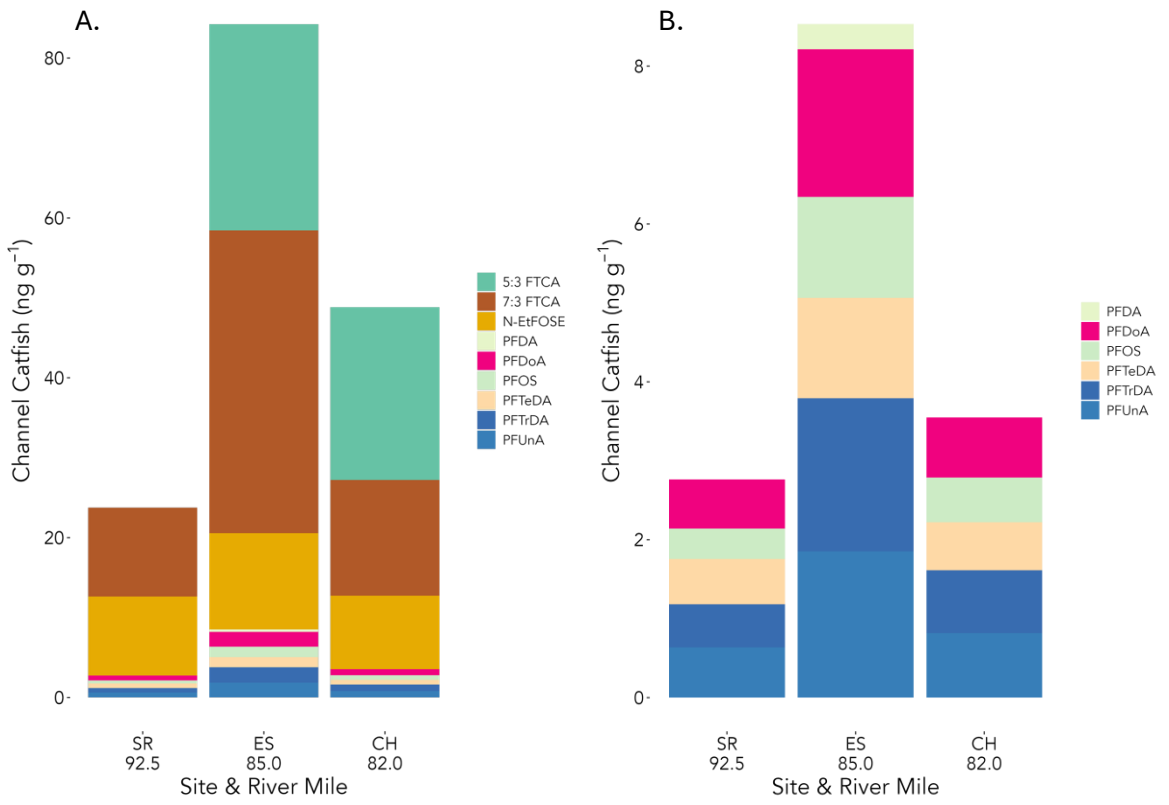

Figure 7. A) PFAS compounds quantified in channel catfish fillet tissue at three tidal Delaware River sites. B) The three dominant PFAS compounds, 5:3 FTCA, 7:3 FTCA and N-EtFOSE have been removed to better depict the presence of the less dominant compounds found in these channel catfish samples.

Chester catfish Σ_{PFAS} concentrations have shown great variability across the studies, ranging from 1.7 ng g^{-1},[8] to 178 ng g^{-1},[5] with this study measuring 49 ng g^{-1}.

As stated above, the 1.25 to 3-mile home range of channel catfish potentially enables the assessment of PFAS presence within those general spatial areas. The Schuylkill River site is approximately three miles upstream of its confluence with the Delaware River at river mile 92.5, while Eddystone and Chester are located at river miles 85 and 82, respectively. The distance between the Schuylkill River and Chester sites is ~13.5 miles. Therefore, based on previously reported home ranges, fish caught at the Schuylkill River site are not likely to overlap with fish caught at the Eddystone or Chester sites. However, fish caught at Eddystone and Chester, which are ~3 miles apart, could have overlapping exposures. This implies that the PFAS concentrations observed in channel catfish from the Schuylkill River should have a distinct exposure signature. In contrast, the Eddystone and Chester fish may have a somewhat similar PFAS exposure. This may be seen in the absence of 5:3 FTCA from the Schuylkill River fish.

3.7 White Perch

White perch are native to the Delaware River Basin and tolerate a wide range of salinities. While they can be found from the mouth of Delaware Bay into the non-tidal river north of Trenton, their population is most concentrated in the estuary. In spring, white perch converge in freshwater areas of river systems to spawn, with some individuals traveling many miles.[17] After spawning, a majority of the juvenile fish migrate into brackish waters, although some remain in the freshwaters.[17] Outside of spawning season, adult white perch have a relatively small home range of 0.11 km^2.[18] As opportunistic foragers, they consume macroinvertebrates, crustaceans, and other fish.[19] However, they may also serve as prey for larger species such as catfish.[19] Based on these traits, white perch provide an opportunity to examine PFAS accumulation in a trophic level similar to channel catfish with a smaller home range outside of the spring spawning season. Therefore, PFAS concentrations in white perch, particularly in late summer and fall, might reflect water and dietary exposure in a smaller range than that of the channel catfish.

White perch were caught at five of the six sites, with only the Schuylkill River lacking a sample. Samples from the Eddystone and Torresdale sites were collected in fall 2023, while those from the Biles Channel, Florence Bend, and Chester were collected in spring 2024. Given the species' strong site fidelity and range, the samples caught in fall 2023 likely provide a more accurate representation of PFAS exposure and bioaccumulation at those specific sites than the samples caught during spring 2024.

A suite of seven PFAS compounds—PFDA, PFDoA, PFOS, PFOSA, PFTeDA, PFTrDA, and PFUnA—was detected in white perch at all sites (Figure 8), with the number of quantified compounds ranging from seven at Biles Channel to nine at Eddystone. The concentrations of these compounds exhibited an increasing trend from Biles Channel to Torresdale, followed by a decline from Eddystone to Chester. However, this general pattern is interrupted by the presence of two precursor chemicals, 5:3 FTCA and N-EtFOSE, which spike the Σ_{PFAS} at Eddystone. As stated above, regarding the concentrations detected in channel catfish, N-EtFOSE in white perch could be real due to a nearby source, a result of lab contamination, or, as with 7:3 FTCA, a false positive due to a yet-to-be-identified interferent.

Among all quantified PFAS with more than one detection, PFOS had the highest average concentration across all sites, at 6.26 ± 2.31 ng g^{-1}.

3.8 Fish Consumption

While PFAS compounds are receiving significant attention, established toxicity thresholds remain limited. PFOS is one exception. In 2016, the USEPA published a chronic Reference Dose (RfD) of 0.02 µg $kg^{-1}day^{-1}$.[20] This represents an estimate, accounting for an order of magnitude of uncertainty, of the daily exposure level per kilogram of body weight that is likely to be without considerable health

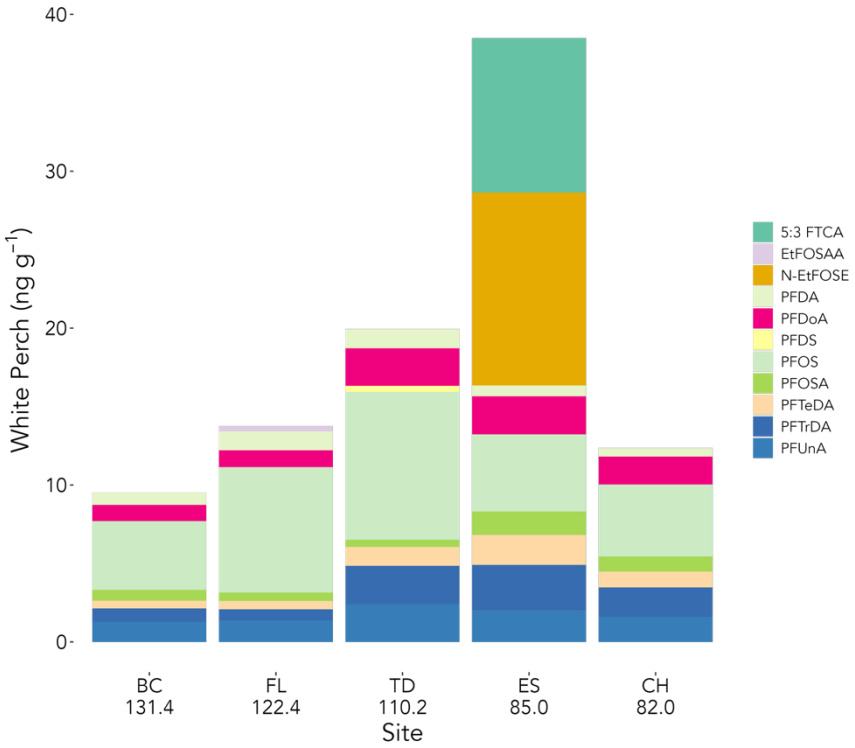

Figure 8. PFAS compounds quantified in white perch fillet tissue at five tidal Delaware River sites.

risk over a lifetime. For a 70 kg (154 lb) adult, this equates to a daily intake limit of 1.4 µg day^{-1} of PFOS over the course of their life.

$$0.02\ \frac{\mu g}{kg\ \cdot\ day} \times\ 70kg = 1.4 \frac{\mu g}{day}$$

The NJ Department of Environmental Protection and Health's *Fish Smart, Eat Smart* guide (2021), defines a single serving of fish as 8 ounces or 226.8 g.[21] Using this serving size, potential PFOS exposure from fish consumption can be estimated based on concentrations observed in the fish collected during this study and compared to USEPA RfD values.

For channel catfish, the average PFOS exposure from an 8 oz serving was 0.12 ± 0.03 µg, similar to findings from DRBC's first PACZM study. This value is approximately an order of magnitude below the EPA's chronic RfD, suggesting that, based on PFOS levels alone, these fish present a relatively low risk if consumed occasionally.

In contrast, the average PFOS exposure from an 8 oz serving of white perch was 1.42 ± 0.52 µg, comparable to the previous PACZM study (1.96 ±1.07 µg), and approaches the EPA's chronic daily threshold for a 154 lb adult. Notably, three of the five white perch samples (Florence Bend, Torresdale, and Eddystone) exceeded this PFOS threshold.

To reiterate, the EPA RfD value is based on lifetime daily exposure. Most individuals do not consume locally caught fish on a daily basis, and PFOS concentrations can vary widely between individual fish. The state of Pennsylvania currently does not issue a fish consumption advisory for PFOS in the section of the Delaware River sampled in this study. However, New Jersey does have an advisory in place for this stretch of the river. While it includes PFOS among the contaminants of concern, the advisory does not distinguish between species or specific pollutants. It does recommend limiting white perch consumption in this area to four meals per year, with some location-specific variations.[21]

4. Conclusions

This study explores the complex distribution of PFAS in the Pa. Coastal Zone of the Delaware River Estuary, finding these chemicals in water, sediment, and fish tissue. The variety of PFAS compounds and the differences in suites of compounds in each environmental matrix demonstrate the need for comprehensive environmental studies. The findings indicate that the sources of PFAS entering the waterways are likely diverse, potentially stemming from industrial discharges, wastewater treatment plants, and runoff from urban and agricultural areas. This complexity necessitates the implementation of targeted monitoring and management strategies to mitigate the release of these persistent pollutants. Given the findings, a multi-faceted approach to sampling and analysis is not just beneficial but essential to accurately characterize PFAS dynamics in the environment and inform effective mitigation efforts, particularly in areas with known PFAS sources or elevated levels of contamination. This study adds to the existing PFAS dataset in the Delaware River Basin and will also help guide future research and efforts by DRBC to mitigate these compounds.

5. Environmental Data Sets

These data and related items of information have not been formally disseminated by NOAA, and do not represent any agency determination, view, or policy. Data generated with this funding were uploaded to the USEPA's Water Quality Exchange (WQX; https://www.epa.gov/waterdata/water-quality-data-upload-wqx). These data are then accessible through the U.S. Government's National Water Quality Portal (WQP; https://www.waterqualitydata.us) as of July 4th, 2025. The following links provide direct access to the WQP queries and datasets for all data from this project, as well as separate links for water, sediment, and fish.

Complete project dataset

***Query*:** https://www.waterqualitydata.us/#sampleMedia=Water&project=PACZM%20-%20PFAS&mimeType=csv&dataProfile=resultPhysChem&providers=NWIS&providers=STORET

Data: https://www.waterqualitydata.us/data/Result/search?sampleMedia=Water&project=PACZM%20-%20PFAS&mimeType=csv&zip=yes&dataProfile=resultPhysChem&providers=NWIS&providers=STORET

Water Dataset

Query: https://www.waterqualitydata.us/#sampleMedia=Water&project=PACZM%20-%20PFAS&mimeType=csv&dataProfile=resultPhysChem&providers=NWIS&providers=STORET

Data: https://www.waterqualitydata.us/data/Result/search?sampleMedia=Water&project=PACZM%20-%20PFAS&mimeType=csv&zip=yes&dataProfile=resultPhysChem&providers=NWIS&providers=STORET

Sediment Dataset

Query: https://www.waterqualitydata.us/#sampleMedia=Sediment&project=PACZM%20-%20PFAS&mimeType=csv&dataProfile=resultPhysChem&providers=NWIS&providers=STORET

Data:
https://www.waterqualitydata.us/data/Result/search?sampleMedia=Sediment&project=PACZM%20-%20PFAS&mimeType=csv&zip=yes&dataProfile=resultPhysChem&providers=NWIS&providers=STORET

Fish Tissue Dataset

Query: https://www.waterqualitydata.us/#sampleMedia=Tissue&project=PACZM%20-%20PFAS&mimeType=csv&dataProfile=resultPhysChem&providers=NWIS&providers=STORET

Data: https://www.waterqualitydata.us/data/Result/search?sampleMedia=Tissue&project=PACZM%20-%20PFAS&mimeType=csv&zip=yes&dataProfile=resultPhysChem&providers=NWIS&providers=STORET

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