PFAS Concentrations in Surface Water, Freshwater Fish and Invertebrates, and Coastal Fish and Shellfish in Massachusetts

Prepared for:
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Notice of Availability

This report is available on the Massachusetts Department of Environmental Protection website.

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Cover Photo

Various 2024 PFAS sampling locations. Courtesy of Normandeau Associates, Inc.

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Acronyms & Abbreviations

AFFF	aqueous film-forming foam
ANOVA	analysis of variance
AWQC	Ambient Water Quality Criteria
BAF	bioaccumulation factor
CZM	Massachusetts Office of Coastal Zone Management
DIW	de-ionized water
MA DMF	Massachusetts Division of Marine Fisheries
DQO	data quality objective
EDD	electronic data deliverable
EPA	U.S. Environmental Protection Agency
ERG	Eastern Research Group, Inc.
FOD	frequency of detection
g	gram
HHC	Human Health Criteria
ITRC	Interstate Technology & Regulatory Council
kg	kilogram
L	liter
LC-MS/MS	liquid chromatography tandem mass spectrometry

MA DPH	Massachusetts Department of Public Health
MassDEP	Massachusetts Department of Environmental Protection
MassWildlife	Massachusetts Division of Fisheries and Wildlife
MDCR	Massachusetts Department of Conservation and Recreation
MDL	method detection limit
Media	Soil, water, air, biota (plants and animals), or any other parts of the environment that can contain contaminants.
MRL	method reporting limit
mL	milliliter
mm	millimeter
ng	nanogram
NA	not applicable
NHDES	New Hampshire Department of Environmental Services
Normandeau	Normandeau Associates, Inc.
ORS	MassDEP Office of Research and Standards
PFAS	per- and polyfluoroalkyl substances
PFCA	perfluorinated carboxylic acid
PFSA	perfluorinated sulfonic acid
RCRA	Resource Conservation and Recovery Act
RPD	relative percent difference
SAP	sampling and analysis plan
SD	standard deviation
SOP	standard operating procedures
USGS	U.S. Geological Survey
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
VTDEC	Vermont Department of Environmental Conservation
WES	MassDEP William X. Wall Experiment Station
WPP	MassDEP Watershed Planning Program
ww	wet weight
Σ	sigma/sum
ΣPFAS40	sum of 40 PFAS measured in EPA Method 1633A
ΣPFAS39	sum of 40 PFAS measured in EPA Method 1633A, excluding NEtFOSE

For a list of PFAS Analyte acronyms, see Table 6.

Executive Summary

Per- and polyfluoroalkyl substances (PFAS) are a large group of man-made fluorinated chemicals that break down slowly and can build up in humans, wildlife, and the environment. Due to their persistence and solubility, PFAS have been detected in many drinking water sources, as well as in surface water, aquatic life, and other parts of the environment. In response to their presence in the environment and related toxicity, environmental and public health agencies at all levels of government across the U.S. are working to better understand the scope of PFAS contamination and its potential impacts on human health and ecosystems.

This project assessed the extent and magnitude of PFAS contamination at selected sampling locations in both freshwater and coastal environments in Massachusetts. Sampling occurred during the summer and fall of 2024 at 10 freshwater and 26 coastal locations. While most sampling locations were selected based on proximity to known or suspected PFAS sources—such as industrial areas, major river mouths, and busy harbors—five "reference" waterbodies not near any known sources were also included for comparison. At freshwater sites, co-located samples of fish (processed as both whole-body and boneless, skinless filets), invertebrates (composited by taxonomic class), and surface water were collected. This resulted in 41 whole fish, 33 fish filets, 45 composite invertebrate samples, and 10 surface water samples. At coastal sites, sampling included fish (processed as boneless, skinless filets), shellfish (composited by species), and surface water, yielding 89 fish filets, 81 composite shellfish samples (comprised of 380 individual shellfish), and 27 surface water samples. All samples were analyzed for 40 PFAS using EPA Method 1633A, and detection limits were consistently low. Laboratory results were evaluated against the project's data quality objectives (DQOs), outlined in the Quality Assurance Project Plan (QAPP), and were validated by MassDEP.

Using the final validated data, descriptive statistics were calculated by sample type and PFAS analyte. Differences in PFAS concentrations were compared across several variables, including waterbody characteristics (e.g., region, reference versus non-reference) and sample characteristics (e.g., species). The contribution of individual PFAS analytes to the total PFAS detected in a sample were examined for surface water and biota. Where possible, bioaccumulation factors (BAFs) were calculated using co-located tissue and surface water samples for a subset of PFAS detected in both media. Finally, sample results were compared to final recommended ambient water quality criteria (AWQC) and benchmarks for the protection of aquatic life and draft recommended AWQC for the protection of human health (HHC) published by the U.S. Environmental Protection Agency (EPA), as well as screening values from the Massachusetts Department of Public Health (MA DPH).

Freshwater Results

- <u>Surface Water</u>: PFAS were detected at nine of the 10 freshwater sites, with PFOA most frequently detected (90% of sites) and with the highest median concentration

(4.39 ng/L). Of the measured PFAS, perfluorinated carboxylic acids (PFCAs), such as PFOA, contributed the greatest amount to the total PFAS. PFOS, a perfluoroalkyl sulfonic acid (PFSA), was detected at the highest concentration, 66.4 ng/L from a sample collected at Studleys Pond (Rockland, MA).

- Fish: In general, analyte concentrations in whole fish were higher than in fish filets from the same species. PFTrDA was detected most frequently (97% of fish filets), followed by PFDoA, PFOS, and PFUnA in fish filets. These same analytes were detected in all whole fish samples (100%), at median concentrations that were two to five times higher than in filets. The sum of measured PFAS ranged from 0.167 ng/g to 156 ng/g in filets and 3.33 ng/g to 1,336 ng/g in whole fish. PFNA and PFOA were also detected at much higher rates in whole fish compared to filets, suggesting PFAS tend to accumulate in various tissues (blood and internal organs) within the fish, not just muscle tissue.
- Invertebrates: All sites had detectable concentrations of at least one PFAS, with PFOS found in all samples. Similar to fish, PFDoA, PFUnA, and PFTrDA were also commonly detected. Notably, PFOA, PFNA, and PFTeDA were detected in at least one invertebrate sample from each waterbody. The sum of measured PFAS ranged from 0.491 ng/g to 184 ng/g. PFAS profiles varied considerably by waterbody, suggesting that waterbody-specific factors may influence PFAS composition more than species-specific factors.

Freshwater data showed considerable differences in the PFAS analytes detected across media, particularly between water and tissue samples. For instance, PFTeDA, PFTrDA, PFUnA, and PFDoA were detected in over 50% of fish filets, whole fish, and invertebrates, but were not detected in any water samples.

For freshwater fish filets, whole fish, and invertebrates, BAFs were calculated for frequently detected PFAS (PFOS, PFOA, PFNA, and PFHxS) based on co-located tissue and water samples. Whole fish showed greater bioaccumulation than fish filets for each PFAS. Additionally, PFOS exhibited higher bioaccumulation compared to PFOA or PFNA within species and tissue type. For invertebrates, BAFs were only able to be calculated for PFHxS.

At one location, Studleys Pond, PFAS concentrations were orders of magnitude higher than other freshwater sites. Located downstream of the former South Weymouth Naval Air Station, a known PFAS contamination site, Studleys Pond was previously sampled in 2023 for PFAS in surface water and fish tissue. This report reaffirms those high concentrations and adds new data on PFAS in additional media and at a different point in time. Notably, Studleys Pond had high levels of commonly detected PFAS, like PFOS, as well as less frequently detected analytes, including 7:3 FTCA (up to 546 ng/g in whole fish) and 8:2 FTS (up to 135 ng/g in invertebrates).

Coastal Results

- Surface Water: PFAS were detected in 63% of coastal surface water sites. PFOA was the most frequently detected analyte (59% of sites), followed by PFOS (41%).

The highest concentrations were recorded for PFOA (3.20 ng/L) and PFOS (2.67 ng/L) at Pine Creek (Ipswich, MA), where the highest total PFAS concentrations were also measured. At five of the 26 locations, only a single PFAS analyte was detected, all at low levels.

- Fish: All coastal sampling locations with fish had at least one fish filet with detectable concentrations of at least one PFAS. PFOSA, a precursor to PFOS, was most frequently detected (68.5% of samples). PFOS and PFTrDA were also found in more than half of the samples, though concentrations were low (below 0.2 ng/g). The highest total PFAS concentration was 5.94 ng/g from Great Pond (Falmouth, MA).
- Shellfish: Sixty-five percent of shellfish samples had detectable PFAS. PFOSA was the most frequently detected PFAS, detected in 48% of samples and in at least one sample from roughly half of the coastal locations. The highest total PFAS concentration was 1.37 ng/g, indicating that overall PFAS concentrations in shellfish were lower compared to those found in coastal fish filets.

The number of PFAS detected in coastal media, as well as the concentrations of PFAS in these samples, were generally low across sample types. In surface water, PFOA and PFOS were the most frequently detected compounds. In fish filets, PFOSA and PFOS had the highest detection frequencies, while in shellfish, PFOSA and PFOA were most frequently detected.

Due to limited detections in paired coastal water and tissue samples, BAFs were only calculated for PFOA in quahogs.

Freshwater and Coastal Results Comparison

PFAS concentrations in surface water were much lower in coastal samples compared to freshwater samples, which is consistent with the literature (Barbo et al., 2023; Yamada et al., 2014). For instance, in this study, PFOA, the only PFAS detected in more than half of both coastal and freshwater samples, was on average 88% lower in coastal water than freshwater. Despite these differences, the types of PFAS present were similar across coastal and freshwater locations. In nearly all waterbodies where PFAS were detected, PFCAs (including PFOA) represented more than half of the total PFAS, while PFSAs (including PFOS) usually accounted for 40% or less.

Similarly, PFAS concentrations in fish filets were generally higher in freshwater compared to coastal samples. PFOS was the only PFAS detected in at least 50% of filets from both freshwater and coastal sites, and its concentration was, on average, 94% lower in coastal fish filets compared to freshwater fish filets.

Comparisons to PFAS Criteria, Benchmarks and Screening Values

PFAS concentrations in all media were compared to appropriate criteria and benchmark values to put the results in context for human and environmental health. Additionally, because toxicity data are lacking for many PFAS, there are no established comparison values for many of the compounds measured using EPA Method 1633A. A lack of toxicity data does not mean these compounds are safe; it means these compounds have not been studied as thoroughly as others.

Surface water: Results for surface water samples were compared to EPA's recommended acute and chronic aquatic life AWQC for PFOS and PFOA in freshwater, acute freshwater benchmarks for eight other PFAS, and acute estuarine/marine benchmarks for PFOA and PFOS. Overall, PFAS concentrations in this study were much lower—by several orders of magnitude—than these criteria and benchmarks.

Surface water results were also compared to EPA's draft recommended Human Health Criteria (HHC) for PFOS, PFOA, and PFBS. The draft HHC for PFOS and PFOA are lower than the detection limits in this study, meaning all detections of PFOS (18 of 30 sites) and PFOA (24 of 30 sites) exceeded these criteria. In contrast, the draft human health criterion for PFBS was not exceeded in any surface water sample.

Tissue and whole-body: Results for tissue and whole-body samples from freshwater locations were compared to EPA's recommended chronic aquatic life AWQC for PFOS and PFOA. None of the samples exceeded the criteria for PFOA in whole fish, filets, or invertebrates. However, PFOS concentrations exceeded the criteria in all three tissue types collected from Studleys Pond.

Edible fish tissue (filet) sample results were also compared to a health-based fish action level developed by MA DPH (0.22 ng/g for select PFAS, including PFOS). This value was exceeded in at least one fish filet sample at 26 of 30 sites where fish were collected (including freshwater and coastal sites).

NOTE: All references to MA DPH PFAS guidance and action levels in this report are for general comparison or discussion purposes only and are not intended to imply or recommend human-health based advisories, which are the purview of MA DPH.

Conclusions

This study characterizes PFAS contamination across selected aquatic ecosystems in Massachusetts, including both freshwater and coastal sites. While only 40 of potentially hundreds of PFAS present in ambient waters were investigated, PFAS were detected at all locations, including reference sites, with concentrations varying by location, sample type, and species. Overall, for the sites sampled, PFAS were more frequently detected and at higher concentrations in freshwater than coastal environments.

All **freshwater sites** had detectable PFAS in fish and invertebrates, and most had detectable levels in surface water. PFOS, PFDoA, and PFUnA were frequently detected in freshwater fish and invertebrates, while PFOA was the most common analyte in surface water. Invertebrates, who live in or near sediments, where PFAS tend to accumulate over time, showed a broader range of PFAS detections than fish. This suggests that invertebrates may be sensitive indicators of PFAS contamination. Notably, whole fish had higher PFAS concentrations than filets, indicating accumulation in non-muscle tissues and blood.

For **coastal areas** sampled, PFAS were generally detected less frequently and at lower concentrations than at freshwater sites. Note that lower concentrations in coastal waters compared to freshwater are expected, due to greater water volumes, flushing rates, and dilution. The coastal sites sampled also had fewer proximal known or suspected sources of PFAS contamination compared to freshwater sites. PFOA was the most commonly detected compound in surface water, while PFOSA was the most frequently found compound in fish and shellfish. Even though concentrations were lower, PFAS were still present in many coastal samples, including species that are commonly harvested and consumed, like quahogs, which showed some evidence of PFAS accumulation. Differences in PFAS concentrations among coastal locations may be influenced by factors such as ocean currents and species movement, which make patterns harder to interpret.

Overall, PFAS were detected, generally at low concentrations, at all project locations and in all media sampled. All results were less than recommended and/or applicable human health and aquatic life thresholds (i.e., criteria, benchmarks, action levels, and/or screening values), except for the following:

- All PFOS and PFOA detections (surface water and tissue) exceeded EPA's draft recommended HHC.
- At least one fish filet sample at 26 of the total 30 sites where fish were collected (i.e., freshwater and coastal sites, including three reference locations) exceeded the health-based fish action level developed by MA DPH. Note: These results are subject to further evaluation and risk assessment by MA DPH to assess the potential need for fish consumption advisories.
- Tissue samples from Studleys Pond exceeded EPA's final recommended AWQC for PFOS.

Together, these findings highlight the ongoing environmental and human health relevance of PFAS in Massachusetts and the need for continued monitoring, risk assessment, and mitigation efforts—particularly in areas with elevated exposure risk or sensitive populations.

1. Introduction

This project assessed the occurrence and magnitude of per- and polyfluoroalkyl substances (PFAS) in coastal and freshwater locations across the Commonwealth of Massachusetts. In coastal waters, surface water and muscle tissues of fish and shellfish were sampled; and in freshwater, fish (whole fish and filets), invertebrates, and surface water were sampled from lakes and rivers. Samples were collected from 26 coastal locations and 10 freshwater locations, with a focus on waterbodies for which there is evidence of elevated PFAS concentrations. Sampling occurred during the summer and fall of 2024, and all samples were analyzed for 40 unique PFAS analytes. This report summarizes the study design, sampling and analysis methods, and analytical results.

This project was funded by the Watershed Planning Program (WPP) within the Division of Watershed Management, Bureau of Water Resources, Massachusetts Department of Environmental Protection (MassDEP). The project team included MassDEP, Eastern Research Group, Inc. (ERG), Normandeau Associates, Inc. (Normandeau), and SGS AXYS laboratories. MassDEP and ERG managed the overall effort, Normandeau was responsible for field sampling and sample preparation, and SGS AXYS conducted laboratory analyses for PFAS using EPA Method 1633A. As needed throughout the project, WPP staff consulted with MassDEP's Office of Research and Standards (ORS) and the Department's environmental analysis laboratory, the William X. Wall Experiment Station (WES). Additional coordination occurred with state agency partners, including the Massachusetts Department of Public Health (MA DPH), the Massachusetts Department of Fish and Game's Division of Fisheries and Wildlife (MassWildlife) and Division of Marine Fisheries (MA DMF), and the Office of Coastal Zone Management (CZM). Local town administrators and shellfish constables also assisted in coordinating sample collection at specific locations.

In addition to this report, supplementary information is available on MassDEP's PFAS in Surface Water and Fish Tissue webpage. Online materials include:

- Quality Assurance Project Plan (QAPP): A document describing the procedures used throughout the project to ensure that environmental samples were collected and analyzed to meet project requirements and that the resulting data are of a known and documented quality. The QAPP covers project management, schedule, goals and objectives, data quality objectives (DQOs), sampling design, sample handling, analytical methods, quality control procedures, data management, data usability, and more. The document also includes a copy of the laboratory's standard operating procedures (SOP) for the analytical method used.
- Sampling and Analysis Plan (SAP): A document detailing sampling procedures and logistics.
- Analytical Results: A downloadable file that includes surface water, fish tissue, shellfish tissue, and invertebrate tissue results, as well as relevant field data.
- PowerPoint presentation: A PDF of a PowerPoint presentation summarizing key findings.

The remainder of this report presents methods and findings. Section 2.0 offers background information on PFAS, including an overview of prior studies that informed this effort. Section 3.0 outlines the study design and summarizes the sampling and analytical methods used; additional methodological details can be found in the QAPP and SAP. Section 4.0 presents the analytical results and data limitations. Section 5.0 provides conclusions and offers recommendations for future research. Finally, Section 6.0 contains the references cited throughout the report. Additional information on sampling locations and the types of samples collected at each site can be found in Appendices A and B, respectively. Media-specific results are presented in Appendices C through H. The QAPP, SAP, and details on MassDEP's data validation process are included in Appendices I through K and project fact sheets are provided in Appendices L and M.

2. Background

PFAS are a large class of synthetic fluorinated chemicals that have been widely manufactured and used for decades. Known for their heat-resistance, chemical stability, grease-resistance, and non-stick properties, PFAS have been used in a broad range of consumer products, including paper food packaging, non-stick cookware, and textiles, as well as incorporated into industrial processes and firefighting foams, particularly aqueous film-forming foam (AFFF). Over the past 80 years, these chemicals have accumulated in the environment, contaminating waterbodies and biota, and have also been detected in humans (MA PFAS Interagency Task Force, 2022).

PFAS enter freshwater and marine surface waters through several pathways, including contaminated groundwater, stormwater runoff, and discharges from wastewater treatment plants, landfills, composting operations, and other industrial facilities. Atmospheric deposition, both from local sources and long-range transport, can also contribute to PFAS contamination. In Massachusetts, previous reports and studies have documented widespread PFAS contamination in surface water and fish tissue, originating from wastewater discharges, chemical spills, and historical use of AFFF (MA PFAS Interagency Task Force, 2022).

The widespread nature of PFAS in the environment is of concern due to their persistence, potential for bioaccumulation, and well-documented toxicological effects. In aquatic organisms, PFAS exposure has been linked to reproductive and developmental toxicity, oxidative stress, disruption of the metabolic and immune system, and, at high concentrations, cellular damage and necrosis (EPA, 2024a; EPA, 2024b). In humans, PFAS have been linked to various adverse health effects including, but not limited to elevated cholesterol levels, decreased antibody response to vaccines, developmental effects in children, pregnancy-induced hypertension/pre-eclampsia, and some cancers. In humans, exposure can occur through multiple pathways, including ingestion of contaminated drinking water, incidental ingestion and dermal contact during recreational activities, and consumption of affected fish and shellfish (EPA, 2024d, 2024e, 2024f).

Once in the environment, some PFAS precursors can degrade into more stable and persistent compounds, such as PFOS and PFOA, further contributing to long-term contamination and associated health risks (Guelfo et al., 2021). In the early 2000s, manufacturers voluntarily phased out PFOA and several other legacy PFAS as part of EPA's PFOA Stewardship Program (Bock & Laird, 2022). EPA also introduced the Significant New Use Rules under the Toxic Substances Control Act, which requires companies to notify EPA before using a chemical in a new way, thereby preventing these legacy PFAS from being reintroduced into the market without oversight (Bock & Laird, 2022). However, these compounds are often replaced by newer PFAS, such as GenX (HFPO-DA) and other short-chain alternatives, which were initially marketed as safer (Bock & Laird, 2022). Research suggests that many of these replacement PFAS also pose health and environmental risks, though far less is known about their toxicity and bioaccumulation potential (ITRC, 2023). In addition, less is known about the occurrence of these newer PFAS in the environment and people, as current analytical methods only detect a small portion of the thousands of PFAS potentially present in the environment.

2.1. PFAS Regulations, Criteria, and Benchmark Values

Although scientists have studied PFAS in biota and humans for many years, regulatory action in the United States has largely taken shape in the past decade. In October 2024, EPA published final ambient water quality criteria (AWQC) recommendations for the protection of aquatic life for PFOA and PFOS (EPA, 2024a, 2024b). For freshwater, EPA established acute and chronic AWQC for the water column, as well as chronic tissue-based concentrations to account for bioaccumulation. EPA also published recommended acute saltwater benchmarks for the protection of aquatic life for both PFAS. At this same time, EPA published acute freshwater aquatic life benchmarks for eight other PFAS with more limited toxicity data, including PFBA, PFHxA, PFNA, PFDA, PFBS, PFHxS, 8:2 FTUCA, and 7:3 FTCA (EPA, 2024c).

In December 2024, EPA published draft recommended human health water quality criteria (HHC) for PFOA, PFOS, and PFBS (EPA, 2024d, 2024e, 2024f). These draft HHC specify PFAS concentrations in surface water that are protective of human health through water ingestion and consumption of fish and shellfish from affected waterbodies. These values are based solely on data and scientific judgment, and do not consider analytical capabilities or laboratory detection limits. EPA also published draft national bioaccumulation factors (BAFs) for the same three compounds (EPA, 2024g).

In Massachusetts, state agencies have sought to characterize PFAS contamination and mitigate exposure through ongoing monitoring and regulatory efforts. For surface water, MA DPH has issued *Operational Guidance for Bathing Beaches at PFAS-Impacted Waterbodies* that includes health-protective action levels for PFAS. These levels are applied at permitted bathing beaches across the state (MA DPH, 2024). This guidance sets a health-protective screening value of 20 ng/L for eight individual PFAS—PFBA, PFBS, PFHxA, PFHxS, PFOA, PFOS, PFNA, and HFPO-DA (also known as GenX)—and outlines follow-up actions if concentrations exceed that value. In addition, MA DPH has developed draft fish action levels, protective of human consumption, for seven PFAS (excluding PFHxA) (MA DPH, 2023a).

Other states have also developed surface water and/or fish tissue screening levels and guidelines for PFAS. These state-level efforts, along with federal initiatives, are guided by data from studies evaluating PFAS in various environmental media. While a comprehensive review of all state regulatory and advisory frameworks across the U.S. is beyond the scope of this study, some examples illustrate the breadth and ongoing nature of this work. The Minnesota Pollution Control Agency has developed health-based chronic surface water quality criteria for six PFAS, including PFOS (criteria developed in 2020), PFBS, PFBA, PFHxS, PFHxA, and PFOA (criteria developed in 2023). These standards protect against exposures through water ingestion, fish consumption, and recreational activities (MPCA, 2020, 2023, 2024). The Michigan Department of Environment, Great Lakes, and Energy has established aquatic life (acute and chronic) and human health water quality criteria for several PFAS, most recently publishing human health water quality values for PFHxS and PFNA (MI EGLE, 2023). In 2022, the Wisconsin Department of Natural Resources finalized surface water quality criteria for PFOS to protect against risks from fish consumption, and for PFOA to address incidental ingestion of surface water during recreational activities (WI DNR, 2022).

Numerous state agencies and entities have also developed screening values, guidance, and/or fish consumption advisories for PFAS, such as the Michigan Department of Health and Human Services (MI DHHS, 2016), Maine Center for Disease Control and Prevention (ME CDC, 2024), Oregon Health Authority (OHA, 2022), and Great Lakes Consortium for Fish Consumption Advisories (Great Lakes Consortium, 2019). Additional relevant screening values are available through the Interstate Technology Regulatory Council (ITRC), which has compiled information on PFAS regulations and guidance for water, soil, and air (ITRC, 2023, 2025). The compilation includes surface water screening values and was most recently updated in March 2025.

2.2. *Prior Related PFAS Studies*

This section identifies and briefly describes relevant research on PFAS in freshwater and marine systems. It is not intended to be a comprehensive literature review, but rather to provide background information that helps place the data generated from this study in context.

Selected Freshwater PFAS Studies

Several studies have investigated PFAS in freshwater aquatic environments in Massachusetts, including:

- MassDEP, through its WPP, collaborated with the U.S. Geological Survey (USGS) in 2020 to conduct repeated surface water sampling at river sites located upstream and downstream of wastewater treatment plants (USGS, 2023). PFAS were detected in all 27 rivers and streams sampled, with consistently higher concentrations observed downstream of the plants.
- In 2021, MA DPH collected surface water samples from 16 lakes and ponds, along with fish from a subset of five of these waterbodies, located near Joint Base Cape Cod, a site of known PFAS contamination (MA DPH, 2021). PFAS were detected in all surface water samples, and fish consumption advisories were issued for all five waterbodies where fish samples were collected.
- Additionally, in 2022, MA DPH collected surface water and fish samples at 13 Massachusetts Department of Conservation and Recreation (MDCR) freshwater properties with public beaches, as well as surface water samples at seven additional marine MDCR beach locations. This study aimed to assess potential human exposure to PFAS through recreational activities, including swimming and fishing. Of the 20 waterbodies sampled, 11 had detectable levels of at least one PFAS in surface water, though only one detection exceeded MA DPH's screening value of 20 ng/L. PFAS were either not detected or were present at low levels in

surface water from the coastal sites. In contrast, PFAS were detected in fish tissue at all 13 freshwater locations, with concentrations exceeding the MA DPH draft fish action level prompting the issuance of fish consumption advisories at all sites (MA DPH, 2023b).

- Also in 2022, MassDEP-WPP undertook a broader statewide investigation of PFAS in fish and surface water across 52 freshwater rivers, streams, and lakes (referred to throughout this report as the "MassDEP 2023 PFAS Study"; MassDEP, 2023). PFOA was detected in surface water at all sites, including reference locations with no known nearby PFAS source. PFOS was detected in fish from all locations, resulting in the issuance of numerous fish consumption advisories. The current study builds on this investigation.
- From 2020-2023, a study funded by the Sudbury, Assabet, and Concord Wild & Scenic River Stewardship Council assessed site-specific differences in PFAS contamination in fish from Ashumet Pond, Sudbury River, and Great Herring Pond (reference site) in Massachusetts (Walsh et al., 2025).

Similar studies or surveys on PFAS in surface water and freshwater fish have been conducted across other New England states, such as:

- In 2021, the Vermont Department of Environmental Conservation (VTDEC) collected surface water samples from 19 lakes and rivers in northern Vermont, as well as fish tissue samples at eight sites and effluent samples at three wastewater treatment facilities (VTDEC, 2022). All surface water samples were below the comparison value used at the time—the Vermont Drinking Water Health Advisory of 20 ng/L. PFOS was found in all fish tissue samples but was generally reported by VTDEC to be at low levels, with only a few exceptions. Based on these results, VTDEC conducted follow-up monitoring in 2022 at 10 additional locations in the watershed (VTDEC, 2024). PFAS were detected above laboratory reporting limits at three of the 10 sites (all in the same river) and in fish at all four sites where fish were collected.
- In 2020, the New Hampshire Department of Environmental Services assessed PFAS concentrations in fish, surface water, and sediment from 12 target and two reference lakes (NHDES, 2021). PFAS were detected in at least one of these media in all 14 lakes.
- In 2022, fish samples were collected by Roger Williams University and RIDEM from 10 locations along the Pawcatuck River and in the Grills Preserve Pond. PFAS were found at levels of concern in all fish in both waterbodies (RI DOH, 2024).

Studies in the peer-reviewed literature also document PFAS in freshwater ecosystems, such as:

- Méndez et al. (2025) studied spatial trends of PFAS in San Francisco Bay fish from 2009 to 2019. PFOS was detected in fish at all time points, with varying concentrations across the regions of the bay.
- Goodrow et al. (2020) measured 13 PFAS in surface water, sediments and fish tissue samples from 11 waterbodies in New Jersey.

- Penland et al. (2020) examined 14 PFAS in water, sediment, organic matter, and aquatic biota across a freshwater food web in the Yadkin-Pee Dee River (North and South Carolina), with aquatic insects showing the highest frequency of detection (FOD).
- Ren et al. (2022) studied PFAS in freshwater fish and benthic and pelagic macroinvertebrates in the Lake Ontario food web, finding that PFAS concentrations increased with trophic level and were higher in benthic compared to pelagic organisms.
- Brase et al. (2022) analyzed 44 PFAS in benthic macroinvertebrates, surface water, and sediment in the Hudson River Valley, New York, finding elevated concentrations in most benthic macroinvertebrate samples.
- Barbo et al. (2023) analyzed PFAS concentrations in fish tissue using data from the 2015 Great Lakes Human Health Fish Filet Tissue Study and the 2013–2014 National Rivers and Streams Assessment. Their findings confirm that freshwater fish consumption is potentially an important source of PFAS exposure, especially for individuals who engage in subsistence fishing.
- Lewis et al. (2023) exposed freshwater benthic macroinvertebrates to varying PFAS concentrations in a controlled laboratory environment and observed differences in bioaccumulation and PFAS profiles depending on organism type.

Selected Marine PFAS Studies

State agency reports and peer-reviewed studies have documented PFAS concentrations in surface waters, fish, and shellfish from marine environments, though research specific to Massachusetts remains limited (Brandt & Campbell, 2024). Selected examples from Northeastern states include:

- The Maine Department of Environmental Protection (Maine DEP) analyzed PFAS in lobsters from 18 coastal locations in 2021, and in six softshell clams and one oyster in 2022 (ME DEP, 2023). PFAS were not detected in lobster meat from half of the sites. In samples from the other sites, PFOS was present at reportedly low concentrations, well below Maine Center for Disease Control and Prevention’s fish tissue action level of 3.5 ng/g. PFAS concentrations in the clams and oyster were also reported as low, supporting human consumption without advisories.
- The New York State Department of Environmental Conservation analyzed PFAS concentrations in blue crabs from 14 sites in the Hudson River Estuary of New York Harbor, detecting PFAS in 36% of the leg muscle samples (Pochini, 2024).

Studies in peer-reviewed literature also document PFAS concentrations in marine ecosystems:

- Pickard et al. (2024) evaluated PFAS in surface water, aquatic biota, and sediment downgradient of a known site of AFFF contamination. Sampling occurred on Cape Cod and extended to estuarine locations along the coast. PFAS concentrations were higher in samples closer to the AFFF source location, but PFAS concentrations remained elevated throughout the downgradient zones.

- Nolen et al. (2021) evaluated 12 PFAS in surface water, fish, and shellfish collected from Galveston Bay, Texas following a petrochemical fire that was extinguished with AFFF. The researchers monitored PFAS in these media immediately after the fire, in March 2019, and then continued to do so through November 2019. Elevated PFAS concentrations, particularly PFOS, were detected in both surface water and marine organisms, prompting seafood consumption advisories and underscoring the need for continued environmental monitoring.
- Hedgespeth et al. (2023) investigated 24 PFAS across 18 marine species from Narragansett Bay in Rhode Island. Significant relationships were found between PFAS concentrations and certain variables, including collection location, feeding guild, habitat, body size, and species.
- Lemos et al. (2022) evaluated PFAS in oysters from three sites in Florida and found detectable levels in at least one oyster from each location.

Other researchers have also examined PFAS in commercially available seafood products. For example:

- Young et al. (2022) evaluated 81 commonly consumed seafood products in the U.S. for 20 PFAS and found the highest levels in clams and crabs, with a wide range of levels across samples.
- Crawford et al. (2024) evaluated 26 PFAS in commonly consumed seafood products from a market in NH, primarily sourced from the Gulf of Maine. PFAS concentrations were highest in lobster, and in some cases at levels that the researchers suggest may present a health risk.

Although these efforts have significantly advanced our understanding of PFAS contamination in aquatic environments, they do not fully characterize the nature and extent of PFAS in freshwater aquatic life or marine systems within the Commonwealth.

2.3. Goals and Objectives of the Current PFAS Study

The primary objective of this study was to characterize the nature and extent of PFAS contamination in surface waters and aquatic biota from selected freshwater and coastal locations across Massachusetts, in a manner that supports public health risk assessment and informs the development of surface water quality standards. Specifically, the study focused on the sample collection and analysis of PFAS in two areas: (1) surface water, whole-body and fileted fish, and invertebrates from inland waterbodies and (2) surface water, fileted finfish, and shellfish tissue from coastal areas. Details are provided below.

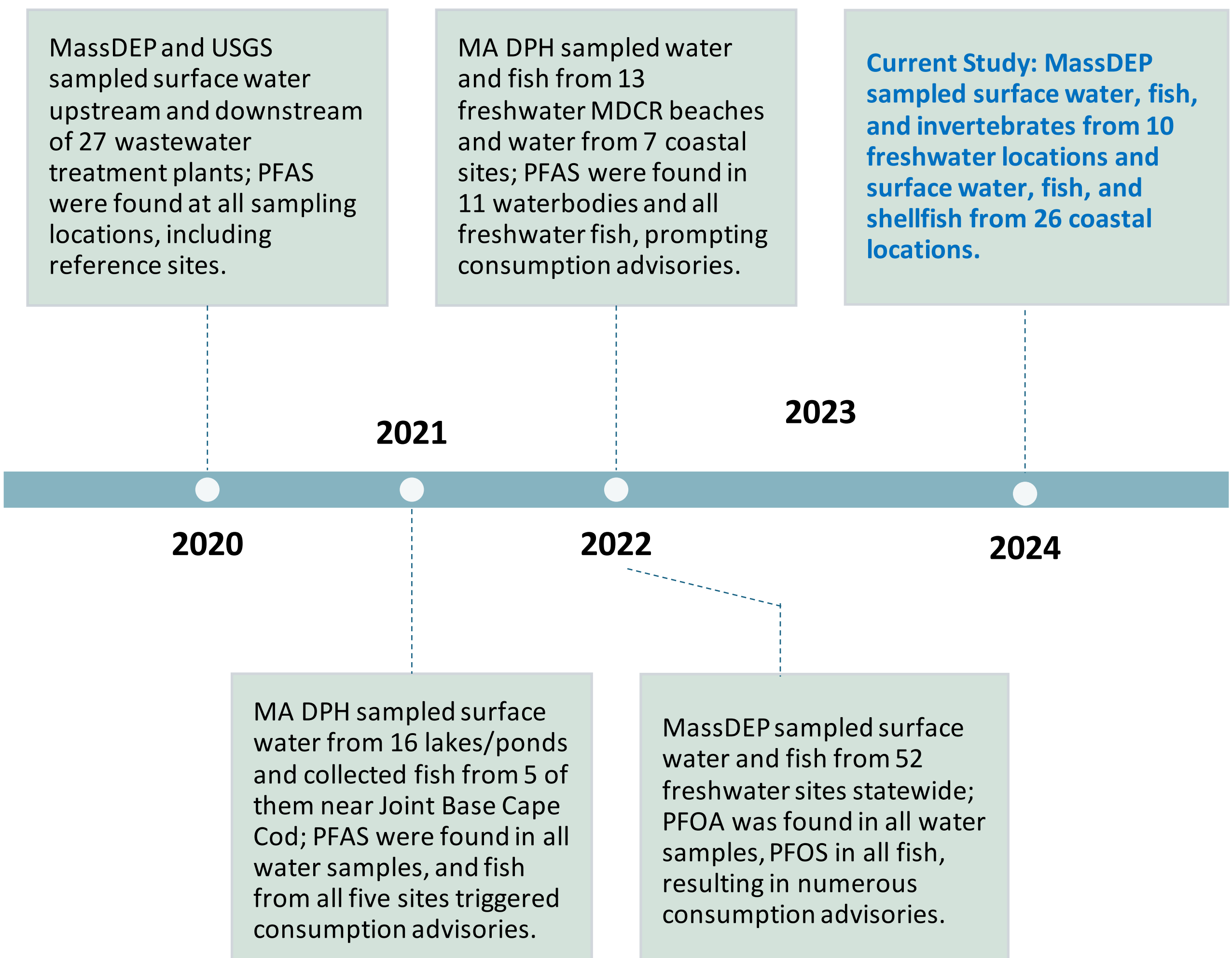
- At freshwater locations, surface water, fish, and invertebrate samples were collected to facilitate direct comparison to EPA's freshwater aquatic life criteria and benchmarks for PFAS (EPA, 2024a, 2024b, 2024c). These data will enhance MassDEP's understanding of ambient PFAS concentrations and their implications for the aquatic life designated use in the Massachusetts Surface Water Quality Standards. Fish filet tissue and surface water results will also inform public health risk evaluations related to fish consumption and recreational surface water exposure.

- At coastal locations, sampling was designed to generate data for evaluating potential public health risks associated with the consumption of fish and shellfish, and to support comparison to EPA's recommended aquatic life surface water benchmarks for estuarine and marine environments (EPA, 2024a, 2024b).

The secondary objectives of this study included deriving species-specific bioaccumulation factors (BAFs) based on paired surface water and biota samples in both freshwater and coastal settings; comparing whole-body and filet PFAS concentrations in freshwater fish from the same location; and comparing PFAS concentrations in freshwater and coastal media.

Note that this study builds on previous MassDEP studies conducted by WPP in 2020 and 2022. Figure 1 illustrates the timeline of those monitoring efforts and the progression to the current study.

Figure 1: Massachusetts Surface Water PFAS Sampling (2020-2024)



3. Methods

This study was conducted in two phases. Phase 1 (referred to as the "pilot phase") occurred between March and June 2024. During this phase, the project team developed initial versions of the QAPP and SAP and collected, processed, and analyzed surface water and tissue samples from nine waterbodies (four freshwater lakes/ponds/rivers and five coastal locations). Data and lessons learned during this pilot phase were used to update the QAPP and SAP and to inform the selection of Phase 2 sampling locations.

Phase 2 began in July 2024 and concluded in June 2025. During this phase, the project team implemented the updated QAPP and SAP and collected samples from an additional 27 waterbodies (six freshwater lakes/ponds/rivers and 21 coastal locations). Phase 2 sampling was conducted between July and November of 2024. The project team also developed a database to house laboratory analytical results and field data (e.g., waterbody and fish characteristics). The changes to the QAPP and SAP between phases were primarily minor clarifications, and data from both phases are comparable.

The remainder of this section describes the process for selecting waterbodies and the final sampling locations (Section 3.1), field procedures for sample collection and processing (Section 3.2), laboratory analyses performed on the samples (Section 3.3), data validation and processing methods (Section 3.4), and data analysis performed for this report (Section 3.5). All study design decisions described herein were made to ensure that PFAS measurement data met the project's primary objectives. Additional details on the study methods and project timeline can be found in the QAPP and SAP, both of which are posted online (MassDEP's PFAS in Surface Water and Fish Tissue webpage).

3.1. Sampling Locations

This study involved collecting samples from freshwater (lakes, ponds, and rivers) and coastal locations across the state. The process used to select waterbodies for each category is described below, followed by a summary of the 36 sampling locations included in this study.

3.1.1. Freshwater Site Selection

This study focused on freshwater lakes, ponds, and rivers in Massachusetts that were anticipated to have a high likelihood of PFAS contamination based on data from nearby potential sources and where fish are commonly collected and consumed by the public. Waterbodies designated for "catch-and-release" fishing, those smaller than five acres, and those located on Martha's Vineyard and Nantucket were excluded due to logistical constraints. All selected freshwater sampling sites were required to be outside the tidal zone and within an existing MassDEP freshwater assessment unit.

The project team used various resources to identify waterbodies in areas with known or suspected PFAS contamination, as well as "reference" locations in areas without any known sources. The team began by compiling a universe of candidate waterbodies using

MassWildlife's "GoFishMA" tool, then narrowed that list by ranking waterbodies based on proximity to known or suspected PFAS sources.[1] For rivers, only PFAS sources located upstream of the candidate sites were considered; for lakes and ponds, only those within the same drainage basin were evaluated. The project team prioritized sites near known or suspected PFAS sources, but also considered accessibility for field crews, environmental conditions favorable for fish and invertebrate collection, geographic distribution across MassDEP's four regions, and proximity to environmental justice (EJ) census blocks. Reference locations were selected from the same universe of waterbodies but were limited to waterbodies located away from any identified PFAS sources and focused in areas with the lowest population density.

This study did not include any of the same freshwater sites as MassDEP's 2023 PFAS study, except for Studleys Pond. The project team decided to include this waterbody for additional sampling due to the high PFAS concentrations observed in the previous study. For further details on the selection process, refer to the project QAPP.

3.1.2. Coastal Site Selection

This study focused on coastal locations along the Massachusetts shoreline where recreational fishers are known to collect fish and shellfish for consumption. Potential coastal sites on islands (e.g., Martha's Vineyard and Nantucket) and those that only had deeper-water recreational fishing (i.e., beyond the nearshore area) were not considered. The project team used a combination of public databases, shellfish classification maps, and local recreational fishing information to identify and evaluate candidate sampling sites. Other considerations that factored into site selection were ensuring at least three sampling locations in each of state's five CZM regions, safe access for field crews, and locations where both shellfish and fish could be collected in close proximity. Due to the complexities of PFAS fate and transport in marine locations (e.g., influence of tides, currents, and other factors), proximity to known or suspected PFAS sources was not prioritized in this site selection process; however, many selected sites are near harbors or river mouths where PFAS impacts are likely.

To identify candidate coastal sites, the project team compiled popular recreational fishing locations from MassWildlife's "GoFishMA" tool and the Massachusetts Department of Fish and Game's Office of Fishing and Boating Access database. Candidate sites were screened for proximity to shellfish harvesting areas that MA DMF has classified as

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[1] For purposes of this project, known sources of PFAS included those identified by the Massachusetts PFAS Interagency Task Force in its 2022 Report, titled PFAS in the Commonwealth of Massachusetts, as well as sites and locations captured in EPA's PFAS Analytic Tools web application (i.e., Superfund sites with reported PFAS detections, federal agency locations with known or suspected PFAS contamination, AFFF spills reported to the National Response Center, and facilities reporting on-site releases of PFAS to EPA's Toxics Release Inventory). Suspected sources of PFAS included commercial airports, wastewater treatment plants, municipal solid waste landfills, sites accepting diverted food materials, and other sites in EPA's PFAS Analytic Tools website (i.e., historic manufacturers of PFAS and facilities that generate or receive Resource Conservation and Recovery Act [RCRA] waste contaminating PFAS).

“approved” or “conditionally approved;” shellfish classification maps and other publicly available resources were also used in this process. Additional candidate locations were identified using other sources, including the Massachusetts Shellfish Initiative and regional tourism and fishing websites. Sites without suitable shellfishing access were excluded, which limited options in the Boston Harbor region. There, three fish-only sites were selected based on areas of high fishing activity, and shellfish samples were not collected at these locations. Refer to the QAPP for more information on the coastal sampling location selection process.

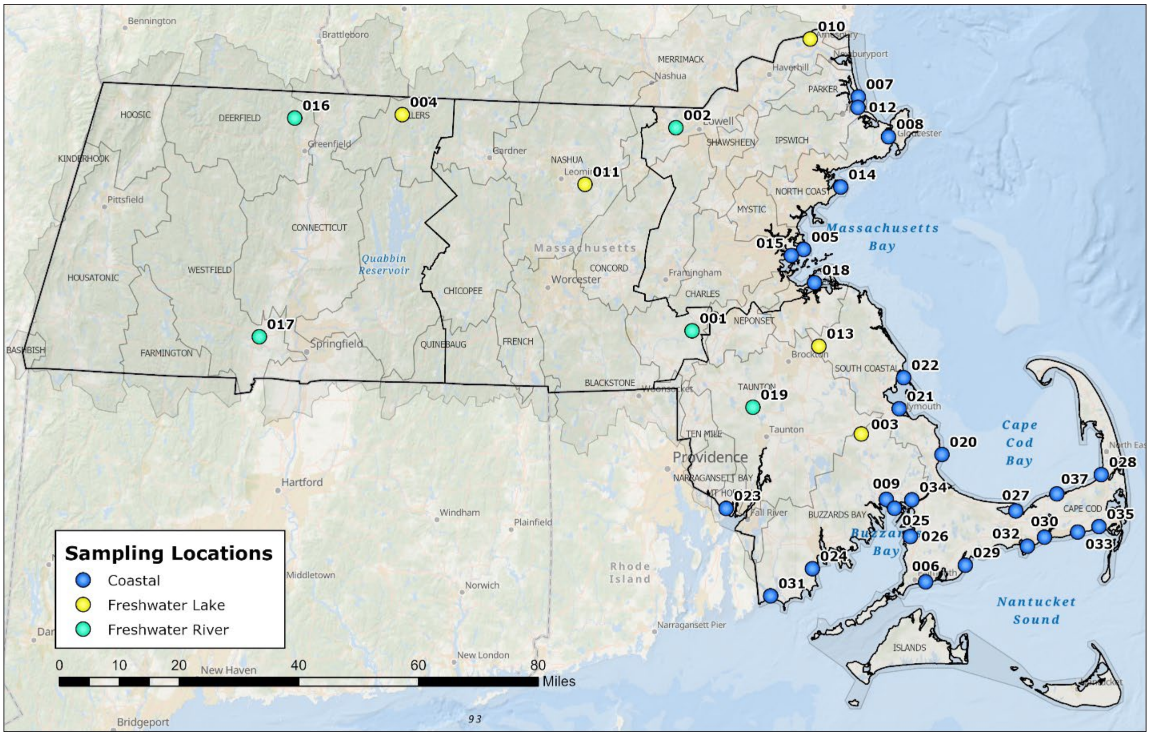
3.1.3. Sampled Sites

Appendix A provides additional details on the sampling locations, including latitude and longitude coordinates for each site. For coastal sites where fish and shellfish could not be collected from the same general area, separate coordinates are provided. Figure 2 shows the freshwater and coastal sampling locations and Table 2 presents additional waterbody characteristics. A brief overview is provided below for each waterbody type.

- Freshwater sampling locations: During the pilot phase, sampling occurred at four waterbodies. At Sheomet Pond, Johns Pond, and the Charles River, field crews completed all sampling activity in one day. At the Merrimack River, field crews conducted sampling across two days. In Phase 2, an additional six freshwater locations were sampled. Of the 10 waterbodies sampled across the two phases, two sampling locations (Green River and Sheomet Pond) were classified as reference locations. Surface water, fish, and invertebrates were collected at all 10 locations.
- Coastal sampling locations: During the pilot phase, sampling took place at five coastal locations. At Pine Creek and the Annisquam River, field crews conducted sampling over two days to collect additional fish samples. At the other sites, sampling was completed in one day. In Phase 2, the sampling effort expanded to include 21 additional locations, bringing the total to 26. Three of these locations (Plum Island Sound, Cape Cod Bay, and Rock Harbor Creek) were designated as reference sites due to their distance from harbors and river mouths. At most sites, field crews were able to collect samples for all three media in a single day. However, they needed to resample three waterbodies in an attempt to collect more fish (Boston Harbor near Castle Island, Hingham Bay, and Cape Cod Bay); no fish were caught at Hingham Bay. Sampling in Boston Harbor was limited to fish and surface water only, as shellfish collection was not permitted in that area. In total, surface water samples were collected at 26 locations, shellfish samples at 23 locations, and fish samples at 20 locations. At most sites, these three sample types were collected in the same area; however, due to field conditions, temporary shellfish bed closures, and guidance from local shellfish constables, fish and shellfish were sometimes collected from different nearby locations. Although they were still considered part of the same site for data analysis purposes by the project team, they were collected at different locations. This occurred at five coastal sites.

Appendix A provides additional details on the sampling locations, including latitude and longitude coordinates for each site. For coastal sites where fish and shellfish could not be collected from the same general area, separate coordinates are provided.

Figure 2. Sampling Locations



Note: Black boundaries indicate MassDEP regions (i.e., Central, Northeast, Southeast, and Western) and gray boundaries indicate major watersheds. GIS layers for both were obtained from MassGIS data (MassGIS 2000; MassGIS, 2022a). Refer to Table 1 for the waterbody names corresponding to the IDs shown here. Additional information, including latitude and longitude coordinates, is provided in Appendix A.

Table 1. Project Sampling Locations

ID[a]	Waterbody Name[b]	Town	Region[c]	Watershed	Ref Location[d]
Freshwater Locations					
001	Charles River	Millis	Central	Charles	No
002	Merrimack River	Chelmsford	Northeast	Merrimack	No
003	Johns Pond	Carver	Southeast	Taunton	No
004	Sheomet Pond	Warwick	Western	Millers	**Yes**
010	Lake Gardner	Amesbury	Northeast	Merrimack	No
011	Spectacle Pond	Lancaster	Central	Nashua	No
013	Studleys Pond	Rockland	Southeast	South Coastal	No
016	Green River	Leyden	Western	Deerfield	**Yes**
017	Powdermill Brook	Westfield	Western	Westfield	No
019	Canoe River	Norton	Southeast	Taunton	No
Coastal Locations					
005	Boston Harbor (near Deer Island)	Boston	Boston Harbor	Mystic	No

ID[a]	Waterbody Name[b]	Town	Region[c]	Watershed	Ref Location[d]
006	Great Pond-Bournes Pond*	Falmouth	Cape Cod & Islands	Cape Cod	No
007	Pine Creek	Ipswich	North Shore	Merrimack	No
008	Annisquam River-Mill River*	Gloucester	North Shore	North Coast	No
009	Wareham River	Wareham	South Coastal	Buzzards Bay	No
012	Plum Island Sound	Ipswich	North Shore	Parker	**Yes**
014	Marblehead Harbor-Atlantic Ocean*	Marblehead	North Shore	North Coast	No
015	Boston Harbor (near Castle Island)	Boston	Boston Harbor	Charles	No
018	Hingham Bay	Weymouth	Boston Harbor	Weir	No
020	Cape Cod Bay	Plymouth	South Shore	South Coastal	**Yes**
021	Plymouth Harbor	Plymouth	South Shore	South Coastal	No
022	Back River - Duxbury Bay*	Duxbury	South Shore	South Coastal	No
023	Cole River	Swansea	South Coastal	Mt Hope Bay	No
024	Apponagansett Bay	Dartmouth	South Coastal	Buzzards Bay	No
025	Little Harbor	Wareham	South Coastal	Buzzards Bay	No
026	Megansett Harbor	Falmouth	Cape Cod & Islands	Cape Cod	No
027	Barnstable Harbor	Barnstable	Cape Cod & Islands	Cape Cod	No
028	Rock Harbor Creek	Eastham	Cape Cod & Islands	Cape Cod	**Yes**
029	Popponesset Bay	Barnstable	Cape Cod & Islands	Cape Cod	No
030	Bass River	Dennis	Cape Cod & Islands	Cape Cod	No
031	Westport River	Westport	South Coastal	Buzzards Bay	No
032	Lewis Bay	Yarmouth	Cape Cod & Islands	Cape Cod	No
033	Allens Harbor	Harwich	Cape Cod & Islands	Cape Cod	No
034	Buttermilk Bay-Cohasset Narrows*	Wareham	Cape Cod & Islands	Buzzards Bay	No
035	Mill Creek	Chatham	Cape Cod & Islands	Cape Cod	No
037	Sesuit Harbor	Dennis	Cape Cod & Islands	Cape Cod	No

[a] Each waterbody was assigned a unique ID during sample collection. The site originally assigned ID 036 was not sampled.

[b] As noted previously, in several instances, fish and shellfish were collected from separate areas within the same general location. Although shown as a single site in this table, these cases have two sets of GIS coordinates included in Appendix A: one for the shellfish collection location and the other for the fish collection location. These instances are marked with an asterisk (*) in this table.

[c] For freshwater sites, "region" refers to the MassDEP region (MassGIS, 2022a); for coastal sites, it refers to the CZM region (MassGIS, 2022b).

[d] "Ref"=Reference location

Overall, samples were collected at 36 waterbodies: 10 freshwater sites and 26 coastal sites. Five of these waterbodies (two freshwater and three coastal) are designated as reference locations. The freshwater locations span all four MassDEP regions: 20% in the Central region, 20% in the Northeast region, 30% in the Southeast region, and 30% in the

Western region. These sites represent eight distinct watersheds and seven are located within two miles of an EJ census block. The coastal sites cover all CZM regions, with 12% in Boston Harbor, 12% on the South Shore, 15% on the North Shore, 19% in the South Coastal region, and 42% in the Cape Cod and Islands region. Note that project resources supported additional sampling beyond the originally targeted 30 sites, which the project team chose to allocate to shellfish collection in the Cape Cod and Islands region. As a result, a higher proportion of coastal sites were sampled in that area than originally planned.

3.2. Sample Collection

Surface water and biological tissue samples (fish, shellfish, and invertebrates) were collected between May 14, 2024 and November 7, 2024. Overall, 40 surface water samples, 41 whole-body fish samples, 122 fish filet samples, 45 invertebrate composite samples, and 81 shellfish composite samples were collected. Section 3.2.1 outlines procedures for surface water sampling, and Sections 3.2.2 and 3.3 describe the biological sample collection methods used at freshwater and coastal locations, respectively. Appendix B lists how many of each type of sample were collected at each waterbody.

Given the widespread presence of PFAS in consumer products and the standard sampling equipment used in this study, as well as the low method detection limits (MDLs) for PFAS, special precautions were taken during all stages of sample collection and handling to prevent PFAS cross-contamination. Section 3.3.1, the QAPP, and the SAP provide further details on field quality control (QC) samples used to evaluate potential influences from cross-contamination.

3.2.1. Surface Water Sampling Methods

Field crews collected one unfiltered surface water sample at each freshwater and coastal waterbody. These samples were collected in the immediate vicinity of where biological samples were taken. In cases where biological samples were collected from two different locations at a site, such as fish and invertebrates in freshwater or fish and shellfish in coastal areas, two surface water samples were collected—one at each biological sampling location. This approach ensured that each biological tissue sample had a corresponding surface water sample, which was important for calculating BAFs from surface water to aquatic life (invertebrates, fish, and shellfish).

Water samples were collected at a depth of 1 to 1.5 feet below the water surface. To minimize the potential for water from the surface layer to enter the samples, sample bottles were uncapped underwater during collection. All samples were collected using containers provided by the laboratory, immediately stored on ice in coolers (<6°C), and then frozen until shipment. Samples were shipped to the laboratory in a fully frozen state and packed on ice. Field crews followed strict protocols when collecting samples and during all sample handling to limit PFAS cross contamination.

3.2.2. Biological Sampling Methods at Freshwater Locations

At each freshwater location, field crews aimed to collect (a) up to eight legal-sized fish and (b) sufficient mass to prepare up to six composite invertebrate samples.

Freshwater Fish Collection

Fish collection methods varied based on site conditions and access. For example, at larger lakes and rivers with boat ramps, an electrofishing boat was used, while at smaller ponds and streams, field crews employed hook-and-line angling or backpack electrofishing. The target was to collect four fish from each of two species per waterbody. When this was not possible, crews collected fish from additional species, but only up to a total of eight fish. Any fish collected beyond this target were humanely returned to the waterbody before the field crew departed the site.

Across the 10 freshwater sites, field crews collected 74 individual fish for analysis of PFAS. These fish represent 13 different species, with bluegill and yellow perch being the most frequently collected (Table 2). After sample collection, field crews placed the fish on ice and then transported them to Normandeau's office in Bedford, New Hampshire (hereafter referred to as Normandeau) for processing. There, field crews recorded the length and weight of each fish and prepared them as either individual whole-body samples or boneless, skinless filet samples. For each site, crews aimed to collect enough fish to prepare two whole-body fish samples and two fish filets samples for each of two species. If this target was not met, crews used their judgment to prepare approximately 50% of the samples as whole-body and 50% as filets, ensuring that both sample types were represented for each species. All prepared samples were double-bagged in PFAS-free zip-seal bags, labeled, and shipped frozen to the laboratory for homogenization and PFAS analysis.

Across the 10 freshwater locations, 41 whole-body fish samples and 33 filet samples were submitted for analysis. Table 2 provides further details, including the average weight and length by species. Section 3.6 of the SAP has additional details on fish sample collection and processing methods.

Table 2. Characteristics of Freshwater Fish Collected

Family Name	Common Name	Scientific Name	Habitat[a]	Trophic Level[b]	Total Fish Caught (n=74)				
					# of Whole Fish	# of Fish Filets	Average Weight (g)[c]	Average Length (mm)[c]	# of Lakes or Rivers
Anguillidae	American eel	*Anguilla rostrata*	demersal	4	2	2	77	350	1
Catostomidae	White sucker	*Catostomus commersonii*	demersal	3	3	2	974	433	2
Centrarchidae	Bluegill	*Lepomis macrochirus*	benthopelagic	3	9	9	152	196	5
	Largemouth bass	*Micropterus salmoides*	benthopelagic	4	2	0	475	330	2
	Pumpkinseed	*Lepomis gibbosus*	benthopelagic	3	3	3	114	175	2
	Smallmouth bass	*Micropterus dolomieu*	benthopelagic	4	2	2	453	336	1
Cyprinidae	Creek chub	*Semotilus atromaculatus*	demersal	4	2	2	22	120	1
	Longnose Dace	*Rhinichthys cataractae*	demersal	3	2	0	10	99	1
Ictaluridae	Brown bullhead	*Ameiurus nebulosus*	demersal	3	3	3	271	246	2
Percidae	Yellow perch	*Perca flavescens*	benthopelagic	3	8	7	125	216	5
Salmonidae	Eastern Brook Trout	*Salvelinus fontinalis*	benthopelagic	3	2	0	11	108	1
	Brown trout	*Salmo trutta*	pelagic-neritic	4	2	2	317	313	1
	Rainbow trout	*Oncorhynchus mykiss*	benthopelagic	4	1	1	546	377	2

[a] Habitat classifications were obtained from FishBase (version 02/2025), available at: https://www.fishbase.se/home.php. FishBase is a publicly available global biodiversity information system that is hosted by Quantitative Aquatics, Inc and guided by a consortium of 13 international organizations. The descriptions below are based on information provided by FishBase.

- Demersal species: These species feed on benthic organisms, such as detritus, plankton, and small invertebrates, and live on or near the bottom.
- Pelagic-neritic species: These species live in midwaters and near the surface, as well as in nearshore ocean ecosystems (0-200 meter depth). They often consume plankton and other free-living organisms like small fish and crustaceans.
- Benthopelagic species: These species live and feed near the bottom, in midwaters, and near the surface. These species also opportunistically forage both free benthic and free-living organisms.

[b] Trophic levels were obtained from FishBase (version 02/2025) and describe a species' position within a food chain or food web and is based on a species' diet (Christensen and Pauly 1993): Level 3=Carnivores that consume herbivorous fish and zooplankton. Level 4=Carnivores that consume other carnivorous fish.

[c] Fish weight and fish length are from the whole fish, prior to processing, for all fish samples.

Freshwater Invertebrate Collection

For freshwater invertebrates, field crews aimed to collect enough organisms to prepare six composite samples, each with a minimum wet weight of five grams. Crews waded into the water and used D-frame kick nets to gather specimens. They gently rinsed the net contents with source water to allow fine sediments to pass through and washed larger debris within the net to ensure no invertebrates were clinging to it. Larger invertebrates were carefully removed, cleaned of excess debris using a spray bottle, and placed into sample containers. Once larger specimens were collected, the remaining material, consisting of smaller organisms and some residual substrate or detritus, was transferred into a sieve. Crews rinsed this material to further remove debris and extract any additional smaller invertebrates. This process continued until no more invertebrates could be readily separated. Magnification was not used; only invertebrates visible to the naked eye were collected. Additionally, if snails, crayfish, or larger aquatic insects were observed and could be easily captured, field crews collected these organisms individually using gloves, forceps, or another clean tool, and added them to the sample obtained with the kick net process.

Collected invertebrate specimens were placed into sample jars, initially separated by taxonomic categories. Each sample was weighed using a portable scale, and if the required minimum mass was not met, further collection and processing continued until the target mass was achieved. Large invertebrates were classified into **three main categories — *aquatic insects*** (i.e., benthic macroinvertebrates); ***gastropods*** (e.g., snails); and ***crustaceans*** (e.g., crayfish) — with the goal of collecting enough material to prepare two samples per category for each waterbody. If any samples were completely composed of certain classes, such as the bivalvia *Corbicula fluminea* at the Charles River site, these were analyzed and documented separately. When the target sample mass could not be met, organisms from different classes were combined into a single "combined benthic invertebrate" sample. These samples varied but often contained a mix of aquatic insects, small snails, and occasionally small crayfish. After sorting, the samples were placed on ice and transported to Normandeau's facility for further processing, sorting, and documentation before being frozen and shipped to the laboratory.

Across the 10 freshwater locations, 45 composite invertebrate samples were prepared and submitted for PFAS analysis. Table 3 summarizes the types of invertebrate samples that were collected, including the number of samples, average mass, and the number of waterbodies where each sample type was collected. Section 3.6 of the SAP includes additional details on this process.

Table 3. Characteristics of Freshwater Invertebrates Collected

Organism Group	Description	# of Composite Samples	Average Mass (g)	# of Lakes/ Rivers
Bivalves	Samples contained between five and 10 *Corbicula fluminea* organisms.	2	10.0	1

Organism Group	Description	# of Composite Samples	Average Mass (g)	# of Lakes/ Rivers
Crustaceans	Samples contained between two and five crayfish.	7	21.8	4
Gastropods	Samples typically contained five to 20 smaller snails (Bassomatophora or unidentified) or two larger snails (*Cipangopaludina chinensis*).	13	32.5	4
Insects	Samples included various aquatic insects, commonly identified at the order level as Odonata (dragonflies and damselflies), Hemiptera (true bugs), Diptera (true flies), Trichoptera (caddisflies), Ephemeroptera (mayflies), Megaloptera (dobsonflies and alderflies), and Plecoptera (stoneflies). Each sample contained 10 to 70 organisms.	11	5.5	5
Combined Invertebrates	Samples were classified as "combined invertebrates" when taxonomic variability was high, and further separation would not provide sufficient mass for analysis. On average, these samples contained 50 organisms and were often a mix of insects and small snails.	12	6.2	6

3.3. Biological Sampling Methods at Coastal Locations

At each coastal location, field crews aimed to collect (a) up to six legal-sized fish to be prepared as boneless, skinless filets and (b) enough individual shellfish to prepare three composite samples, each consisting of three to five organisms of the same species. Efforts focused on fish and shellfish commonly collected by recreational fishers and shellfishers for consumption.

Coastal Fish Collection

Fish were collected at coastal locations using hook-and-line angling, for which field crews used both surf casting rods (for larger fish) and light casting rods (for smaller fish). Depending on site conditions, angling was performed from shoreline locations (e.g., jetties, piers, docks) or from boats. The goal was to collect fish close to the shoreline to represent the fish most commonly caught by recreational fishers. At each coastal site, field crews aimed to collect six fish, two of each of three species.

After collecting the fish, field crews transported them on ice to Normandeau's facility for processing. There, Normandeau staff recorded the length and weight of each fish and prepared them as individual boneless, skinless filet samples; one filet was prepared for each fish caught. As with freshwater fish, crews placed the filets in double-bagged PFAS-free zip-seal bags. Each bag was labeled and shipped frozen to the laboratory for homogenization and PFAS analysis.

Across the 26 coastal sites, field crews collected and prepared filets from 89 individual fish for PFAS analysis. These fish represent 14 species; scup, black sea bass, and Atlantic mackerel were collected most frequently. Table 4 summarizes the fish analyzed in this study, including the average weight and length by species. Section 3.6 of the SAP provides additional details on the collection and processing methods for coastal fish samples.

Coastal Shellfish Collection

For shellfish, field crews aimed to collect up to 15 individual organisms per waterbody. These were then composited into three samples, each consisting of three to five organisms of the same species. Crews used species-appropriate collection methods, including clam rakes/forks, shovels, or hand collection. Crews attempted to collect composite samples for up to three different species per location; however, in many cases, they were only able to collect one or two species per location. Field crews weighed and measured the individual shellfish that they collected, after which they removed the edible portion using species-specific methods (e.g., shucking knives). To prepare the composite, they combined edible tissue from three to five individuals of the same species into a single sample jar. The composite samples were then frozen before shipment to the laboratory.

Field crews collected 380 shellfish from the 23 coastal locations, which were then prepared into 81 composite samples for PFAS analysis. Five species were collected, with quahogs, blue mussel, and eastern oyster accounting for more than 90% of the shellfish collected. Table 5 summarizes shellfish composite samples that were analyzed, including the number of individuals, average shell length, and the number of waterbodies where each species was collected. Section 3.6 of the SAP provides additional details on this project's shellfish sample collection and processing methods.

Table 4. Characteristics of Coastal Fish Collected

Family Name	Common Name	Scientific Name	Habitat[a]	Trophic Level[b]	Total Fish Caught (n=89)			
					# of Fish Filets	Average Weight (g)	Average Length (mm)	# of Locations
Alosidae	Atlantic menhaden	*Brevoortia*	pelagic-neritic	3	2	220	289	1
Labridae	Cunner	*Tautogolabrus*	reef-associated	3	3	116	194	2
	Tautog	*Tautoga onitis*	reef-associated	3	1	481	283	1
Merluccidae	Silver hake	*Merluccius*	demersal	4	4	126	272	1
Moronidae	Striped bass	*Morone saxatilis*	demersal	4	8	1,146	457	5
Paralichthyidae	Summer flounder	*Paralichthys*	demersal	4	6	224	279	4
Pomatomidae	Blue fish	*Pomatomus*	pelagic-oceanic	4	2	1,094	507	2
Rajidae	Little skate	*Leucoraja*	demersal	3	2	688	299	1
Scombridae	Atlantic bonito	*Sarda sarda*	pelagic-neritic	4	1	1,581	523	1
	Atlantic mackerel	*Scomber*	pelagic-neritic	3	12	217	302	3
Serranidae	Black sea bass	*Centropristis*	reef-associated	4	17	588	351	8
Sparidae	Scup	*Stenotomus*	demeral	3	20	307	273	7
Squalidae	Smooth dogfish	*Mustelus canis*	demersal	3	5	1,575	755	2
Triglidae	Striped searobin	*Prionotus evolans*	reef-associated	4	6	375	311	5

[a] Habitat classifications were obtained from FishBase (version 02/2025), available at: https://www.fishbase.se/home.php. FishBase is a publicly available global biodiversity information system that is hosted by Quantitative Aquatics, Inc and guided by a consortium of 13 international organizations. The descriptions below are based on information provided by FishBase.

- Demersal species: These species feed on benthic organisms, such as detritus, plankton, and small invertebrates, and live on or near the bottom.
- Pelagic-neritic species: These species live in midwaters and near the surface, as well as in nearshore ocean ecosystems (0-200 meter depth). They often consume plankton and other free-living organisms, such as small fish and crustaceans.
- Reef-associated: These species feed and live on or near coral reefs.

[b] Trophic levels were obtained from FishBase (version 02/2025) and describe a species' position within a food chain or food web and are based on species' diet (Christensen and Pauly (1993).

- Level 3: Carnivores that consume herbivorous fish and zooplankton.
- Level 4: Carnivores that consume other carnivorous fish.

Table 5. Characteristics of Coastal Shellfish Collected

Family Name	Common Name	Scientific Name	Total Shellfish Collected (n=380)			
			# of Shellfish	# of Composite Samples	Average Length (mm)	# of Locations
Mytilidae	Blue mussel	*Mytilus edulis*	111	23	67.3	7
Buccinidae	Channel	*Busycotypus*	5	2	163.6	1
Ostreoidea	Eastern	*Crassostrea*	74	16	97.3	6
Veneridae	Quahog	*Mercenaria*	175	37	70.9	13
Myidae	Soft-shell	*Mya arenaria*	15	3	76.6	1

3.3.1. Field Quality Control Samples

In addition to the primary surface water and fish/shellfish/invertebrate tissue samples described above, numerous field QC samples were prepared and analyzed to evaluate data quality. These include field blanks, equipment blanks, and field duplicates. Field and equipment blanks were collected to assess potential cross-contamination during the data acquisition process, from field collection through laboratory analysis. Field duplicates were collected to assess the precision of sampling and laboratory analysis. Additionally, before any field sampling began, the project team confirmed that the de-ionized water (DIW) used in the project was indeed PFAS-free. To do so, water was obtained from the DIW system at MassDEP's WES laboratory and sent to SGS AXYS for analysis. None of the 40 PFAS measured by EPA Method 1633A were detected above the laboratory MDL for each analyte (i.e., all results were non-detect) in that sample. This was repeated at the start of phase 2, and again, none of the 40 PFAS measured by EPA Method 1633A were detected above laboratory MDLs. An overview of the other field QC sample results is provided below. Additional details can be found in Section 6.1 of the SAP; related DQO criteria are presented in Section 2.5 of the QAPP.

Field and Equipment Blanks

Field blanks were prepared in the field using PFAS-free DIW at 10 percent of the sampled waterbodies. Of the four field blanks analyzed, only one showed a low-level detection for one PFAS—PFOA at 0.58 ng/L. This concentration is above the MDL but below the method reporting limit (MRL).

Equipment blanks were prepared either in the field or at Normandeau's facility by running PFAS-free DIW over the equipment used during tissue processing (e.g., measuring boards, knives, scales), after the equipment was cleaned and rinsed according to study protocols. Equipment blanks were prepared during the processing of fish filets, invertebrates, and shellfish.

- Fish filet equipment blanks: Equipment blanks were prepared at Normandeau's facility while processing fish from 10 of the 30 freshwater and coastal waterbodies where fish were collected. PFOS was detected in three of these blanks, all at low levels above the MDL but below the MRL.

- Invertebrate equipment blanks: Equipment blanks were prepared at Normandeau's facility while processing composite invertebrate samples from three of the 10 freshwater sites. PFOS was detected in one blank at low levels.
- Shellfish equipment blanks: Equipment blanks were collected in the field while preparing composite shellfish samples for six of the 26 coastal waterbodies; no PFAS were detected.

Field Duplicates

Field duplicates were collected for surface water and fish filet samples in accordance with QAPP specifications. Field duplicates were not collected for whole fish, invertebrates, or shellfish, since those samples required the entire organism(s). The relative percent difference (RPD) was calculated for all measured PFAS within each sample–duplicate pair and compared to project DQOs.

- Surface water field duplicates: Field crews collected two grab samples at the same location, one immediately after the other, at six of the waterbodies. These paired samples represent a parent sample and a duplicate sample. RPDs were calculated for each of the 40 PFAS analytes for each duplicate pair. All but four of the RPDs calculated for these paired duplicate and parent sample results met the project's DQOs (four out of total 240 calculated RPDs across these six sample duplicate pairs). The four RPDs that did not meet DQOs were from the same duplicate pair.
- Fish filet duplicates: Field crews prepared duplicates for 20 fish samples, using tissue from one side of each fish for the parent sample and tissue from the other side of the same fish for the duplicate. RPDs were calculated for each of the 40 PFAS analytes in the 20 duplicate pairs. The RPDs for all paired parent and duplicate samples met the project's DQOs.
- During the pilot phase of the project, field crews collected additional shellfish to prepare replicate composite samples—consisting of different organisms of the same species, collected from the same waterbody. This was done at two waterbodies. The RPDs for all paired parent and replicate shellfish samples met the project's DQOs. Replicates were not prepared for invertebrates or whole fish, as the study design included multiple samples of each species for those sample types.
- In addition, MassDEP's WES laboratory prepared six performance evaluation (PE) samples at three dilution levels with known PFAS concentrations. These PE samples were shipped to the lab blind. When results were received, MassDEP compared the known concentrations to those reported by the analytical laboratory. Acceptance criteria were met for all compounds, with the exception of NEtFOSE. Full results of the PE sample review are available in Appendix K.

3.4. Laboratory Analysis

Processed water and tissue samples were sent to SGS AXYS for PFAS analysis, and all analyses were conducted using SGS AXYS' Method MLA-110, which is equivalent to EPA Method 1633A (EPA, 2024h). This EPA-developed method quantifies up to 40 PFAS analytes in non-potable water (e.g., wastewater, surface water, leachate) and various other matrices (e.g., biosolids, fish tissue, sediment, soil). While EPA has validated other methods for PFAS analysis in finished drinking water (i.e., Method 533, Method 537, and Method 537.1 for 29 PFAS) and non-drinking water sources (i.e., Method 8327 for 24 PFAS in surface water, groundwater, and wastewater), Method 1633A is currently the analytical method of choice for tissue samples.

EPA Method 1633A involves preparing and extracting environmental samples followed by analysis of the extracts using liquid chromatography–tandem mass spectrometry (LC-MS/MS) in multiple reaction monitoring mode. PFAS concentrations are determined by isotope dilution or extracted internal standard quantification, using isotopically labeled compounds added to the samples prior to extraction. This method was selected for the project because it can be applied consistently across all sample types (surface water and tissue), supports quantification of a wide range of PFAS, and ensures comparability with results from MassDEP's 2023 PFAS Study, which used the same method.

Table 6 lists the 40 PFAS that were measured by the laboratory. Surface water results were reported in units of nanograms PFAS per liter (ng/L). Tissue samples were homogenized prior to analysis and reported in units of nanograms PFAS per gram of fish in wet weight (ng/g, wet weight). All results were reported at concentrations as low as the laboratory MDL. The QAPP and the laboratory's SOP for Method MLA-110 provide additional information on the laboratory's analytical procedures.

Table 6. PFAS Analytes

PFAS Analyte	Acronym	Number of Carbons	CAS Number	Water MDL (ng/L)	Tissue MDL (ng/g)	Short- or Long-Chain[a]
Perfluoroalkyl Carboxylic Acids (PFCAs)						
Perfluorobutanoic acid	PFBA	4	375-22-4	1.6	0.4	Short- chain
Perfluoropentanoic acid	PFPeA	5	2706-90-3	0.8	0.2	
Perfluorohexanoic acid	PFHxA	6	307-24-4	0.4	0.1	
Perfluoroheptanoic acid	PFHpA	7	375-85-9	0.4	0.1	
Perfluorooctanoic acid	PFOA	8	335-67-1	0.4	0.1	Long-chain
Perfluorononanoic acid	PFNA	9	375-95-1	0.4	0.1	
Perfluorodecanoic acid	PFDA	10	335-76-2	0.4	0.1	
Perfluoroundecanoic acid	PFUnA	11	2058-94-8	0.4	0.1	
Perfluorododecanoic acid	PFDoA	12	307-55-1	0.4	0.1	
Perfluorotridecanoic acid	PFTrDA	13	72629-94-8	0.4	0.1	
Perfluorotetradecanoic acid	PFTeDA	14	376-06-7	0.4	0.1	
Perfluoroalkyl Sulfonic Acids (PFSAs)						
Perfluorobutanesulfonic acid	PFBS	4	375-73-5	0.4	0.1	Short- chain
Perfluoropentansulfonic acid	PFPeS	5	2706-91-4	0.4	0.1	
Perfluorohexanesulfonic acid	PFHxS	6	355-46-4	0.4	0.1	Long-chain
Perfluoroheptanesulfonic acid	PFHpS	7	375-92-8	0.4	0.1	
Perfluorooctanesulfonic acid	PFOS	8	1763-23-1	0.4	0.1	
Perfluorononanesulfonic acid	PFNS	9	68259-12-1	0.4	0.1	
Perfluorodecanesulfonic acid	PFDS	10	335-77-3	0.4	0.1	
Perfluorododecanesulfonic acid	PFDoS	12	79780-39-5	0.4	0.1	
Fluorotelomer Sulfonic and Carboxylic Acids						

PFAS Analyte	Acronym	Number of Carbons	CAS Number	Water MDL (ng/L)	Tissue MDL (ng/g)	Short- or Long-Chain[a]
1H,1H,2H,2H-Perfluorohexane sulfonic acid	4:2FTS	6	757124-72-4	1.6	0.4	N/A
1H,1H,2H,2H-Perfluorooctane sulfonic acid	6:2FTS	8	27619-97-2	1.6	0.4	
1H,1H,2H,2H-Perfluorodecane sulfonic acid	8:2FTS	10	39108-34-4	1.6	0.4	
3-Perfluoropropyl propanoic acid	3:3FTCA	6	356-02-5	1.6	0.4	
2H,2H,3H,3H-Perfluorooctanoic acid	5:3FTCA	8	914637-49-3	10	2.5	
3-Perfluoroheptyl propanoic acid	7:3FTCA	10	812-70-4	10	2.5	
Sulfonamides, Sulfo Mido Acetic Acids, and Sulfonamidoethanols						
Perfluorooctanesulfonamide	PFOSA	8	754-91-6	0.4	0.1	N/A
N-methyl perfluorooctanesulfonamide	NMeFOSA	9	31506-32-8	0.4	0.1	
N-ethyl perfluorooctanesulfonamide	NEtFOSA	10	4151-50-2	0.4	0.1	
N-methyl perfluorooctanesulfonamidoacetic acid	NMeFOSAA	11	2355-31-9	0.4	0.1	
N-ethyl perfluorooctanesulfonamidoacetic acid	NEtFOSAA	12	2991-50-6	0.4	0.1	
N-methyl perfluorooctanesulfonamidoethanol	NMeFOSE	11	24448-09-7	4	12	
N-ethyl perfluorooctanesulfonamidoethanol	NEtFOSE	12	1691-99-2	4	12	
Ether carboxylic acids and Other Compounds						
Hexafluoropropylene oxide dimer acid	HFPO-DA	6	13252-13-6	1.6	0.4	N/A
4,8-Dioxa-3H-perfluorononanoic acid	ADONA	7	919005-14-4	1.6	0.4	
Perfluoro-3-methoxypropanoic acid	PFMPA	4	377-73-1	1.6	0.2	
Perfluoro-4-methoxybutanoic acid	PFMBA	5	863090-89-5	0.8	0.1	
Nonafluoro-3,6-dioxaheptanoic acid	NFDHA	5	151772-58-6	0.8	0.2	
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid	9Cl-PF3ONS	8	756426-58-1	1.6	0.4	
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid	11Cl-PF3OUdS	10	763051-92-9	1.6	0.4	
Perfluoro(2-ethoxyethane)sulfonic acid	PFEESA	4	113507-82-7	0.4	0.1	

[a] Chain length classification per ITRC: https://pfas-1.itrcweb.org/wp-content/uploads/2023/12/Full-PFAS-Guidance-12.11.2023.pdf; note chain length classifications are only for PFCAs and PFSAs.

3.5. Data Validation

Before providing analytical results to the project team, SGS AXYS conducted its routine quality assurance and quality control (QA/QC) review to determine whether the data met the standards outlined in their SOP. For each batch of samples, at a minimum frequency of one per batch, or one per 20 samples for larger sets, analysts evaluated method blanks, matrix spikes/matrix spike duplicates, laboratory control samples, isotopically labeled extraction standards, and non-extracted internal standards to verify compliance with defined acceptance criteria. If any results exceeded the laboratory's QA/QC limits, SGS AXYS re-extracted and re-analyzed the affected samples and, when necessary, applied data qualifiers.

As results were received, ERG reviewed laboratory reports and electronic data deliverables (EDDs) to identify discrepancies and to evaluate field blanks, laboratory blanks, and duplicate samples against the DQOs specified in the QAPP. ERG immediately consulted with the laboratory or field team after identifying potential QA/QC concerns to discuss QAPP and SAP procedures.

After completing its review of laboratory reports and resolving any discrepancies, ERG compiled data from the EDDs and linked each sample result to its corresponding metadata. The metadata included waterbody characteristics (e.g., site name, site ID, freshwater or coastal classification, longitude, and latitude) and sample-specific details (e.g., sample matrix, type, collection date, species [fish or shellfish], taxonomic class [invertebrates], length, mass, and sex [for fish filets]). ERG also standardized analyte names and CAS numbers before submitting a project database to MassDEP for review.

MassDEP then conducted its data validation review of the complete database with the objective of finalizing the data. During this validation, MassDEP reviewed whether any observations did not meet project DQOs and therefore should be qualified or censored. As part of the validation process, WPP reviewed the following materials:

- SGS AXYS' SOP for EPA Method 1633A
- SGS AXYS' laboratory reports, EDDs, and completed chain of custody forms
- Field sheets and fish sample preparation data from field crews
- ERG's project database, sample tracking, and crosswalk tables

MassDEP used the data validation protocol outlined in Appendix K to determine which data points should be qualified or censored. By WPP convention, laboratory-reported qualifiers were carried forward and retained in the final dataset and, when necessary, translated to WPP's issue-specific qualifiers. As with all other WPP data, qualified results are considered usable for decision making but censored data are not published or usable for analysis.

With one exception, MassDEP determined that all project data are acceptable (i.e., with and without qualification) for decision-making. The one exception was that all NEtFOSE (CASRN 1691-99-2) results in tissue (fish, invertebrates, and shellfish) below a concentration of 20 ng/g were censored and removed from the final dataset. This analyte exhibited blank sample interference in the tissue matrix, resulting in unreliable low-level results. The same did not occur with surface water NEtFOSE analyses. Appendix K provides additional details on MassDEP's data validation process.

3.6. Statistical Analysis

This section describes how the validated project data were processed and analyzed. ERG conducted all analyses using either SAS (version 9.4) or R (version 4.5.0). Once MassDEP finished its data validation, ERG used the final project database for all analyses, with the following considerations:

- Field duplicates: Results from field duplicate pairs were averaged into one observation per PFAS before conducting statistical analyses. In the case of a duplicate pair with a non-detect and detected result for a given PFAS, the average of one half the MDL for the non-detect and the measured result were used. When a PFAS analyte was not detected in either the parent or duplicate sample, the analyte was marked as a non-detect and the observation was assigned the higher of the MDLs from the duplicate pair (if the lab reported different MDLs for the parent and corresponding duplicate). For further analysis of the data from the duplicate pair, we used one-half of this MDL for any substitutions.
- Multiple water samples for an individual site: Several sites had surface water samples collected on different dates due to unsuccessful fishing attempts or the need to collect different media on separate days. The following outlines how water samples were handled for these cases:
    - Boston Harbor: Only the second attempt at fishing was successful; therefore, only the surface water sample associated with the successful fishing event was included.
    - Hingham Bay: Neither of the two attempts at fishing was successful, and no other tissue samples were collected. Although two surface water samples were collected, only the most recent sample was included in the analysis.
    - Great Pond–Bournes Pond: Surface water samples were collected from two locations, one where fish were collected and another where shellfish were collected. These were treated as separate samples in the surface water analysis. For cross-media analysis, fish and shellfish were each matched to their corresponding surface water sample.
    - Cape Cod Bay: Fish and shellfish were collected on different dates, and a unique surface water sample was collected on each day. For surface water-only analysis, the two water samples were averaged and treated as a single data point. In cross-media analyses (e.g., surface water and fish or surface water and shellfish), each tissue sample was matched with the surface water sample collected on the same day and from the same location.
- PFAS sum: In addition to individual PFAS analytes, the sum of all detected PFAS concentrations (ΣPFAS40) was calculated for each sample. NEtFOSE was excluded from tissue sums due to blank sample interference in the tissue matrix, which caused low-level results to be unreliable and resulted in censoring below 20 ng/g (fish, shellfish, invertebrates). The resulting sum of the other 39 PFAS for tissue samples is referred to as ΣPFAS39.

Descriptive Statistics

Descriptive statistics were calculated for all surface water and tissue PFAS results, including stratified analyses by media type (e.g., tissue type, reference versus non-reference locations, region, species). Reported statistics include the FOD, range, mean, standard deviation (SD), 25th percentile, median, and 75th percentile for individual PFAS analytes, as well as summed metrics (i.e., ΣPFAS40 and ΣPFAS39). For all analyses, non-detects were assigned a value equal to half the MDL. For tissue samples (fish, shellfish, and invertebrates), the FOD was calculated at both the sample and waterbody level. Weighted statistics were applied where necessary to reduce the potential for bias at the waterbody- or sample-level. Shellfish results were weighted by the number of individuals in composite samples and fish results were weighted by the number of fish per location. Weighting was not applied to water or invertebrate statistics.

Means and SDs are reported only when a PFAS analyte was detected in at least 50% of samples of a given type. Statistics were generated using PROC MEANS and PROC SURVEYMEANS in SAS 9.4, with weighted statistics calculated using the VARDEF=WEIGHT option. In R, the wtd.mean(), wtd.quantile(), and wtd.var() functions from the *Hmisc* package were used. All calculations were cross-checked between software platforms as a QC measure.

Statistical Tests by Sample and Waterbody Characteristics

Additional stratified analyses and hypothesis tests were conducted to explore differences in PFAS concentrations across waterbodies and sample characteristics. Because the PFAS data were positively skewed, concentrations were log-transformed before analysis. An analysis of variance (ANOVA) was performed on the log-transformed values using the PROC GLM procedure in SAS to evaluate the following factors: (1) reference versus non-reference sites in fish filets, whole fish, and invertebrate PFAS concentrations at freshwater locations and in filets from coastal locations; (2) whole fish versus filets; (3) fish species in freshwater (analyzed separately for whole fish and filets) and coastal environments (filets only); (4) CZM region for filets; and (5) invertebrate type in freshwater samples. These tests were only conducted when there were enough samples and sufficient detections to support meaningful conclusions about the sampled population. Note that ANOVA indicates whether there is a statistically significant difference among groups overall but does not identify which specific groups differ when more than two groups are compared. A p-value less than 0.05 was considered statistically significant.

Simple linear regression models were conducted using PROC GLM in SAS to assess associations between fish length and weight in freshwater filets, freshwater whole fish, and coastal filets. To compare PFAS concentrations between coastal and freshwater sites, additional regression analyses were performed for both water and fish samples. Like the hypothesis tests described above, these analyses were only done when there were sufficient samples and detections.

These analyses were limited to PFAS detected in at least 50% of samples within a given media type. (Note: No PFAS met this threshold in shellfish.) Additionally, analyses were limited to groups with sufficient sample sizes—for example, species that were rarely caught and had too few samples were excluded from species-level analyses. Further details on sample groupings and the number of samples used in each test can be found in the results section.

Analysis of Variance, or **ANOVA**, is a statistical method used to compare the average values (means) across multiple groups to determine if there are any significant differences between them. It considers both the variation within each group and the differences between groups. In this study, PFAS data were log-transformed before performing ANOVA to ensure the data met the assumption of normality, which is important for valid results. When comparing just two groups, ANOVA produces the same result as an independent sample t-test. It is important to note that although medians are sometimes shown alongside ANOVA results for illustrative purposes, the statistical tests were not performed on the median values.

Bioaccumulation Factors

BAFs were estimated using co-located surface water and tissue sample data from freshwater and coastal sites, where sufficient data were available. BAFs were calculated using Equation 1. The quality of these estimates was assessed using the evaluation criteria described by Burkhard (2021), who recommended that a calculated BAF is determined to be of high, medium, or low quality based on the sum of five "criteria quality values" (i.e., number of water samples, number of organism samples, temporal coordination of samples, spatial coordination of samples, and general experimental design). This method for assessing BAF quality was also used by EPA in creating aquatic life criteria recommendations for PFOA and PFOS (EPA, 2024a, 2024b). A BAF calculation of the highest quality is based on more than three water and fish samples (of a single species) collected at the same time and place.

$$BAF\ (\frac{L}{Kg}) = C_{tissue}/C_{water} \quad \text{X } 1{,}000 \qquad \text{[Equation 1]}$$

Where:

C_{tissue} = PFAS concentration measured in fish, shellfish, or invertebrates (ng/g)

C_{water} = PFAS concentration measured in co-located surface water sample (ng/L)

Species-specific BAFs (or in the case of invertebrates, organism type-specific BAFs) were calculated for PFAS analytes that were detected in both surface water and tissue in at least 25% of the waterbodies. All calculated BAFs are reported in units of log L/kg; the logarithm of the BAF was taken after the BAF was calculated. The logarithmic scale was used because BAFs often vary over several orders of magnitude depending on the fish species, PFAS analyte, and chain length (Pickard et al. 2022). BAFs were calculated for each surface water and tissue pair and then used to calculate geometric mean and median BAFs for each species of fish, shellfish, or type of invertebrate.

4. RESULTS AND DISCUSSION

Across the study's surface water, invertebrate, fish, and shellfish samples, 32 of the 40 PFAS measured by the laboratory were detected above the MDL at least once (Table 7). The remaining eight PFAS were not detected above the MDL and are not discussed further.

Table 7. PFAS Detected by Media

PFAS	Freshwater			Coastal		
	Detected in Surface Water	Detected in Fish	Detected in Invertebrates	Detected in Surface Water	Detected in Fish	Detected in Shellfish
Perfluoroalkyl Carboxylic Acids (PFCAs)						
PFBA	✓	✓	✓		✓	
PFPeA	✓	✓	✓	✓		✓
PFHxA	✓		✓	✓	✓	
PFHpA	✓	✓	✓	✓	✓	
PFOA	✓	✓	✓	✓	✓	✓
PFNA	✓	✓	✓	✓	✓	
PFDA	✓	✓	✓		✓	
PFUnA		✓	✓		✓	
PFDoA		✓	✓		✓	✓
PFTrDA		✓	✓		✓	✓
PFTeDA		✓	✓		✓	✓
Perfluoroalkyl Sulfonic Acids (PFSAs)						
PFBS	✓			✓		
PFPeS	✓		✓			
PFHxS	✓	✓	✓	✓		✓
PFHpS	✓	✓	✓			
PFOS	✓	✓	✓	✓	✓	✓
PFNS		✓				
PFDS		✓	✓		✓	
PFDoS		✓				
Fluorotelomer Sulfonic and Carboxylic Acids						
4:2FTS						
6:2 FTS	✓		✓		✓	
8:2 FTS	✓	✓	✓			
3:3FTCA						
5:3 FTCA		✓	✓			
7:3 FTCA		✓	✓		✓	
Sulfonamides, Sulfo Mido Acetic Acids, and Sulfonamidoethanols						
PFOSA	✓	✓	✓	✓	✓	✓
NMeFOSA					✓	
NEtFOSA						
NMeFOSAA		✓	✓			✓
NEtFOSAA		✓	✓	✓	✓	✓

PFAS	Freshwater			Coastal		
	Detected in Surface Water	Detected in Fish	Detected in Invertebrates	Detected in Surface Water	Detected in Fish	Detected in Shellfish
NMeFOSE			✓			
NEtFOSE		NA	NA		NA	NA
Ether carboxylic acids and Other Compounds						
HFPO-DA			✓			
ADONA						
PFMPA						
PFMBA			✓			
NFDHA		✓	✓			
9Cl-PF3ONS						
11Cl-PF3OUdS						
PFEESA						

NA: Not applicable.
NEtFOSE was not detected in water samples, and it was censored in tissue samples.

The remainder of this section summarizes results for the 32 detected PFAS. Results from freshwater locations are discussed in Section 4.1 and results from coastal locations are discussed in Section 4.2. Section 4.3 compares freshwater and coastal data, and Sections 4.4 and 4.5 evaluate and present comparisons to reference values. Study limitations are addressed in Section 4.6.

4.1. Results from Freshwater Locations

This section presents results from surface water, fish filets, whole fish, and invertebrates collected across the 10 freshwater sites. Descriptive statistics are presented by sample type, followed by additional analyses, such as comparisons across media.

4.1.1. Surface Water Results

Table 8 presents descriptive statistics for the 15 PFAS detected in at least one surface water sample and for ΣPFAS40. Some noteworthy observations are listed below. Results for each waterbody are shown in Appendix C.

- PFOA was the most frequently detected analyte, found in 90% of waterbodies, followed by PFHpA, PFHxA, and PFOS, each detected in 80% of waterbodies.
- PFOS had the highest reported concentration (66.4 ng/L), followed by PFOA (32.9 ng/L).
- PFOA had the highest median concentration (4.39 ng/L), although it did not have the highest mean. The highest mean was observed for PFOS (8.88 ng/L), which also had the highest standard deviation, indicating highly skewed data for this analyte.

Table 8. Descriptive Statistics for Freshwater Surface Water (n=10)

Analyte	FOD (%)	Min (ng/L)	25th Percentile (ng/L)	Median (ng/L)	75th Percentile (ng/L)	Max (ng/L)	Mean (ng/L)	SD (ng/L)
PFOA	90	<MDL	1.05	4.39	8.61	32.9	7.55	9.81
PFHpA	80	<MDL	0.709	1.57	2.72	13.7	2.82	4.04
PFHxA	80	<MDL	0.585	2.56	3.86	20.6	4.04	6.00
PFOS	80	<MDL	0.446	2.00	5.44	66.4	8.88	20.3
PFBA	70	<MDL	0.885	2.87	3.53	10.8	3.26	2.96
PFBS	70	<MDL	0.222	1.72	2.64	3.72	1.74	1.28
PFHxS	70	<MDL	0.255	0.771	2.32	27.7	3.85	8.45
PFPeA	70	<MDL	0.444	2.51	3.69	29.8	4.98	8.85
PFNA	50	<MDL	<MDL	<MDL	0.780	3.63	0.736	1.04
PFOSA	30	<MDL	<MDL	<MDL	0.504	1.88	NA	NA
6:2 FTS	10	<MDL	<MDL	<MDL	<MDL	18.6	NA	NA
8:2 FTS	10	<MDL	<MDL	<MDL	<MDL	27.7	NA	NA
PFDA	10	<MDL	<MDL	<MDL	<MDL	0.922	NA	NA
PFHpS	10	<MDL	<MDL	<MDL	<MDL	0.740	NA	NA
PFPeS	10	<MDL	<MDL	<MDL	<MDL	1.74	NA	NA
ΣPFAS40	NA	<MDL	6.22	22.8	32.7	261	42.4	77.8

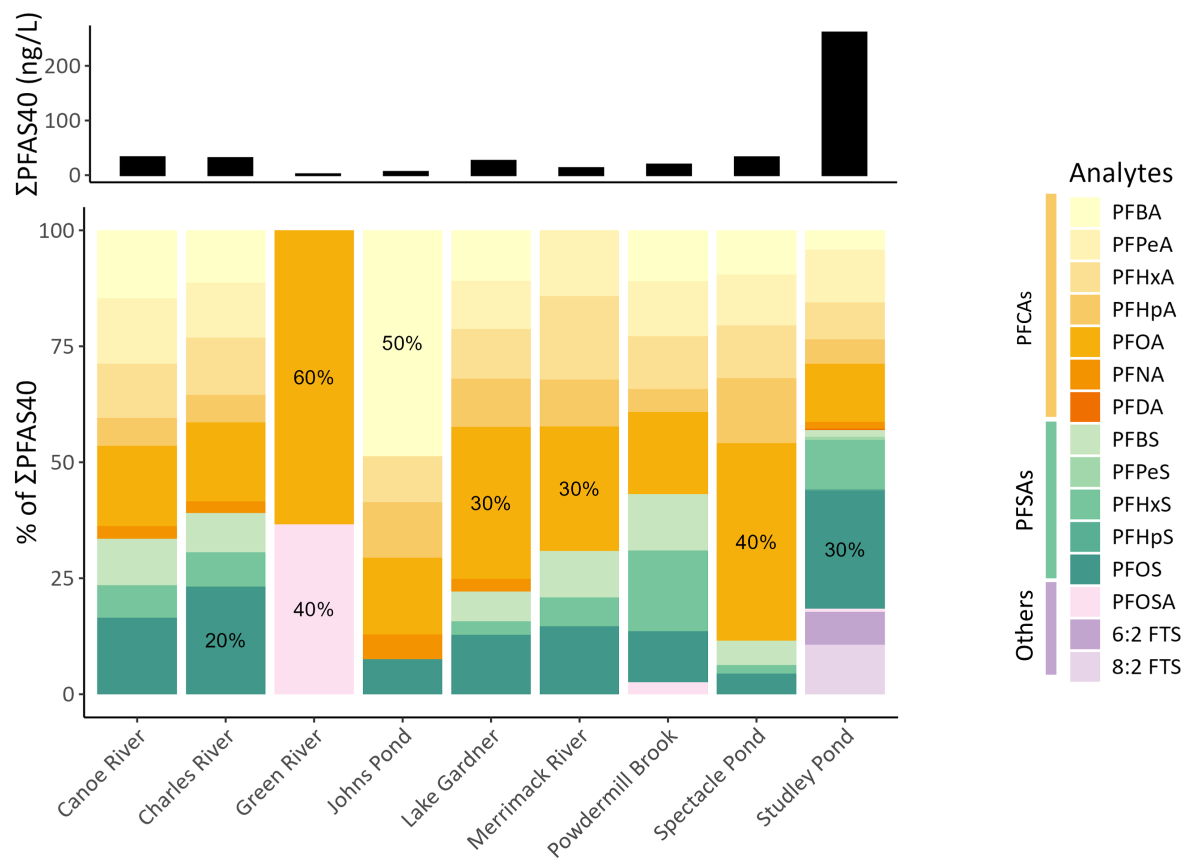
FOD = frequency of detection, MDL = method detection limit, SD = standard deviation, NA = not applicable (means and standard deviations were only calculated for analytes detected in at least 50% of samples).

Percentiles indicate the value below which a certain percentage of data points fall within a dataset. For example, the 75th percentile for PFOA in Table 8 shows that 75% of surface water samples had PFAS levels below 8.61 ng/L. In some cases, percentiles are marked as "<MDL," which means there were not enough detections to calculate a value for that percentile. For instance, 6:2 FTS was detected in only 10% of samples, and its 75th percentile is listed as "<MDL" in Table 8. This means that 6:2 FTS was below the detection limit in at least 75% of the samples, or equivalently, the 75th percentile value falls below the laboratory's MDL. Laboratory MDL values are provided in Table 6.

The highest ΣPFAS40 concentration was 261 ng/L, detected in a surface water sample from Studleys Pond in Rockland, MA. This waterbody was also included in MassDEP's 2023 PFAS Study, which reported an even higher ΣPFAS40 concentration of 396 ng/L (MassDEP, 2023). In both studies, PFOS was a major contributor to total PFAS concentrations, with recorded concentrations of 66.4 ng/L and 80.0 ng/L in the current study and 2023 study, respectively. Studleys Pond is located south of the former South Weymouth Naval Air Station, a facility that operated from 1944 to 1997 and is now designated as an EPA Superfund site. Elevated levels of PFAS at Studleys Pond likely stem from the former air station's past use of AFFF. There are several possible reasons why many PFAS concentrations appear to have decreased in surface water and fish tissue in the years between sampling events (2022, 2024), including adsorption to sediment, dilution, and transport out of the pond (e.g., water inflow and outflow).

Figure 3 graphically displays the relative contribution of each PFAS analyte and different PFAS categories to the total measured PFAS (ΣPFAS40, range: <MDL to 261 ng/L). This information is displayed for nine out of the 10 freshwater sampling locations; at the tenth location (Sheomet Pond: reference waterbody), no PFAS were detected above the MDL in surface water. In the figure, perfluorinated carboxylic acids (PFCAs) are shown in shades of orange and yellow, perfluorinated sulfonic acids (PFSAs) are shown in shades of green, and other PFAS in shades of purple. For all locations in the figure, PFCAs made up the greatest percentage of ΣPFAS40 (from 43.1% at Studleys Pond to 92.4% at Johns Pond); PFSAs made up the next greatest percentage of ΣPFAS40 for eight of the nine locations (PFSAs contributed between 0% [Green River] and 40.6% [Powdermill Brook]). Other PFAS (PFOSA, 6:2 FTS, and 8:2 FTS) were only detected in three of the freshwater surface water samples; these PFAS may be indicative of unique PFAS sources at those waterbodies, such as AFFF. Note that manufacturers have unique AFFF formulations with different PFAS composition. Legacy AFFF formulations manufactured in the US from the late 1960s to 2002 typically contained PFOS, legacy AFFF formulations manufactured in the US from the 1970s to 2016 typically contain other long-chain PFAS, and modern AFFF formulations typically contain short-chain PFAS (ITRC, 2023b).

Figure 3. PFAS Profiles for Freshwater Surface Water Samples



Freshwater sampling included two reference waterbodies (Sheomet Pond and Green River) and eight non-reference waterbodies, across the MassDEP regions. Because of the small sample sizes in these groups, comparisons of PFAS concentrations in surface water between reference and non-reference waterbodies, as well as across MassDEP regions, are not presented.

Summary of Freshwater Surface Water Results

- Fifteen PFAS were detected in freshwater surface water samples. PFOS and PFOA had the highest reported concentrations of 66.4 ng/L and 32.9 ng/L, respectively. PFOA had the highest median concentration (4.39 ng/L).
- PFOA was the most frequently detected analyte, found in all but one waterbody, followed by PFHpA, PFHxA, and PFOS, each detected in all but two waterbodies.

4.1.2. Fish Tissue Results

Two types of freshwater fish samples were analyzed in this project: boneless, skinless filet samples from individual fish (n=33) and whole-body fish (n=41). Appendix D presents detailed results for each waterbody for the 10 most frequently detected PFAS in both sample types, as well as mean fish weight and length by waterbody and fish species.

Filet sample results

Table 9 presents descriptive statistics for the 18 PFAS detected in at least one fish filet sample. The following observations are evident from the summary data:

- At least one PFAS was detected in fish filets from all waterbodies.
- PFTrDA was detected most frequently, present in 97% of filet samples. Multiple other PFAS—PFDoA, PFOS, PFTrDA, and PFUnA (in order of decreasing frequency of detection)—were detected in more than 90% of samples and in at least one filet sample from each waterbody.
- PFOS had the highest recorded concentration (115 ng/g) and the highest average concentration (median: 3.54 ng/g; mean: 14.5 ng/g). The next highest concentrations were observed for 7:3 FTCA, which was detected in only two waterbodies: the Merrimack River (maximum: 2.6 ng/g) and Studleys Pond (maximum: 33.9 ng/g).
- ΣPFAS39 concentrations ranged from 0.167 ng/g to 156 ng/g, with a median value of 7.09 ng/g.

Consistent with surface water results, the highest PFAS concentrations in fish filets were observed at Studleys Pond, where two bluegill filet samples were collected. In both samples, PFOS was the primary contributor to ΣPFAS39, with concentrations of 115 ng/g and 87.5 ng/g. The second-largest contributor was 7:3FTCA, detected at 25.1 ng/g and 33.9 ng/g. These findings are similar to those from MassDEP's 2023 PFAS Study which included sampling at Studleys Pond in 2022, where PFOS was detected at 150 ng/g in a composite sample of three bluegill filets (MassDEP, 2023). However, in that study, 7:3 FTCA was detected at a lower concentration of 9.3 ng/g, and 8:2 FTS was detected at a higher concentration of 19 ng/g (compared to 7.73 ng/g in the current study).[2]

Table 9. Descriptive Statistics for Freshwater Fish Filet Tissue (n=33)

Analyte	FOD (%) among samples	FOD (%) across waterbodies	Min (ng/g)	25th Percentile (ng/g)	Median (ng/g)	75th Percentile (ng/g)	Max (ng/g)	Mean (ng/g)	SD (ng/g)
PFTrDA	97.0	100	<MDL	0.245	0.427	0.909	1.37	0.553	0.361
PFDoA	93.9	100	<MDL	0.230	0.355	0.583	1.78	0.456	0.370
PFOS	93.9	100	<MDL	1.09	3.54	10.2	115	14.5	29.6
PFUnA	93.9	100	<MDL	0.328	0.514	0.775	1.69	0.579	0.374
PFDA	75.8	90.0	<MDL	0.152	0.309	0.511	1.09	0.333	0.240
PFTeDA	69.7	90.0	<MDL	<MDL	0.218	0.716	1.26	0.390	0.363
PFOSA	33.3	40.0	<MDL	<MDL	<MDL	0.238	4.07	NA	NA
PFDS	24.2	40.0	<MDL	<MDL	<MDL	0.182	0.506	NA	NA
PFNA	15.2	40.0	<MDL	<MDL	<MDL	0.0505	0.244	NA	NA
7:3 FTCA	12.1	20.0	<MDL	<MDL	<MDL	<MDL	33.9	NA	NA
NEtFOSAA	15.2	20.0	<MDL	<MDL	<MDL	<MDL	0.305	NA	NA
NMeFOSAA	6.1	20.0	<MDL	<MDL	<MDL	<MDL	0.19	NA	NA
8:2 FTS	6.1	10.0	<MDL	<MDL	<MDL	<MDL	7.73	NA	NA
PFHpA	6.1	10.0	<MDL	<MDL	<MDL	<MDL	0.263	NA	NA
PFHpS	6.1	10.0	<MDL	<MDL	<MDL	<MDL	0.183	NA	NA
PFHxS	6.1	10.0	<MDL	<MDL	<MDL	<MDL	0.967	NA	NA
PFNS	6.1	10.0	<MDL	<MDL	<MDL	<MDL	0.432	NA	NA
PFOA	3.0	10.0	<MDL	<MDL	<MDL	<MDL	0.164	NA	NA
ΣPFAS39	NA	NA	0.167	2.75	7.09	12.2	156	21.2	42.2

- Fish tissue data represent results from 33 samples collected across 10 waterbodies. Summary statistics shown above give equal weight to waterbodies. All detections are described.
- NA=not applicable and is shown for mean and standard deviation when a PFAS analyte was only detected in <50% of samples.
- NEtFOSE was excluded from ΣPFAS39 due to blank sample interference in the tissue matrix.

[2] Though 7:3 FTCA and 8:2 FTS have been reported in fish elsewhere, these analytes are not detected in the majority of fish as is the case for PFOS. For example, in a report published by the Maine DEP in 2023, where freshwater fish were collected in waterbodies with potential PFAS contamination, 7:3 FTCA and 8:2 FTS were detected in 23.5% and 11.8% of composite skinless fish filets (and at relatively similar levels to this study), respectively (ME DEP, 2023). Conversely, neither of these compounds were detected in a New Hampshire DES sampling effort to provide a baseline reference for PFAS in lake fish, surface water, and sediment (NHDES, 2021). Notably, the detection limits for 7:3 FTCA are higher than many other PFAS in EPA Method 1633A, which constrains interpretation of how widespread the distribution of 7:3 FTCA is in freshwater fish relative to other PFAS measured by this method.

Of the 10 waterbodies where freshwater fish filets were collected, two were designated as reference locations. Six PFAS were detected in at least 50% of samples at combined reference and non-reference locations. For these six PFAS, measured concentrations at reference locations (n= 7 filets) were lower than those at non-reference locations (n= 26 filets), and this difference was statistically significant for each analyte: PFTrDA ($p = 0.01$), PFDoA ($p < 0.01$), PFOS ($p < 0.01$), PFUnA ($p = 0.01$), PFDA ($p < 0.01$), and PFTeDA ($p = 0.04$). Summary statistics by reference location are in Appendix D. Due to the limited sample size for stratified results, comparisons by MassDEP region are not shown.

Two fish species, bluegill (n=9 filets) and yellow perch (n=7 filets), were caught in sufficient quantities across multiple waterbodies to allow comparisons of PFAS concentrations between species. We found a significant difference between the two species for PFDoA, with higher concentrations in bluegill compared to yellow perch (p=0.05). Note that these differences should be interpreted with caution. While the two species overlapped at some waterbodies, there were others for which only bluegill or yellow perch were caught (i.e., waterbody effects may obscure differences between medians). Appendix D presents descriptive statistics for ΣPFAS39 by species.

We explored the relationship between fish length and weight and PFAS concentrations within species. Because each waterbody contains differing concentrations of PFAS, suspended solids, and water dynamics, it was essential to consider the effects of waterbody in modeling. However, because we caught a limited number of fish of each species at each waterbody, and different species were caught across waterbodies, we did not have an adequate sample size to reliably estimate the relationship between fish length or weight and PFAS concentrations.

Whole-body fish results

Table 10 presents descriptive statistics for the 22 PFAS detected in at least one of the 41 whole-body fish samples. The following observations are evident from the data:

- At least one whole-body fish from every waterbody had detectable levels of one or more PFAS.
- PFDoA, PFOS, PFTrDA, and PFUnA were detected in all samples at every waterbody. Several other PFAS—PFDA, PFTeDA, and PFNA—were detected in more than 80 percent of whole-body samples and were present in at least one sample from every waterbody.
- Similar to the filet results, PFOS and 7:3 FTCA were detected at the highest concentrations, with both maximum values observed in samples from Studleys Pond. Further, the highest whole-body concentrations for PFOS (658 ng/g) and for 7:3 FTCA (546 ng/g) at this waterbody were considerably higher than concentrations observed in the filets analyzed from the same species of fish caught at this location. The next highest concentrations for these PFAS were observed in the Charles River (whole-body maximum PFOS: 106 ng/g) and the Merrimack River (whole-body maximum 7:3 FTCA: 9.10 ng/g).

Table 10. Descriptive Statistics for Freshwater Whole-body Fish Tissue (n=41)

Analyte	FOD (%) among samples	FOD (%) across waterbodies	Min (ng/g)	25th Percentile (ng/g)	Median (ng/g)	75th Percentile (ng/g)	Max (ng/g)	Mean (ng/g)	SD (ng/g)
PFDoA	100	100	0.158	0.557	0.991	2.01	5.97	1.69	1.58
PFOS	100	100	0.928	4.69	13.0	32.5	658	65.7	152
PFTrDA	100	100	0.221	0.727	1.08	2.13	4.98	1.59	1.20
PFUnA	100	100	0.380	0.679	1.49	2.29	6.44	1.89	1.49
PFDA	97.6	100	<MDL	0.379	1.05	1.97	4.62	1.44	1.22
PFTeDA	97.6	100	<MDL	0.376	0.597	1.15	3.84	1.04	1.00
PFNA	80.5	100	<MDL	0.100	0.170	0.249	1.44	0.221	0.229
PFOA	56.1	80.0	<MDL	0.0439	0.100	0.157	0.573	0.124	0.106
PFDS	53.7	70.0	<MDL	<MDL	0.115	0.519	2.48	0.409	0.618
PFOSA	53.7	80.0	<MDL	<MDL	0.126	0.455	10.2	1.25	2.53
NEtFOSAA	34.1	40.0	<MDL	<MDL	<MDL	0.187	0.778	NA	NA
PFHxS	31.7	60.0	<MDL	<MDL	<MDL	0.135	10.5	NA	NA
7:3 FTCA	29.3	40.0	<MDL	<MDL	<MDL	3.02	546	NA	NA
NMeFOSAA	24.4	40.0	<MDL	<MDL	<MDL	<MDL	0.544	NA	NA
PFHpS	22.0	40.0	<MDL	<MDL	<MDL	<MDL	2.42	NA	NA
5:3 FTCA	14.6	30.0	<MDL	<MDL	<MDL	<MDL	71.4	NA	NA
PFBA	14.6	40.0	<MDL	<MDL	<MDL	<MDL	6.42	NA	NA
PFNS	9.8	20.0	<MDL	<MDL	<MDL	<MDL	1.75	NA	NA
8:2 FTS	7.3	10.0	<MDL	<MDL	<MDL	<MDL	27.0	NA	NA
PFDoS	7.3	10.0	<MDL	<MDL	<MDL	<MDL	0.848	NA	NA
NFDHA	4.9	20.0	<MDL	<MDL	<MDL	<MDL	1.15	NA	NA
PFPeA	4.9	20.0	<MDL	<MDL	<MDL	<MDL	0.456	NA	NA
ΣPFAS39	NA	NA	3.33	10.4	25.3	45.4	1336	124	308

- Fish tissue data represent results from 41 samples collected across 10 waterbodies. Summary statistics shown above give equal weight to waterbodies.
- NA=not applicable and is shown for mean and standard deviation when a PFAS analyte was only detected in <50% of samples.
- NEtFOSE was excluded from ΣPFAS39 due to blank sample interference in the tissue matrix.

Ten PFAS were detected in more than 50% of whole fish samples collected across reference and non-reference locations combined. For these 10 PFAS, the measured concentrations in reference locations (n=11 whole-body fish) were lower than those at non-reference locations (n=30 whole-body fish). Concentrations were significantly higher for PFOS (p<0.01), PFTeDA (p<0.01), PFDA (p<0.01), PFDoA (p<0.01), PFUnA (p=0.01), PFOA (p=0.02), and PFTrDA (p=0.02). Statistical significance is not reported for PFDS and PFOSA, as there were no detections of these compounds in reference fish, and PFNA was not significantly different between the reference and non-reference fish (p=0.36). Summary statistics for whole-body fish by reference location are provided in Appendix D.

Two fish species, bluegill (n= 9 whole-body fish) and yellow perch (n=8 whole-body fish), were caught in sufficient quantities across multiple waterbodies to allow comparisons of

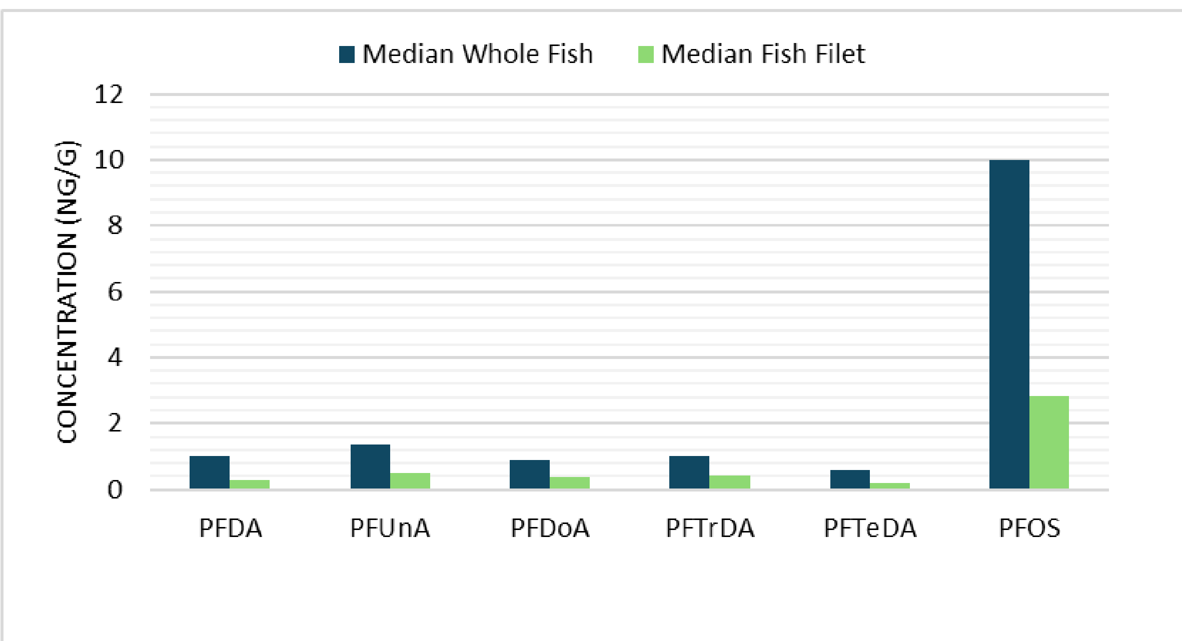
PFAS concentrations between the species. There were significant differences between the species only for PFNA, with the measured concentrations higher in yellow perch than bluegill (p=0.01). As noted above for fish filets, these differences should be interpreted with caution. While the two species overlapped at some waterbodies, there are others for which only bluegill or yellow perch were caught; waterbody effects may obscure differences between medians. Appendix D presents descriptive statistics for ΣPFAS39 by species.

Similar to filets, the relationship between fish length and weight and PFAS concentrations within species was explored, accounting for waterbody effects. However, the sample size was inadequate to reliably estimate the relationship between fish length or weight and PFAS concentrations.

Fish filet vs whole-body fish results

Additional analyses were conducted to determine if PFAS concentrations from whole-body fish samples (n=41) were higher or lower than PFAS concentrations of fish filet samples (n=33). This comparison was conducted using a t-test on log-transformed values for the six analytes detected in at least 50% of both sample types: PFDA, PFUnA, PFDoA, PFTrDA, PFTeDA, and PFOS. For all six analytes, concentrations were significantly higher in whole fish compared to filets (see Table D9). As shown in Figure 3, median concentrations of these PFAS in whole fish were at least twice as high as those observed in filet samples. These findings are similar to other studies, which consistently show higher PFAS concentrations in whole-body fish compared to filets. For example, Fair et al. (2019) reported that PFAS concentrations in freshwater whole-body fish were two to three times higher than those of filets in edible fish species collected in Charleston, South Carolina.

Figure 4. Median Freshwater Whole Fish and Filet Comparison for Six PFAS



These results—showing PFAS detectable in all freshwater fish samples—are consistent with findings from other U.S. studies. For example, in the 2013–2014 National Rivers and Streams Assessment, PFAS were detected in 348 of 349 fish samples analyzed (Stahl et al., 2023). Similarly, the 2015 Great Lakes Human Health Fish Filet Tissue Study reported PFAS in all 152 fish samples tested (Barbo, 2023). In MassDEP's 2023 PFAS Study, PFAS were detected in 241 of 242 composite filet samples, representing 948 individual fish (MassDEP, 2023). In that study, PFOS and PFUnA were the most frequently detected compounds (in 99% and 95% of samples, respectively) and had the highest median concentrations—5.70 ng/g for PFOS and 0.72 ng/g for PFUnA. In the current study, PFOS and PFUnA were detected in 100% of whole-body fish samples and 94% of filet samples, with slightly lower median concentrations in the filets: 3.54 ng/g for PFOS and 0.514 ng/g for PFUnA. Concentrations of PFAS were also lower in reference waterbodies compared to non-reference waterbodies at freshwater sites in this study for both filets and whole-body fish.

Summary of Freshwater Fish Tissue Results

- All waterbodies had detectable levels of at least one PFAS in both fish filets and whole-body fish.
- PFTrDA, PFDoA, PFTrDA, PFUnA, and PFOS were among the most frequently detected PFAS in both filets and whole-body fish. PFOS and 7:3 FTCA had the highest detected concentrations in both filets and whole-body fish; these results were from samples from Studleys Pond.
- PFAS concentrations were generally higher in whole-body fish compared to fish filets; median concentrations of the six PFAS detected in 50% or more of filets and whole-body fish were at least twice as high in whole-body fish compared to filets.

4.1.3. Invertebrate results

Table 11 presents descriptive statistics for the 27 PFAS detected in at least one of the 45 composite invertebrate samples collected from freshwater sites. The observations below are consistent with the summary statistics. Refer to Appendix E for a complete set of invertebrate results for each waterbody.

- At least one PFAS analyte was detected in at least one composite invertebrate sample at each waterbody.
- PFOS was detected in all 45 composite samples and at every waterbody. PFOA, PFDoA, PFUnA, PFNA, PFTrDA, and PFTeDA were also found in at least one sample from each waterbody.
- 7:3 FTCA and 8:2 FTS were detected at the highest concentrations—167 ng/g and 135 ng/g, respectively. However, these compounds were found at limited locations; for example, 8:2 FTS was only detected at Studleys Pond.
- ΣPFAS39 concentrations for invertebrate samples ranged from 0.491 ng/g to 284 ng/g, with a median of 7.31 ng/g.

Table 11. Descriptive Statistics for Freshwater Invertebrates (n=45)

Analyte	FOD (%) among samples	FOD (%) across waterbodies	Min (ng/g)	25th Percentile (ng/g)	Median (ng/g)	75th Percentile (ng/g)	Max (ng/g)	Mean (ng/g)	SD (ng/g)
PFOS	100.0	100.0	0.202	0.543	2.63	5.39	42.3	6.00	8.47
PFOA	93.3	100.0	<MDL	0.290	0.593	1.16	5.33	1.02	1.24
PFDoA	91.1	100.0	<MDL	0.149	0.310	0.418	1.36	0.347	0.266
PFUnA	91.1	100.0	<MDL	0.207	0.323	0.516	1.26	0.406	0.311
PFDA	86.7	90.0	<MDL	0.133	0.223	0.485	1.45	0.362	0.355
PFNA	84.4	100.0	<MDL	0.137	0.243	0.439	1.42	0.317	0.280
PFTrDA	73.3	100.0	<MDL	<MDL	0.206	0.406	0.967	0.263	0.219
PFOSA	71.1	70.0	<MDL	<MDL	0.160	0.373	19.4	1.87	4.37
PFTeDA	60.0	100.0	<MDL	<MDL	0.191	0.232	0.637	0.177	0.127
PFHxS	55.6	70.0	<MDL	<MDL	0.124	0.511	18.6	1.29	3.57
PFPeA	35.6	70.0	<MDL	<MDL	<MDL	0.344	7.15	NA	NA
7:3 FTCA	26.7	40.0	<MDL	<MDL	<MDL	2.57	167	NA	NA
NEtFOSAA	26.7	40.0	<MDL	<MDL	<MDL	0.102	0.483	NA	NA
PFHpA	26.7	40.0	<MDL	<MDL	<MDL	0.0970	0.218	NA	NA
PFHpS	24.4	30.0	<MDL	<MDL	<MDL	<MDL	0.28	NA	NA
PFBA	20.0	50.0	<MDL	<MDL	<MDL	<MDL	5.62	NA	NA
5:3 FTCA	17.8	20.0	<MDL	<MDL	<MDL	<MDL	121	NA	NA
6:2 FTS	15.6	10.0	<MDL	<MDL	<MDL	<MDL	32.8	NA	NA
8:2 FTS	15.6	10.0	<MDL	<MDL	<MDL	<MDL	135	NA	NA
NMeFOSAA	11.1	30.0	<MDL	<MDL	<MDL	<MDL	0.557	NA	NA
PFHxA	11.1	10.0	<MDL	<MDL	<MDL	<MDL	0.189	NA	NA
PFDS	6.7	20.0	<MDL	<MDL	<MDL	<MDL	1.49	NA	NA
NFDHA	4.4	20.0	<MDL	<MDL	<MDL	<MDL	0.398	NA	NA
NMeFOSE	4.4	10.0	<MDL	<MDL	<MDL	<MDL	1.09	NA	NA
PFMBA	4.4	10.0	<MDL	<MDL	<MDL	<MDL	0.318	NA	NA
HFPO-DA	2.2	10.0	<MDL	<MDL	<MDL	<MDL	0.435	NA	NA
PFPeS	2.2	10.0	<MDL	<MDL	<MDL	<MDL	0.153	NA	NA
ΣPFAS39	NA	NA	0.491	3.94	7.31	17.3	284	41.0	79.8

- Invertebrate data represent results from 45 composite samples collected across 10 waterbodies.
- NA=not applicable and is shown for mean and standard deviation when a PFAS analyte was detected in <50% of samples.
- FOD= frequency of detection
- NEtFOSE was excluded from ΣPFAS39 due to blank sample interference in the tissue matrix.

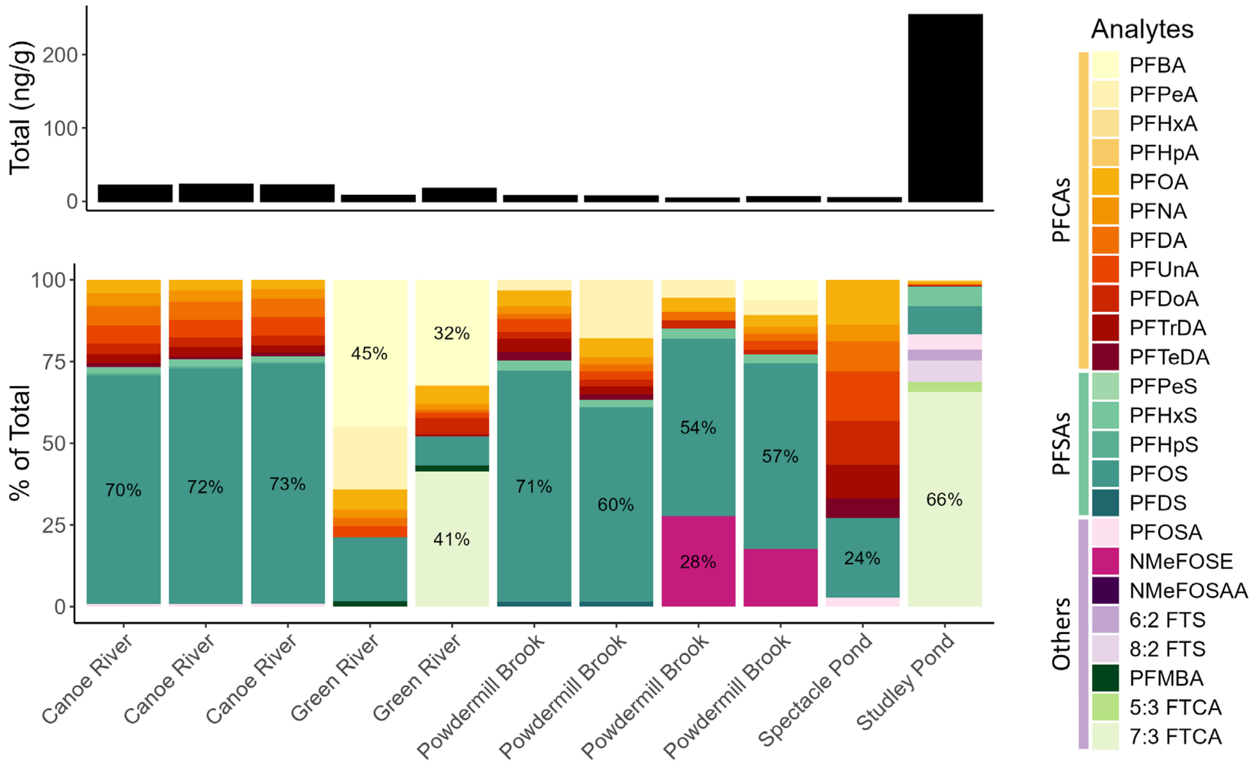
Further analyses were performed to determine if PFAS concentrations in invertebrates from reference locations differed from those from non-reference locations. This comparison was made for the eight PFAS that were detected in at least 50% of invertebrate samples. Concentrations in samples from the reference locations (n=9 composite samples) were significantly lower than those from non-reference locations (n=36 composite samples) for four PFAS: PFOS ($p<0.01$), PFDA ($p<0.01$), PFNA ($p=0.02$), and PFTeDA ($p=0.03$).

For the 10 PFAS detected in 50% or more of the samples, concentrations were compared among invertebrate groups with at least five samples. Significant differences were observed among crustaceans (n=7 composites), gastropods (n=13 composites), insects (n=11 composites), and combined invertebrates (n=12 composites) for PFTrDA ($p = 0.01$) and PFHxS ($p = 0.05$). Crustaceans had higher concentrations of PFTrDA compared to the other groups, while gastropods had lower PFTrDA concentrations compared to the other groups. In contrast, gastropods had the highest concentrations of PFHxS compared to the other groups and crustaceans had the lowest. Importantly, these differences between groups are influenced by site-specific differences in background concentrations, as not all groups were collected at each waterbody. However, there are also differences observed between groups within a given waterbody (e.g., for Studleys Pond, the PFHxS was detected at 15.1 ng/g in a sample of insects, 2.24 ng/g in a sample of crustaceans, and at an average concentration of 5.82 ng/g in five samples of gastropods [note that these numbers are given as an example of one waterbody]). Controlled laboratory studies have also reported differences between types of freshwater invertebrates; for example, Lewis et al. (2023) exposed several types of freshwater benthic macroinvertebrates to the same PFAS concentrations in sediment and found that each had different rates of PFAS bioaccumulation related to different levels of interaction and ingestion of PFAS from sediment.

For each invertebrate group, we also examined differences in PFAS profiles across sample types and sites. Figures 5 through 8 display these profiles for insects, gastropods, crustaceans, and combined invertebrates, respectively. As shown, PFAS profiles vary considerably between waterbodies within each invertebrate group but show less variation among different invertebrate types collected at the same site. For example, as shown in Figure 6, gastropod samples from different waterbodies exhibit markedly different PFAS profiles. However, all five gastropod samples from Studleys Pond display a more consistent profile, with more than 30-40% of ΣPFAS39 attributable to 8:2 FTS.

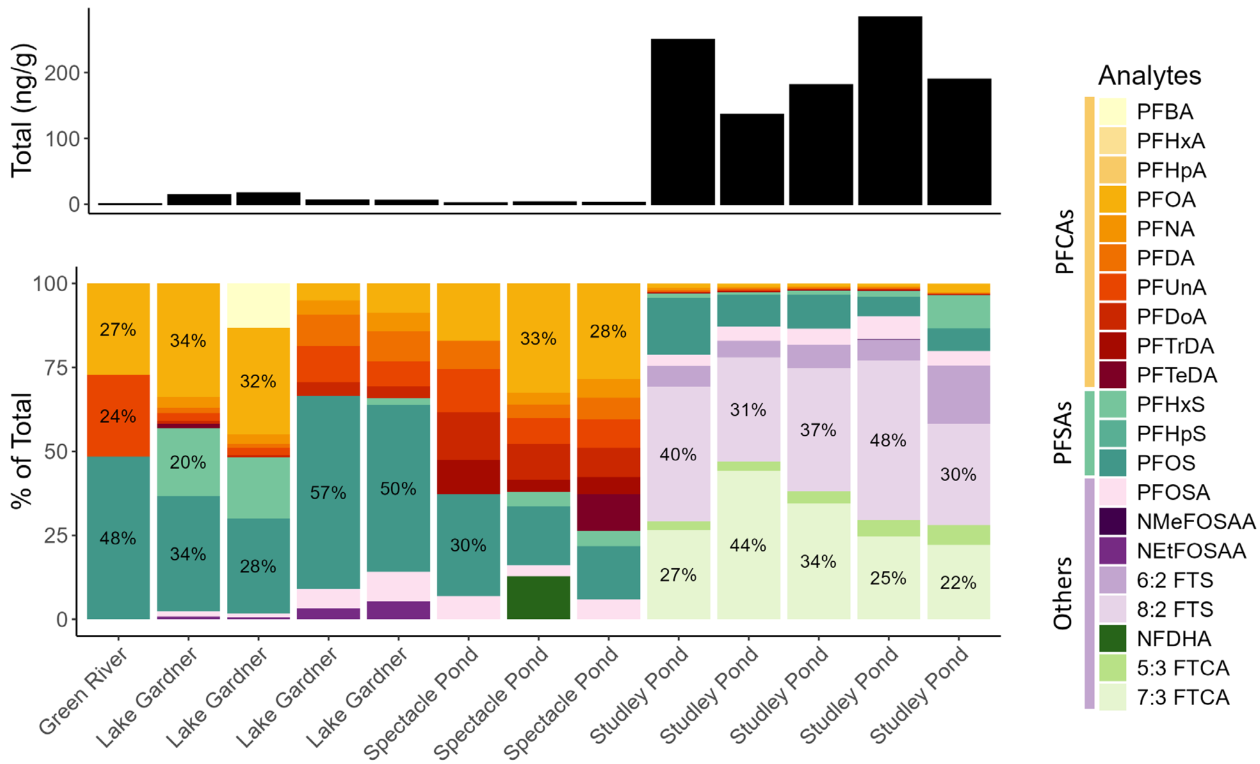
Brase et al. (2022) measured PFAS in benthic macroinvertebrates, surface water, and sediment in a historically PFAS-impacted site in New York. Similar to the current study, they found PFOS and PFOA in the majority of their macroinvertebrate samples, with PFOS at higher concentrations than PFOA, despite the opposite trend in surface water. In another study, Penland et al. (2020) assessed PFAS across the food web in a freshwater aquatic environment, including in invertebrates and fish. Overall, they observed a greater number of PFAS detected in aquatic insects (14 of 14 PFAS tested) and fish tissue (14 of 14 PFAS tested) compared to water (two of 10 PFAS tested). Unlike the current study, Penland et al. (2020) reported higher PFOS values in aquatic insects compared to fish, with a mean PFOS value in aquatic insects that was over seven times that of fish (132.82 g/ng in aquatic insects compared to a mean of 18.21 ng/g in fish). In the current study, the highest PFOS concentration measured in aquatic insects was 21.5 ng/g (Studleys Pond) and the highest concentration measured in fish filets was 115 ng/g (also from Studleys Pond).

Figure 5. PFAS Profiles for Freshwater Aquatic Insects



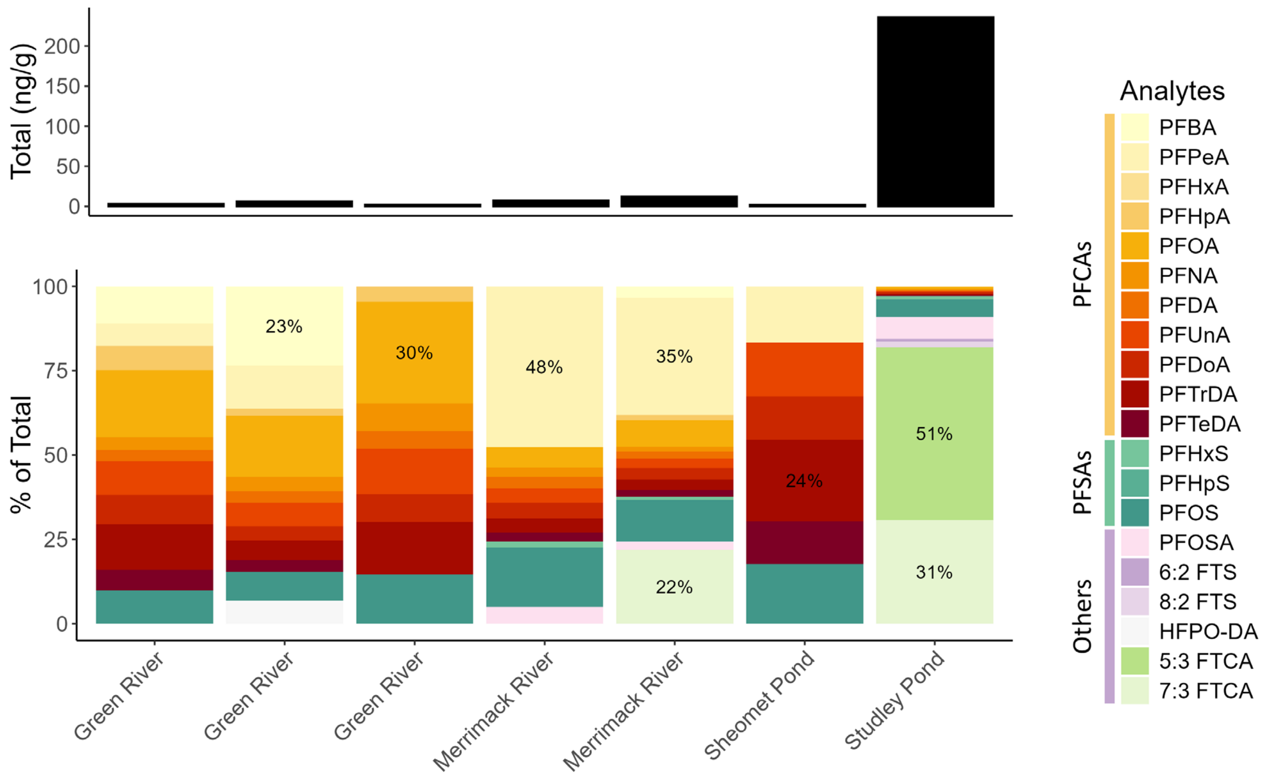
Plot shows the PFAS profiles of each composite sample for insects, along with the total ∑PFAS39 for each sample. Each bar represents one insect sample; multiple insect samples were collected from the same sampling site at some waterbodies. PFAS analytes that were not detected above the MDL are not included in either the sum or the profiles. Waterbodies where insects were collected are represented on the plot.

Figure 6. PFAS Profiles for Freshwater Gastropods



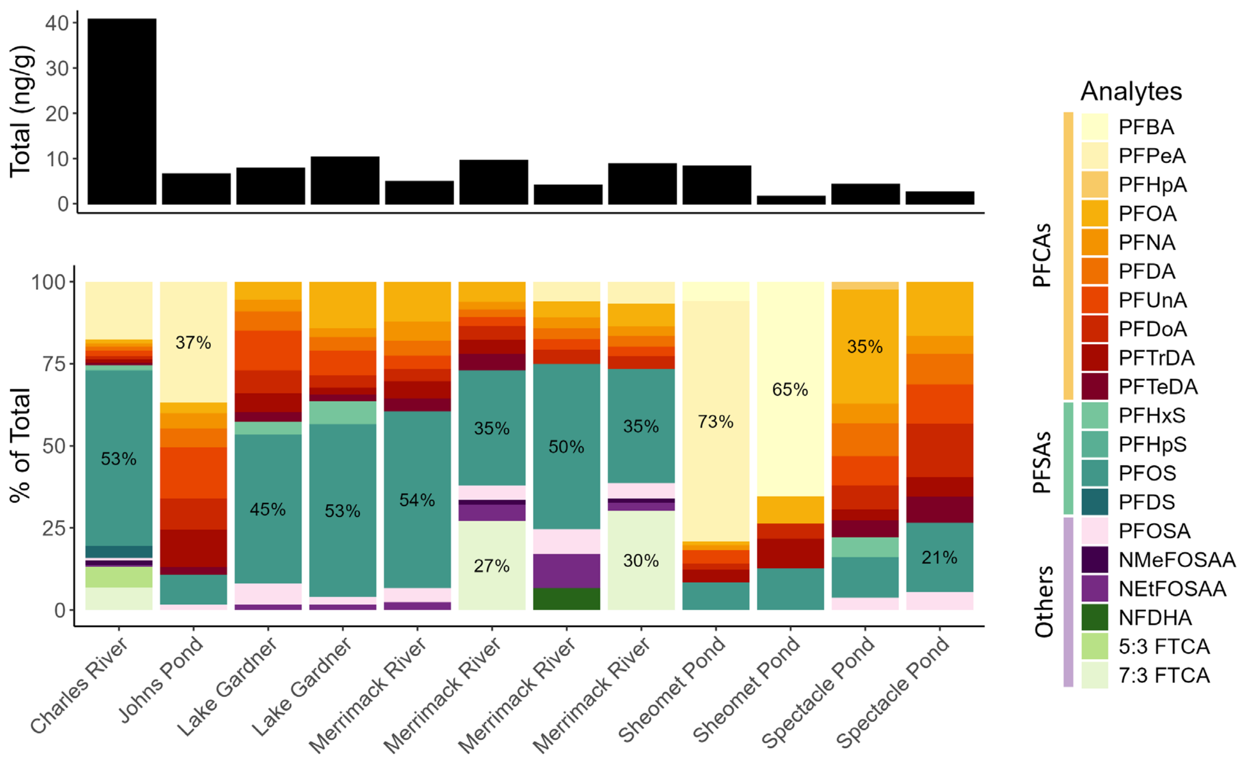
Notes: Plot shows the PFAS profiles of each composite sample for gastropods, along with the total ∑PFAS39 for each sample. Each bar represents one gastropod sample; multiple gastropod samples were collected from the same sampling site at some waterbodies. PFAS analytes that were not detected above the MDL are not included in either the sum or the profiles. Note also that only waterbodies where gastropods were collected are represented on the plot.

Figure 7. PFAS Profiles for Freshwater Crustaceans



Notes: Plot shows the PFAS profiles of each composite sample for crustaceans, along with the total ∑PFAS39 for each sample. Each bar represents one crustacean sample; multiple crustacean samples were collected from the same sampling site at some waterbodies. PFAS analytes that were not detected above the MDL are not included in either the sum or the profiles. Note also that only waterbodies where crustaceans were collected are represented on the plot.

Figure 8. PFAS Profiles for Freshwater Combined Invertebrates



Plot shows the PFAS profiles of each composite sample for combined invertebrates, along with the total ∑PFAS39 for each sample. Each bar represents one combined invertebrate sample; multiple combined invertebrate samples were collected from the same sampling site at some waterbodies. PFAS analytes that were not detected above the MDL are not included in either the sum or the profiles. Waterbodies where combined invertebrates were collected are represented on the plot.

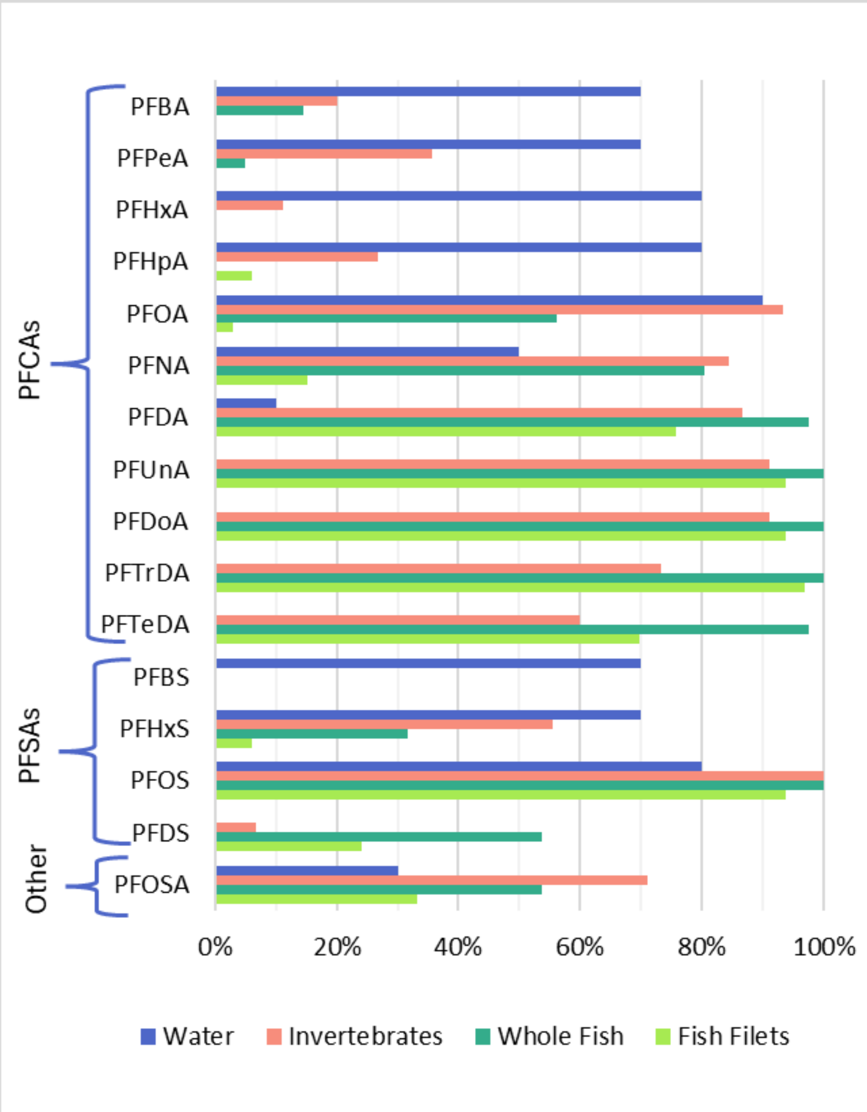
Summary of Freshwater Invertebrate Results

- PFOS was the most frequently detected PFAS and was detected in all 45 composite invertebrate samples.
- A wider range of PFAS was detected in freshwater invertebrates than in fish filets, whole-body fish, or surface water from the same waterbodies.
- ΣPFAS39 concentrations across invertebrate samples ranged from 0.491 ng/g to 284 ng/g, with a median of 7.31 ng/g.

4.1.4. Comparison by Freshwater Sample Type

The frequency of PFAS detection varied across media at freshwater locations. Figure 9 illustrates these variations for PFAS detected in at least 50% of samples from at least one type of sample. Overall, detection frequencies were more similar between fish filets and whole fish, as well as between fish and invertebrates, than between tissue and water. For most PFAS with high detection frequencies in fish and invertebrates, detection in water was low—with the exception of PFOS, which was frequently detected across all media types.

Figure 9. Frequency of Detection in Freshwater by Sample Type

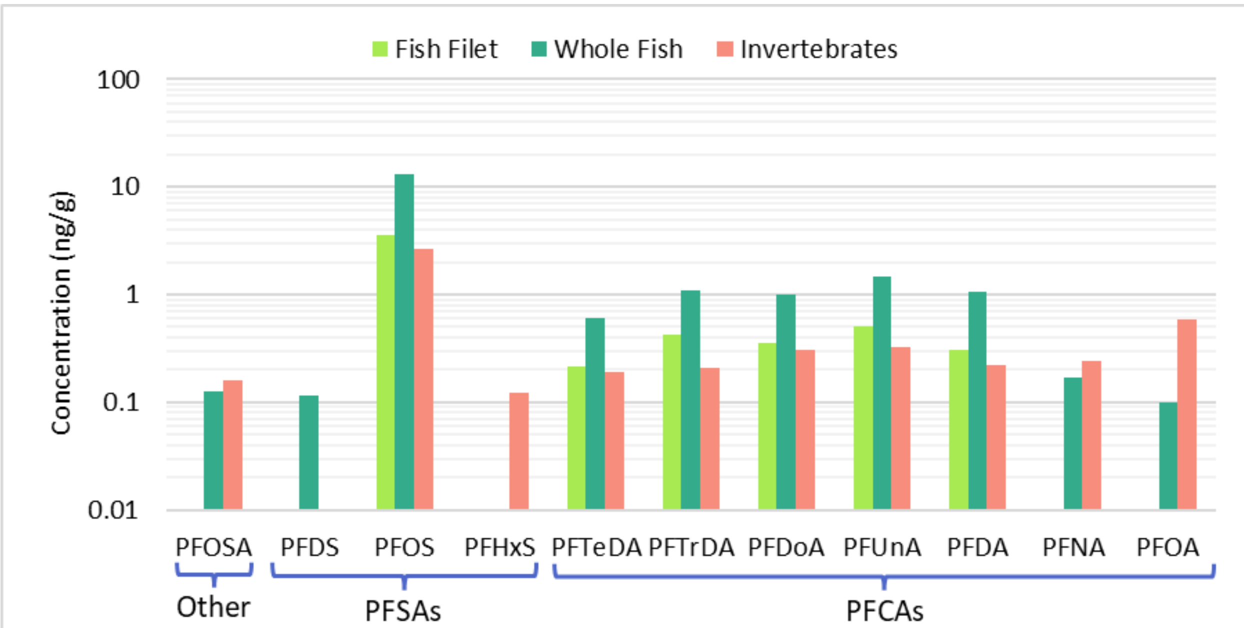


This figure includes all PFAS that were detected in 50% or more of any freshwater sample types. Within PFAS classes, PFAS analytes are ordered from shortest to longest chain length. PFBA, PFPeA, PFHxA, and PFHpA are short-chain PFCAs; PFOA, PFNA, PFDA, PFUnA, PFDoA, PFTrDA, and PFTeDA are long-chain PFCAs. PFBS is the only short-chain PFSA in the figure. PFHxS, PFOS, and PFDS are long-chain PFSAs.

In addition, PFCAs and PFSAs with longer carbon chain lengths were more frequently detected in tissue samples than in water samples. All short-chain PFCAs found in at least 50% of any freshwater samples were also detected in over 50% of surface water samples, but these same short-chain PFAS appeared in less than 40% of fish fillets, whole fish, or invertebrates. In contrast, five of the seven long-chain PFCAs detected in at least 50% of freshwater samples were found in 60% or more of fish fillets, whole fish, and invertebrates, while appearing in 10% or fewer of the surface water samples. See Table 6 for PFAS chain length classifications.

In freshwater tissue samples, whole fish generally showed higher median concentrations than both fish filets and invertebrates. For PFOA, however, median concentrations were higher in invertebrates than whole fish. Figure 10 presents median concentrations for PFAS detected in at least 50% of the fish filet, whole fish, and invertebrate samples. The figure uses a logarithmic scale to allow for meaningful comparisons across media, given the large variations in median concentrations among PFAS analytes.

Figure 10. Freshwater Median PFAS by Tissue Type



This figure includes all PFAS that were detected in 50% or more of any freshwater tissue sample type. Bars represent median values. For media with less than 50% detection for a given PFAS, medians are not shown. Within PFAS classes, PFAS analytes are ordered from longest to shortest chain length. PFDS, PFOS, and PFHxS are long-chain PFSAs. All PFCAs shown are long-chain PFCAs.

4.1.5. Bioaccumulation Factors in Freshwater Media

BAFs quantify the extent to which PFAS bioaccumulate in organisms relative to their surrounding environment. This metric is useful for assessing how bioaccumulation varies across different tissues, species, and trophic levels; other studies have shown significant variation in PFAS bioaccumulation by geochemical factors, organism behavior, and habitat PFAS concentrations (Lewis et al., 2022). In this study, PFAS BAFs were calculated by species (for fish) and by type (for invertebrates) using co-located surface water and tissue samples. Calculations were performed using Equation 1 (see Section 3.5) for PFAS detected in both tissue and surface water at 25% or more of the sampled waterbodies. In this study, BAF calculations were limited to PFOS, PFOA, PFNA, and PFHxS for a select subset of sample types, due to the limited number of paired tissue-water samples which met detection frequency criteria.

Table 12 summarizes BAFs across waterbodies. All summary BAFs meet the criteria outlined in Burkhard (2021), also used by EPA in setting aquatic life criteria (EPA, 2024a, 2024b) to be considered “high” quality, based on the number of water and organism samples, concurrent collection, and co-located sampling. Overall, the BAFs observed in this study are consistent with those reported in other studies. For example, the geometric mean BAF for PFOS in bluegill filets was 3.16 log(L/kg) in this study, compared to 3.26 log(L/kg) reported in MassDEP’s 2023 PFAS study. Among the PFAS for which BAFs were calculated for fish, PFOS had the highest BAFs (3.71 log[L/kg] for bluegill whole-body fish, 3.16 log[L/kg] for bluegill fish filets; 3.86 log[L/kg] for yellow perch whole-body fish) and PFOA had the lowest (1.12 log[L/kg] for bluegill whole-fish; 1.34 log[L/kg] for yellow perch whole-body fish)—consistent with that reported in the meta-analysis of PFAS BAFs by Burkhard (2021). Whole-body fish also had higher BAFs than fish filets of the same species for PFOS, also consistent with Burkhard (2021).

Median BAFs calculated for gastropods, insects, and combined invertebrates were similar across sample types for PFOA. However, gastropods had a lower median BAF for PFOS, and insects had a lower median BAF for PFHxS. Focusing on gastropods, Burkhard (2021) reported a slightly higher BAF for PFOS (3.05 log[L/kg], SD: 1.01 log[L/kg]) among the five studies of freshwater gastropods in their meta-analysis compared to the median found in this study (2.54 log[L/kg]), although this is still within the one standard deviation of the value reported by Burkhard. Similarly, Burkhard reported a higher BAF for PFHxS in gastropods (3.21 log[L/kg]) compared to this study’s median value of 2.23 log[L/kg], although Burkhard’s reported BAF was based on only one study. For PFOA, the average gastropod BAF reported by Burkhard (1.67 log[L/kg]) was in line with the 1.86 log[L/kg] found in this study. Other studies considering accumulation of PFAS in freshwater aquatic life, conducted since Burkhard’s meta-analysis, have reported various BAFs for freshwater invertebrates. For instance, Brase et al. (2022) reported PFOS BAFs in various freshwater invertebrates ranging from 3.53 to 3.71 log(L/kg) in aquatic insect larvae and crayfish in the Hudson River Watershed of New York, which is higher than the maximums BAFs we calculated for each group for PFOS (Table 12).

Table 12. BAFs for Freshwater Media

PFAS	Species or Type	# of Water-bodies[a]	# of Samples[b]	Minimum BAF (log[L/kg])	Geometric Mean BAF (log[L/kg])	Median BAF (log[L/kg])	Maximum BAF (log[L/kg])	Quality[c]
PFOS	Bluegill (whole fish)	4	8	3.38	3.71	3.73	3.92	high
	Bluegill (filet)	4	8	2.97	3.16	3.16	3.33	high
	Yellow perch (whole fish)	3	5	3.63	3.86	3.79	4.16	high
	Combined invertebrates	3	5	2.55	2.96	3.02	3.48	high
	Gastropods	3	12	2.28	2.66	2.54	3.16	high
	Insects	4	9	2.51	3.18	3.29	3.48	high
PFOA	Bluegill (whole fish)	4	7	0.64	1.12	1.21	1.34	high
	Yellow perch (whole fish)	3	5	1.08	1.34	1.21	1.82	high
	Combined invertebrates	3	5	1.48	1.88	1.98	2.23	high

PFAS	Species or Type	# of Water-bodies[a]	# of Samples[b]	Minimum BAF (log[L/kg])	Geometric Mean BAF (log[L/kg])	Median BAF (log[L/kg])	Maximum BAF (log[L/kg])	Quality[c]
	Gastropods	4	13	1.31	1.93	1.86	2.79	high
	Insects	5	11	1.63	2.09	2.03	2.97	high
PFNA	Bluegill (whole fish)	3	4	1.72	1.92	1.77	2.18	high
	Yellow perch (whole fish)	3	5	2.33	2.69	2.59	3.27	high
PFHxS	Combined Invertebrates	3	4	2.41	2.66	2.61	2.98	high
	Gastropods	3	10	1.52	2.44	2.23	3.61	high
	Insects	3	8	1.57	2.04	2.05	2.74	high

- BAFs were reported for sample-water type combinations where PFAS was detected in 25% or more of both media.
- BAF summary statistics reported in the table above represent only values where PFAS was detected in both of a co-located tissue-surface water pair.
- Because BAFs vary over orders of magnitude, we report in units of log(L/kg).

[a] Number of waterbodies represents the number of waterbodies where an analyte was detected above the MRL where that PFAS was also detected in a co-located tissue sample.

[b] Number of samples represents the number of tissue samples where an analyte was detected above the MRL where that PFAS was also detected in the co-located surface water sample. Note that multiple tissue samples may be associated with the same surface water sample.

[c] Quality was assessed using the criteria in Burkhard (2021). Quality designations are "high," "medium," or "low."

EPA published summary statistics for BAF values used in their Freshwater Aquatic Life Ambient Water Quality Criteria recommendations for PFOS and PFOA. These values are based on the lowest species-level BAF measured at a site, compiled across the literature. For PFOS, EPA reported a median BAF of 3.77 log(L/kg) for whole-body fish, which is very similar to our findings for whole-body bluegill and whole-body yellow perch. For PFOS in filets, EPA reported a median BAF of 3.02 log(L/kg), and for PFOS in invertebrates, the median BAF was 2.97 log(L/kg)—both of which align closely with our results (EPA, 2024b). For PFOA, our findings for whole-body fish are slightly higher than EPA's reported median (0.90 log[L/kg]), but consistent with EPA's reported median for invertebrates (1.93 log[L/kg]) (EPA, 2024a).

EPA also recently published draft national BAFs in support of its draft PFAS Human Health Water Quality Criteria recommendations (EPA, 2024g). These values are based on a comprehensive literature review and were developed for PFBS, PFOA, and PFOS across trophic levels two, three, and four. Both bluegill and yellow perch are classified as trophic level two species. The draft national BAF for PFOS at this trophic level is 2.62 log(L/kg), which is lower than the PFOS BAFs we observed for these species. In contrast, the BAFs we calculated for PFOA in both bluegill and yellow perch (1.21 log[L/kg] each) closely align with EPA's draft national BAF for PFOA at trophic level two (1.34 log[L/kg]).

Summary of Freshwater BAFs

- All calculated BAFs meet the criteria outlined in Burkhard (2021), also used by EPA in developing aquatic life criteria recommendations (EPA, 2024a and 2024b); and are considered "high quality", based on the number of water and organism samples, concurrent collection, and co-located sampling.
- Project BAFs are consistent with BAFs reported in the literature.

4.2. Results from Coastal Locations

This section presents results from surface water, fish filets, and shellfish collected across the 26 coastal sites. Descriptive statistics are presented by sample type, followed by additional analyses, such as comparisons across waterbody or sample characteristics for PFAS detected in 50% or more of samples.

4.2.1. Surface water results

Table 13 presents descriptive statistics for the 10 PFAS detected at least once in coastal surface water and for ΣPFAS40. For the purposes of this assessment, the Great Pond-Bournes Pond waterbody was treated as two separate locations. This distinction reflects the fact that this site encompasses two small harbor areas; surface water samples were collected from both, but shellfish were sampled in one and fish in the other. Therefore, coastal surface water results from 27 sites (not 26) are included in this assessment. Some noteworthy observations are listed below. Results for each waterbody are shown in Appendix F.

- PFOA was detected most frequently, found in 59% of waterbodies, followed by PFOS, detected in 41% of waterbodies.
- PFOA had the highest reported concentration (3.20 ng/L), followed by PFOS (2.67 ng/L). Both of these maximum values were observed at Pine Creek, near Plum Island.
- ΣPFAS40 concentrations ranged from <MDL (no PFAS detected) to 8.10 ng/L, with a median concentration of 0.612 ng/L.
- At 10 of the locations, none of the 40 PFAS included in EPA method 1633A were detected.

Table 13. Descriptive Statistics for PFAS in Coastal Surface Water (n = 27)

Analyte	FOD (%)	Min (ng/L)	25th Percentile (ng/L)	Median (ng/L)	75th Percentile (ng/L)	Max (ng/L)	Mean (ng/L)	SD (ng/L)
PFOA	59.3	<MDL	<MDL	0.500	0.633	3.20	0.571	0.600
PFOS	40.7	<MDL	<MDL	<MDL	0.453	2.67	NA	NA
PFHxA	29.6	<MDL	<MDL	<MDL	0.474	0.895	NA	NA

Analyte	FOD (%)	Min (ng/L)	25th Percentile (ng/L)	Median (ng/L)	75th Percentile (ng/L)	Max (ng/L)	Mean (ng/L)	SD (ng/L)
PFHpA	14.8	<MDL	<MDL	<MDL	<MDL	0.581	NA	NA
PFPeA	11.1	<MDL	<MDL	<MDL	<MDL	1.06	NA	NA
NEtFOSAA	3.7	<MDL	<MDL	<MDL	<MDL	0.467	NA	NA
PFBS	3.7	<MDL	<MDL	<MDL	<MDL	0.435	NA	NA
PFHxS	3.7	<MDL	<MDL	<MDL	<MDL	0.978	NA	NA
PFNA	3.7	<MDL	<MDL	<MDL	<MDL	0.510	NA	NA
PFOSA	3.7	<MDL	<MDL	<MDL	<MDL	0.397	NA	NA
ΣPFAS40	NA	<MDL	<MDL	0.612	1.59	8.10	1.30	1.91

- This table captures data from 27 coastal locations (one waterbody [Site ID 007] was considered as two separate locations).
- MDL = method detection limit, FOD = frequency of detection, SD=standard deviation, NA=not applicable (mean and standard deviations were only calculated for PFAS detected in at least 50% of samples).

Figure 11 shows the relative contribution of each PFAS analyte and different PFAS categories to the total measured PFAS (ΣPFAS40). This information is shown only for sites where PFAS concentrations were above the MDL. For all but two sites, PFCAs (PFPeA, PFHxA, PFHpA, PFOA, and PFNA) accounted for the largest percentage of ΣPFAS40. At five locations—Allen Harbor, Barnstable Harbor, Buttermilk Bay-Cohasset Narrows, Little Harbor, and Rock Harbor Creek—only a single PFAS analyte was detected (PFOA), and concentrations were between the MDL and the MRL. Only two sites—Plum Island Sound and Pine Creek—had PFAS detections (PFOSA, NEtFOSAA) that were not PFCAs or PFSAs. Note that many of the detections in surface water at coastal sites were close to the MDL.

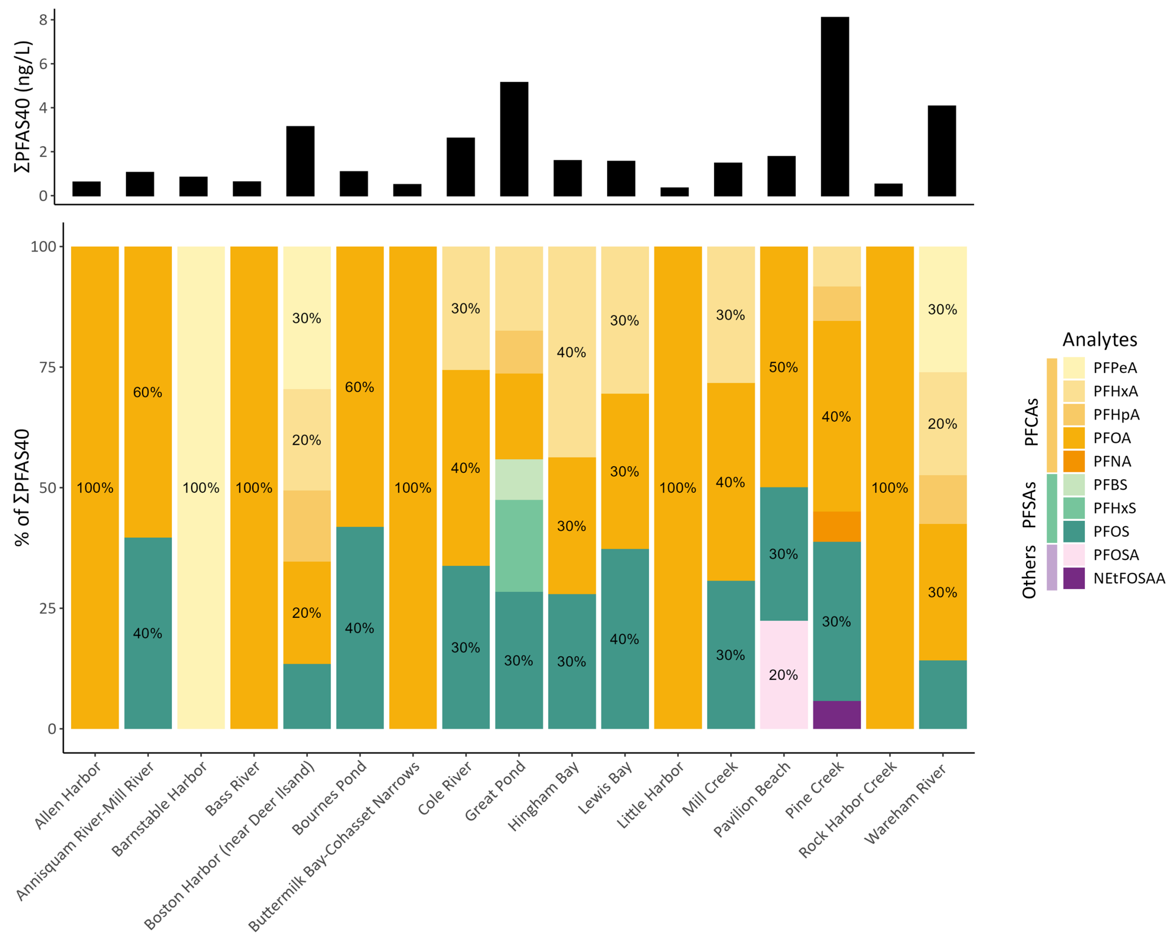
Coastal sampling locations were distributed across the five CZM regions (i.e., North Shore, Boston Harbor, South Shore, Cape Cod and the Islands, and South Coastal) and statistical analyses were used to determine if PFAS concentrations varied significantly across them. This analysis was only conducted for PFOA because it was the only analyte detected in surface water in 50% or more of samples. The North Shore had the highest median PFOA concentration (0.758 ng/L); in contrast, PFOA was not detected in any of the samples collected in the South Shore region. Despite this, no significant regional differences in PFOA concentrations were found using an ANOVA test after log-transforming PFOA concentrations ($p=0.21$).

Coastal sampling included three reference locations and 24 non-reference locations. Because the reference group had a small sample size, surface water concentrations were not compared between the two groups.

Overall, this study found lower PFAS concentrations in surface water from coastal locations compared to freshwater locations, which aligns with existing literature indicating an inverse relationship between salinity and PFAS concentrations (Ohoro et al., 2024; Yin et al., 2022; Zhang et al., 2019). This relationship is due to higher salinity lowering PFAS solubility, leading to greater adsorption into sediments (Yin et al., 2022). This can reduce

PFAS levels in water, though desorption may cause fluctuations. Factors like temperature, pH, organic carbon, chain length, and the dilution capacity of marine systems also affect PFAS occurrence. Prior sampling in Massachusetts has also shown this trend. In its 2022 assessment, MA DPH tested surface water from seven marine and 13 freshwater bathing beaches. They found PFOS concentrations below the reporting limit at 86% of marine beaches, compared to only 62% of freshwater beaches. Additionally, PFOA was below the reporting limit at all marine beaches but above the reporting limit at 77% of freshwater beaches (MA DPH, 2023b).

Figure 11. PFAS Profiles in Coastal Surface Water



- Sites where no PFAS were detected above MDL are not shown (n=10).
- “Pavillion Beach” location name changed to “Plum Island Sound” (site 12)

Summary of Coastal Surface Water Results

- PFOA was the most frequently detected PFAS, followed by PFOS.
- The median ΣPFAS40 was 0.612 ng/L.
- At 10 of the locations, none of the 40 PFAS included in EPA method 1633A were detected.
- PFAS concentrations were generally lower than in freshwater surface water.

4.2.2. Fish Tissue Results

Table 14 presents descriptive statistics for the 17 PFAS detected in at least one fish filet sample. Some noteworthy observations are listed below. Results for each waterbody are shown in Appendix G.

- At least one fish filet sample from each waterbody location (20) had detectable levels of at least one PFAS.
- PFOSA, a precursor to PFOS, was detected most frequently, present in 68.5% of samples and in at least one sample at each location. Along with PFOS and PFTrDA, PFOSA was one of the only PFAS detected in more than 50% of samples.
- 7:3 FTCA has the highest recorded concentration (4.31 ng/g), observed in a scup sample from Apponagansett Bay. The only other detection of 7:3 FTCA in coastal fish filets was also in scup, collected from the Wareham River location.
- ΣPFAS39 concentrations ranged from <MDL (no PFAS detected) to 5.94 ng/g, with a median of 0.643 ng/g.

Table 14. Descriptive Statistics for PFAS in Coastal Fish Filet Tissue (n=89)

Analyte	FOD (%) among samples	FOD (%) across waterbodies	Min (ng/g)	25th Percentile (ng/g)	Median (ng/g)	75th Percentile (ng/g)	Max (ng/g)	Mean (ng/g)	SD (ng/g)
PFOSA	68.5	100	<MDL	<MDL	0.190	0.418	1.96	0.323	0.373
PFOS	59.6	90.0	<MDL	<MDL	0.163	0.414	1.83	0.343	0.414
PFTrDA	59.6	85.0	<MDL	<MDL	0.120	0.202	1.91	0.217	0.333
PFUnA	47.2	90.0	<MDL	<MDL	<MDL	0.186	0.470	NA	NA
PFDoA	30.3	70.0	<MDL	<MDL	<MDL	0.0980	0.436	NA	NA
PFTeDA	23.6	55.0	<MDL	<MDL	<MDL	<MDL	0.588	NA	NA
PFDA	13.5	45.0	<MDL	<MDL	<MDL	<MDL	0.219	NA	NA
PFOA	6.7	20.0	<MDL	<MDL	<MDL	<MDL	0.273	NA	NA
NEtFOSAA	3.4	10.0	<MDL	<MDL	<MDL	<MDL	0.416	NA	NA
PFNA	3.4	10.0	<MDL	<MDL	<MDL	<MDL	0.124	NA	NA
PFHpA	3.4	5.0	<MDL	<MDL	<MDL	<MDL	0.182	NA	NA
7:3 FTCA	2.3	10.0	<MDL	<MDL	<MDL	<MDL	4.31	NA	NA
6:2 FTS	1.1	5.0	<MDL	<MDL	<MDL	<MDL	0.329	NA	NA
NMeFOSA	1.1	5.0	<MDL	<MDL	<MDL	<MDL	0.115	NA	NA
PFBA	1.1	5.0	<MDL	<MDL	<MDL	<MDL	1.06	NA	NA
PFDS	1.1	5.0	<MDL	<MDL	<MDL	<MDL	0.200	NA	NA
PFHxA	1.1	5.0	<MDL	<MDL	<MDL	<MDL	0.115	NA	NA

Analyte	FOD (%) among samples	FOD (%) across waterbodies	Min (ng/g)	25th Percentile (ng/g)	Median (ng/g)	75th Percentile (ng/g)	Max (ng/g)	Mean (ng/g)	SD (ng/g)
ΣPFAS39	NA	NA	<MDL	0.348	0.643	1.68	5.94	1.21	1.22

- Fish tissue data represent results from 89 samples collected across 20 waterbodies. Summary statistics shown above give equal weight to waterbodies.
- NA=not applicable and is shown for mean and standard deviation when a PFAS analyte was only detected in <50% of samples.
- FOD= frequency of detection
- NEtFOSE was excluded from ΣPFAS39 due to blank sample interference in the tissue matrix, which caused low-level results to be unreliable.

Further analyses were conducted to determine if PFAS concentrations differed between filets at reference (n=9 filets) and non-reference (n=80 filets) locations. This comparison focused on PFOSA, PFOS, and PFTrDA, the only PFAS analytes detected in at least 50% of waterbodies. ANOVA tests were performed on log-transformed data for these PFAS, and no significant differences between reference and non-reference locations (PFOS: p=0.66; PFOSA: p=0.10, PFTrDA=0.78). However, when examining concentrations by CZM region, significant regional variation was observed for PFOSA (p=0.02). Differences by region should be interpreted with caution due to lower sample sizes in some regions (i.e., there were six filets from Boston Harbor and eight filets from the South Shore, while there were 14 from the North Shore, 30 from Cape Cod and the Islands, and 31 from the South Coastal region). In addition, while study locations were chosen to be distributed across all CZM regions, they were not chosen with the intent to represent each region and should not be interpreted as such. More details are available in Appendix G.

Additional analyses were run to compare concentrations across the three most commonly caught species. For PFOSA, no significant differences were observed (p=0.2) across Atlantic mackerel (n=12, median: 0.142 ng/g), scup (n=20, median: 0.109 ng/g), and black sea bass (n=20, median: 0.0498 ng/g). Significant differences were found, however, for PFOS concentrations (p<0.01), with Atlantic mackerel having a higher median concentration (0.189 ng/g) than black sea bass (0.101 ng/g) and scup (<MDL). Significant differences were also observed for PFTrDA (p=0.03), with the median concentrations in scup (0.120 ng/g) and Atlantic mackerel (0.128 ng/g) being higher than in black sea bass (<MDL). Note that these results are based on a small sample of fish from these species.

Similar to freshwater fish, we explored the relationship between fish length and weight and PFAS concentrations within species, accounting for waterbody effects. However, we did not have an adequate sample size to reliably estimate these relationships.

The results described above are generally consistent with those reported in the peer-reviewed literature. Hedgepeth et al. (2024) analyzed PFAS in coastal fish from Narragansett Bay, finding that most fish had total PFAS concentrations below 5 ng/g. The most frequently detected compounds in their study were PFTrDA (82%), PFUnA (74%), and PFTeDA (64%). Similarly, a relatively high detection frequency for PFTrDA (60%) was observed in coastal fish filet samples in this study, though PFUnA and PFTeDA were each detected in fewer than 50% of the samples. In another New England study, the Maine DEP (2023) reported that PFOS and PFOSA were detected in all composite marine fish samples, which represented hundreds of individual fish. Other PFAS analytes were detected less frequently and at lower concentrations than PFOS and PFOSA in that study. Studies of coastal fish collected from areas with known PFAS contamination, such as Nolen et al. (2021), have found higher concentrations than those reported here.

Summary of Coastal Fish Tissue Results

- All waterbodies had detectable levels of at least one PFAS in fish filets, with PFOSA being the most frequently detected.
- The median ΣPFAS39 concentration was 0.643 ng/g, with a range of <MDL (no PFAS detected) to 5.94 ng/g.
- PFAS concentrations were generally lower than in freshwater fish filets.

4.2.3. Shellfish Results

Table 15 presents descriptive statistics for the 10 PFAS that were detected in at least one shellfish composite sample. Noteworthy observations are listed below and detailed results by waterbody are provided in Appendix H.

- PFOSA, a precursor of PFOS, was detected at the highest frequency across samples (48%), and in at least one sample from roughly 50% of coastal locations.
- PFOSA and PFPeA were detected at the highest concentrations (0.865 ng/g and 0.706 ng/g).
- All other PFAS were detected at relatively low concentrations.

The low concentrations in shellfish tissue are consistent with the low concentrations of PFAS in surface water. Notably, median values for ΣPFAS39 were highest for oysters (0.335 ng/g) and blue mussels (0.314 ng/g); median values for quahogs, soft shell crab, and channel whelk were all below the MDL.

Because none of the PFAS analytes were detected in 50% or more of the samples, additional statistical tests to investigate differences in concentration by site characteristics were not conducted.

Table 15. Descriptive Statistics for Coastal Shellfish Tissue

Analyte	FOD (%) among samples	FOD (%) across waterbodies	Min (ng/g)	25^{th} Percentile (ng/g)	Median (ng/g)	75^{th} Percentile (ng/g)	Max (ng/g)	Mean (ng/g)	SD (ng/g)
PFOSA	48.1	56.5	<MDL	<MDL	<MDL	0.253	0.865	NA	NA
PFOA	27.2	47.8	<MDL	<MDL	<MDL	0.0870	0.225	NA	NA
PFOS	13.6	21.7	<MDL	<MDL	<MDL	<MDL	0.178	NA	NA
PFTrDA	7.4	17.4	<MDL	<MDL	<MDL	<MDL	0.226	NA	NA
NMeFOSAA	3.7	8.7	<MDL	<MDL	<MDL	<MDL	0.263	NA	NA

Analyte	FOD (%) among samples	FOD (%) across waterbodies	Min (ng/g)	25th Percentile (ng/g)	Median (ng/g)	75th Percentile (ng/g)	Max (ng/g)	Mean (ng/g)	SD (ng/g)
PFPeA	3.7	13.0	<MDL	<MDL	<MDL	<MDL	0.706	NA	NA
PFDoA	2.5	4.3	<MDL	<MDL	<MDL	<MDL	0.0830	NA	NA
PFTeDA	2.5	8.7	<MDL	<MDL	<MDL	<MDL	0.294	NA	NA
NEtFOSAA	1.2	4.3	<MDL	<MDL	<MDL	<MDL	0.0910	NA	NA
PFHxS	1.2	4.3	<MDL	<MDL	<MDL	<MDL	0.158	NA	NA
ΣPFAS39	NA	NA	<MDL	<MDL	0.129	0.340	1.37	0.245	0.303

- Shellfish data represent results from 81 composite samples (consisting of 380 individual shellfish) collected across 23 waterbodies. Summary statistics shown above weight results by the number of shellfish in a sample.
- NA=not applicable and is shown for mean and standard deviation when a PFAS analyte was only detected in <50% of samples.
- FOD= frequency of detection

Other studies have reported a wide range of PFAS concentrations in shellfish. In a review of PFAS in shellfish, Giffard et al. (2022) found that PFOS consistently had the highest average concentration among PFAS analytes, with reported values ranging from the detection limit up to 72.0 ng/g across different taxonomic groups. They also noted that average PFOS concentrations were generally higher in bivalves (1.82 ng/g) and crustaceans (3.94 ng/g) compared to cephalopods (1.08 ng/g). In addition, PFOA was frequently detected in concentrations similar to those of PFOS. Maine DEP reported similarly low detection frequencies and concentrations of PFAS in softshell clams and American oysters, consistent with findings in this study. For example, PFOS was detected in softshell clams at only one of six sampling sites, PFOSA was detected in softshell clams from only three of the six sampling sites, and other PFAS analytes were generally detected at lower frequencies (ME DEP, 2023).

Elsewhere, in Galveston Bay, Texas, an area of known PFAS contamination, Nolen et al. (2021) reported an average PFOS concentration for Eastern oysters at 0.2 ng/g. In the same study, researchers found that PFAS concentrations in fish muscle were four times higher than those in the gill and mantle of oysters. Lemos et al. (2022) reported mean concentrations of PFAS in oysters off the coast of Florida at 0.03 ng/g for PFOA, 0.16 ng/g in PFOS, 0.03 ng/g in PFHxS, and 0.02 ng/g in PFNA. While mean concentrations were not calculated in the present study due to low detection frequencies, the mean values reported by Lemos et al. were all below the MDLs for PFOA, PFHxS, and PFNA used in this assessment. Lemos et al. (2022) also reported the highest mean concentrations for PFPeA, PFBA, and PFTeDA. PFBA was not detected in any shellfish samples in this study, and the mean concentrations of PFPeA and PFTeDA reported by Lemos et al. were higher than the maximum concentrations found in this assessment. Note that studies using low-resolution MS/MS have exhibited interference for several PFAS, including PFBA and PFPeA (Bangma et al., 2022). Results from earlier studies using these methods should be compared to those from high-resolution methods, like EPA 1633A, with caution.

Summary of Coastal Shellfish Results

- Detection frequencies of PFAS in shellfish were relatively low compared to coastal fish filets.
- PFOSA was the most frequently detected PFAS in shellfish samples (48%) and was found at the highest concentrations.

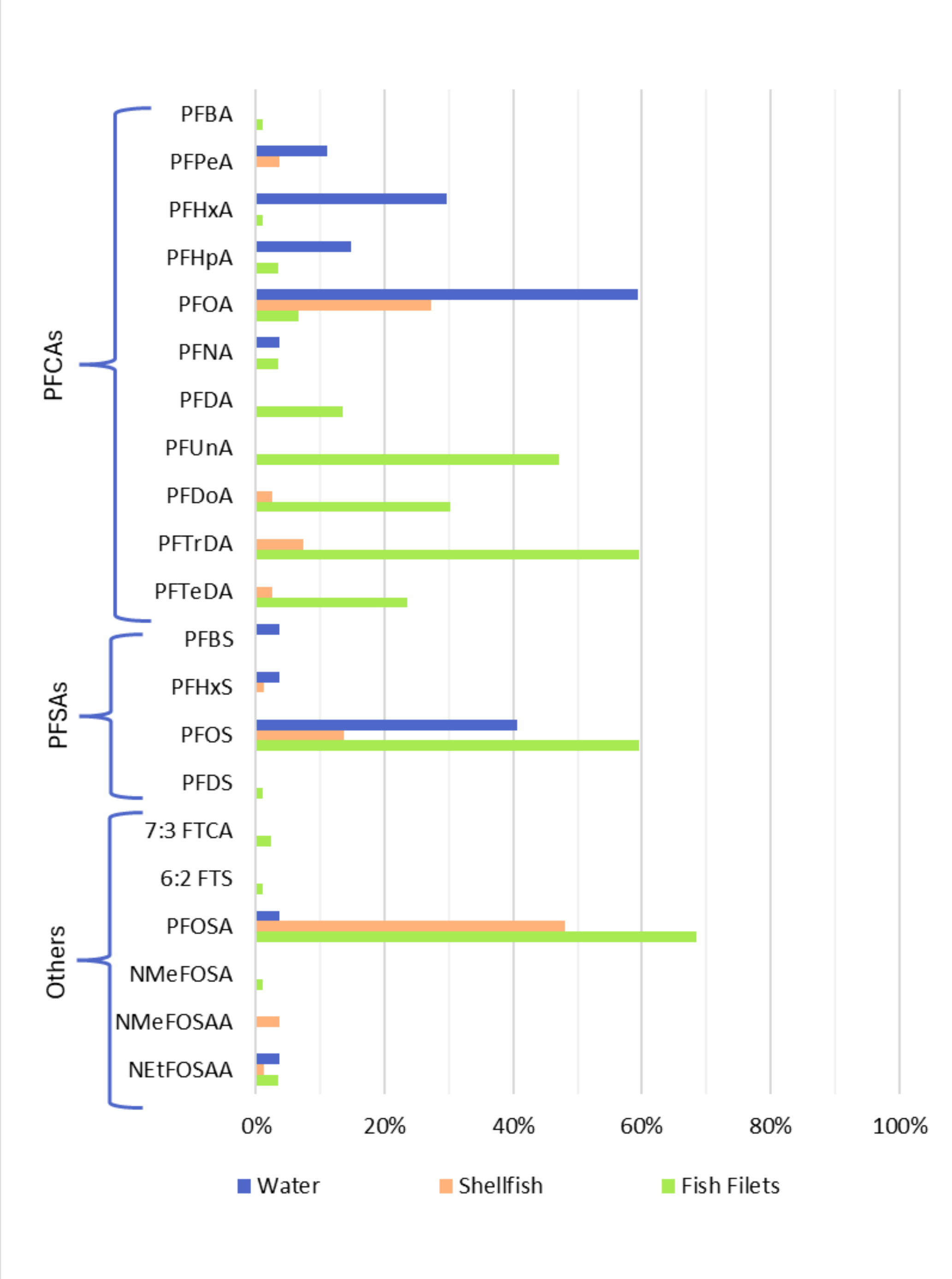
4.2.4. Comparison by Coastal Sample Type

PFAS were detected at relatively low levels across samples from coastal sites, with the greatest number of detected analytes found in fish filets, followed by surface water and shellfish.

Figure 12 displays the FOD for each PFAS analyte by media type. In surface water, PFOA and PFOS were the most frequently detected analytes. In fish filets, PFOSA, PFOS, PFTrDA had the highest detection frequencies; in shellfish, PFOSA and PFOA were the most commonly detected. No single analyte was detected in more than 50% of samples across more than one media type, which limited the ability to perform statistical comparisons between sample types. Additionally, comparisons are complicated by the migratory nature of many marine fish species. Because fish may be exposed to different PFAS concentrations throughout their lifespans in various locations, the PFAS levels measured in their tissue may not reflect contamination at the location where they were caught. It can be difficult to explain why a particular compound is found in one sample type and not another. These differences are influenced by multiple factors, including the source of contamination, the chemical and physical properties of the compound, its concentration in the environment, the composition of the sample matrix, and the biology of the exposed organism.

Figure 12 also demonstrates that as chain length increases within PFCAs and PFSAs, PFAS tend to appear more in tissue than in water. This pattern may be linked to the physicochemical properties of PFAS, including their solubility and sorption characteristics, which are influenced by chain length. It may also be linked to the environments in which species spend time, with different exposure sources (i.e., sediment) among shellfish and bottom-dwelling fish.

Figure 12. Frequency of Detection in Coastal Samples for Surface Water, Fish Filets, and Shellfish



This figure includes all PFAS that were detected in any freshwater sample types. Within PFAS classes, PFAS analytes are ordered from shortest to longest chain length. PFBA, PFPeA, PFHxA, and PFHpA are short-chain PFCAs; PFOA, PFNA, PFDA, PFUnA, PFDoA, PFTrDA, and PFTeDA are long-chain PFCAs. PFBS is the only short-chain PFSA detected in any coastal media. PFHxS, PFOS, and PFDS are long-chain PFSAs.

4.2.5. *Bioaccumulation Factors in Coastal Media*

Similar to the freshwater analysis, BAFs were calculated for surface water-organism pairs where a PFAS analyte was detected above the MDL in more than 25% of waterbodies for each medium. Due to different patterns in the PFAS analytes detected across media, BAF calculations from coastal sampling were limited to shellfish (quahogs only); BAFs were not calculated for fish. Table 16 summarizes BAFs across waterbodies for PFOA—the only analyte for which BAFs could be calculated for this shellfish type. BAFs are reported on a logarithmic scale and were calculated using Equation 1 in Section 3.5.

Table 16. BAFs for Coastal Media

Species or Type	Analyte	Number of Waterbodies[a]	Number of Samples[b]	Minimum BAF (log[L/kg])	Geometric Mean BAF (log[L/kg])	Median BAF (log[L/kg])	Maximum BAF (log[L/kg])	Quality[c]
Quahog	PFOA	6	8	1.93	2.31	2.39	2.65	high

Note: BAFs were reported for sample-water type combinations where PFAS was detected in 25% or more of both media. BAF summary statistics reported in the table above represent only values where PFAS was detected in both of a co-located tissue-surface water pair. Because BAFs vary over orders of magnitude, we report in units of log(L/kg).

[a] Number of waterbodies represents the number of waterbodies where a PFAS was detected above the MRL where that PFAS was also detected in a co-located tissue sample.

[b] Number of samples represents the number of tissue samples where a PFAS was detected above the MRL where that PFAS was also detected in the co-located surface water sample. Note that multiple tissue samples may be associated with the same surface water sample.

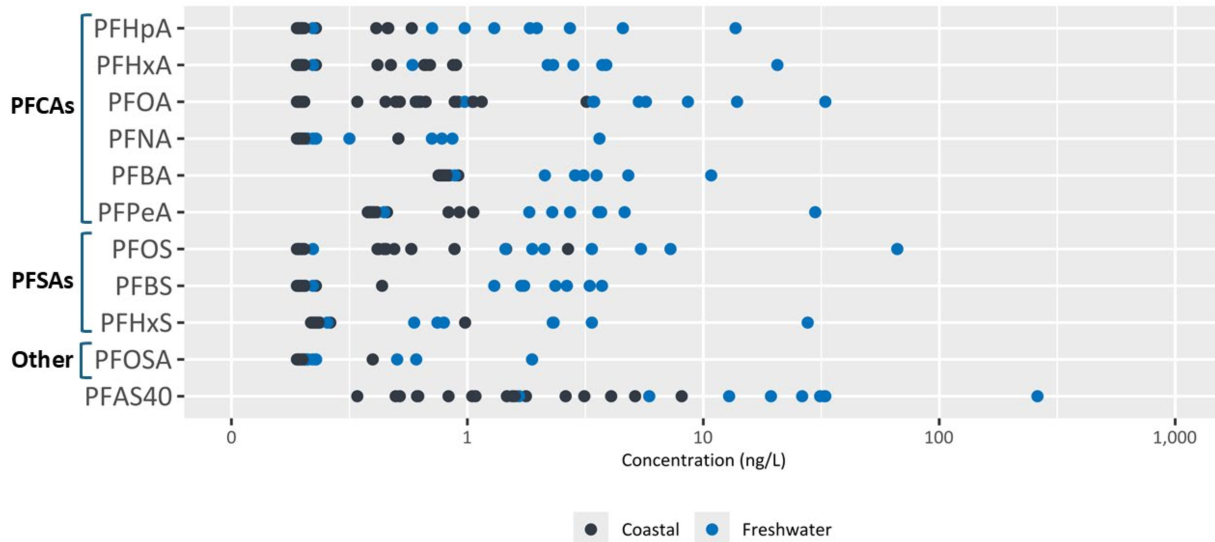
[c] Quality was assessed using the criteria in Burkhard (2021). Quality designations are "high," "medium," or "low."

Burkhard (2021) reviewed BAFs for brackish and marine invertebrates, including Bivalvia, Gastropoda, and Malacostraca. For Bivalvia—primarily mussels—they reported a BAF of 2.01 log(L/kg), which is slightly lower than the BAF calculated from the present study for quahogs (2.30 log[L/kg]).

4.3. *Comparing Coastal and Freshwater PFAS Concentrations*

Overall, PFAS concentrations were higher in freshwater compared to coastal surface water. Figure 13 displays results from each surface water sample, with blue dots representing samples from freshwater locations and black dots representing samples from coastal locations. All maximum surface water detections were found in freshwater samples.

Figure 13. PFAS Concentrations in Freshwater Versus Coastal Surface Water

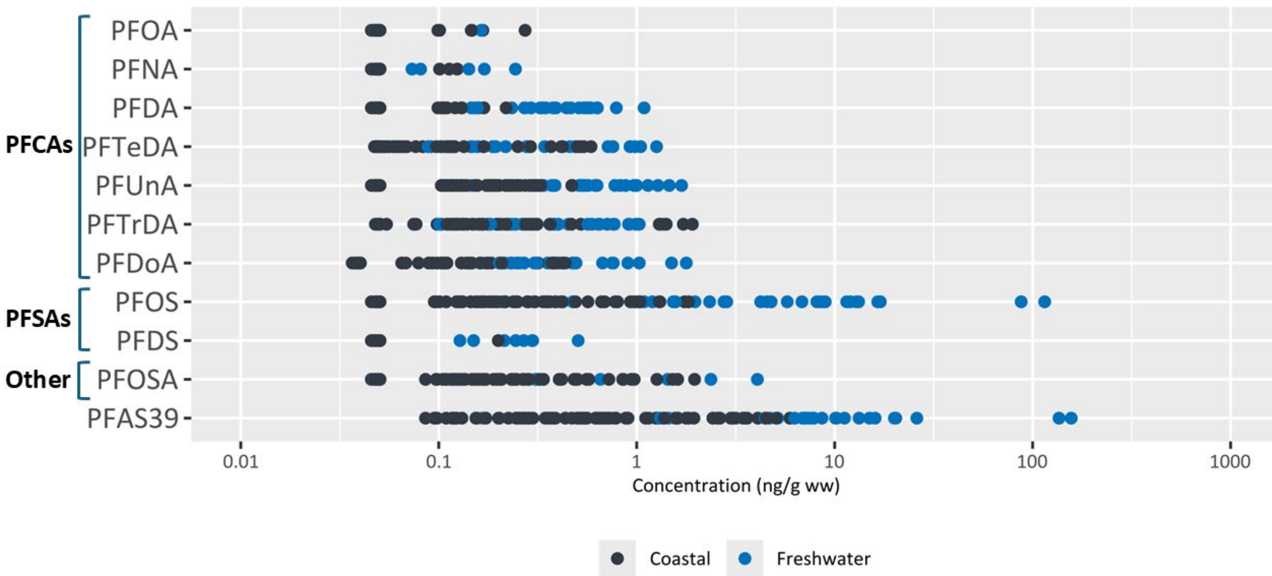


Each point represents an individual surface water sample result. Points are shaded according to whether they represent a data point from a coastal (dark gray) or freshwater (light blue) waterbody. Points may overlap, particularly at lower concentrations. Non-detect values are shown at a concentration equal to ½ the laboratory MDL. PFAS are organized by group, and then by ascending chain length within groups.

Although concentrations were lower at coastal sites, the relative contributions of PFCAs and PFSAs to ∑PFAS40 were similar across both coastal and freshwater surface water samples. PFOA was consistently present across nearly all samples, contributing 20% or more to the ∑PFAS40 at four of the 10 freshwater sites and at 15 of the 27 coastal sites. Short-chain PFCAs (PFHpA, PFHxA) were typically present at lower concentrations than PFOA, which was the only analyte detected in at least 50% of both freshwater and coastal surface water samples. The median PFOA concentration was ten times lower in coastal surface water (0.497 ng/L) compared to freshwater surface water (4.97 ng/L). The results of a t-test on log-transformed individual PFOA results indicated that there was a significant difference ($p<0.01$) between coastal and freshwater surface water concentrations.

Similarly, PFAS concentrations in fish filets tended to be higher in freshwater samples compared to coastal samples. Figure 14 shows results for each fish filet sample, with blue dots corresponding to freshwater fish and black dots corresponding to coastal fish. Whole fish sample results from freshwater locations were not included in this figure.

Figure 14. PFAS Concentrations Freshwater Versus Coastal Fish Filets



Each point represents an individual fish tissue sample result. Points are shaded according to whether they represent a data point from a coastal (dark gray) or freshwater (light blue) waterbody. Points may overlap, particularly at lower concentrations. Non-detect values are shown at a concentration equal to ½ the laboratory MDL. PFAS are organized by group, and then by ascending chain length within groups.

Among fish filets, only PFOS was detected in at least 50% of both freshwater and coastal fish filets. PFOS concentrations were significantly lower in coastal filets compared to freshwater filets ($p<0.01$). For context, the median concentration in coastal filets was 0.132 ng/g compared to 2.85 ng/g in freshwater filets.

4.4. Comparison of PFAS Results to Human Health-based Guidelines and Standards

To provide additional context for the PFAS concentrations measured in surface water and fish tissue, results were compared to applicable human health-based screening values developed by MA DPH and draft HHC developed by EPA. Also, for general context, water quality results were discussed in relation to MA DPH screening values for primary contact recreation. No comparisons were made for shellfish tissue results to the MA DPH Fish Action Level (FAL).

NOTE: All references to MA DPH PFAS guidance and action levels in this report are for general comparison or discussion purposes only and are not intended to imply or recommend human-health based advisories, which are the purview of the MA DPH.

4.4.1. MA DPH Operational Guidance for Surface Water at Beaches

For surface water, MA DPH has published *Operational Guidance for Bathing Beaches at PFAS Impacted Waterbodies* to support the evaluation of potential health risks at public and semi-public beaches in the state (MA DPH, 2024). This guidance establishes a health protective initial screening value of 20 ng/L, applicable to individual PFAS analytes including PFBA, PFBS, PFHxA, PFHxS, PFOA, PFOS, PFNA, and HFPO-DA (also known as GenX). If concentrations of each individual listed PFAS are at or below 20 ng/L, no further action is required. However, if any of these compounds are detected above 20 ng/L, a confirmatory sample should be collected. The higher of the two sample results is then used to assess the potential need for swimming restrictions, based on MA DPH guidance (Table 17).

None of the surface water samples for this project were collected at DPH permitted bathing beaches. Therefore, the results were not compared to the screening values for beaches.

Table 17. MA DPH Health-Based Screening Values for Surface Water at Beaches

Surface Water PFAS Concentrations (ng/L)	MA DPH Guidance
>20 to 90	No restrictions on swimming
>90 to 500	MA DPH conducts beach-specific evaluation to determine whether restrictions on swimming are appropriate
>500	Swimming is prohibited

Screening values and guidance are from MA DPH's Operational Guidance for Bathing Beaches at PFAS Impacted Waterbodies (MA DPH, 2024). The values are applicable to individual PFAS analytes including PFBA, PFBS, PFHxA, PFHxS, PFOA, PFOS, PFNA, and HFPO-DA (GenX).

4.4.2. MA DPH Fish Action Level (FAL) for Fish Tissue

MA DPH has derived a Fish Action Level (FAL) of 0.22 ng/g for PFAS in fish tissue. This value applies to seven specific PFAS analytes: PFBA, PFBS, PFHxS, PFOA, PFOS, PFNA, and GenX (MA DPH, 2023a). If the concentration of any individual compound exceeds 0.22 ng/g in fish tissue, a site-specific risk assessment is recommended to determine appropriate fish consumption advisories for that waterbody. Concentrations below this threshold are considered protective for unrestricted fish consumption by both the general population and sensitive subpopulations.

NOTE: Comparisons to the FAL provided below do not account for DPH's more thorough risk assessment methodology that may lead to fish consumption advisories and do not reflect recommended fish consumption advisories. These results are intended only for general comparison, and the analysis is based exclusively on filet data.

At 26 of the 30 locations (freshwater and coastal) where fish were collected, at least one of the seven PFAS covered by the FAL was detected in fish tissue at a concentration above 0.22 ng/g. As shown in Table 18, PFOS was found at levels above the FAL in fish tissue at all 26 of these locations. Other PFAS — PFNA, PFOA, PFHxS, and PFBA — also exceeded the FAL, but only at one location each. It is important to note that not all individual fish sampled at a given location necessarily exceeded the FAL. PFAS were not detected above the FAL at the Cape Cod Bay (ID 020 -reference location), Apponagansett Bay (ID 024), Rock Harbor Creek (ID 028-reference location), and Westport River (ID 031) sampling locations.

Table 18. Fish Tissue Concentrations Compared to MA DPH Human Health-based Guidance

PFAS	Number (%) of waterbodies with detected concentrations	Number (%) of waterbodies with detected concentrations over 0.22 ng/g
PFOS	28 (93%)	26 (87%)
PFNA	6 (20%)	1 (3%)
PFOA	5 (17%)	1 (3%)
PFHxS	1 (3%)	1 (3%)
PFBA	1 (3%)	1 (3%)
PFBS	0	NA
HFPO-DA	0	NA

This table captures the 30 waterbodies where fish tissue samples were collected. Fish samples were not collected at Pine Creek (ID 007), Hingham Bay (ID 018), Lewis Bay (ID 032), Allens Harbor (ID 033), Mill Creek (ID 035), or Sesuit Harbor (ID 037).

4.4.3. Draft EPA Human Health Water Quality Criteria for Surface Water

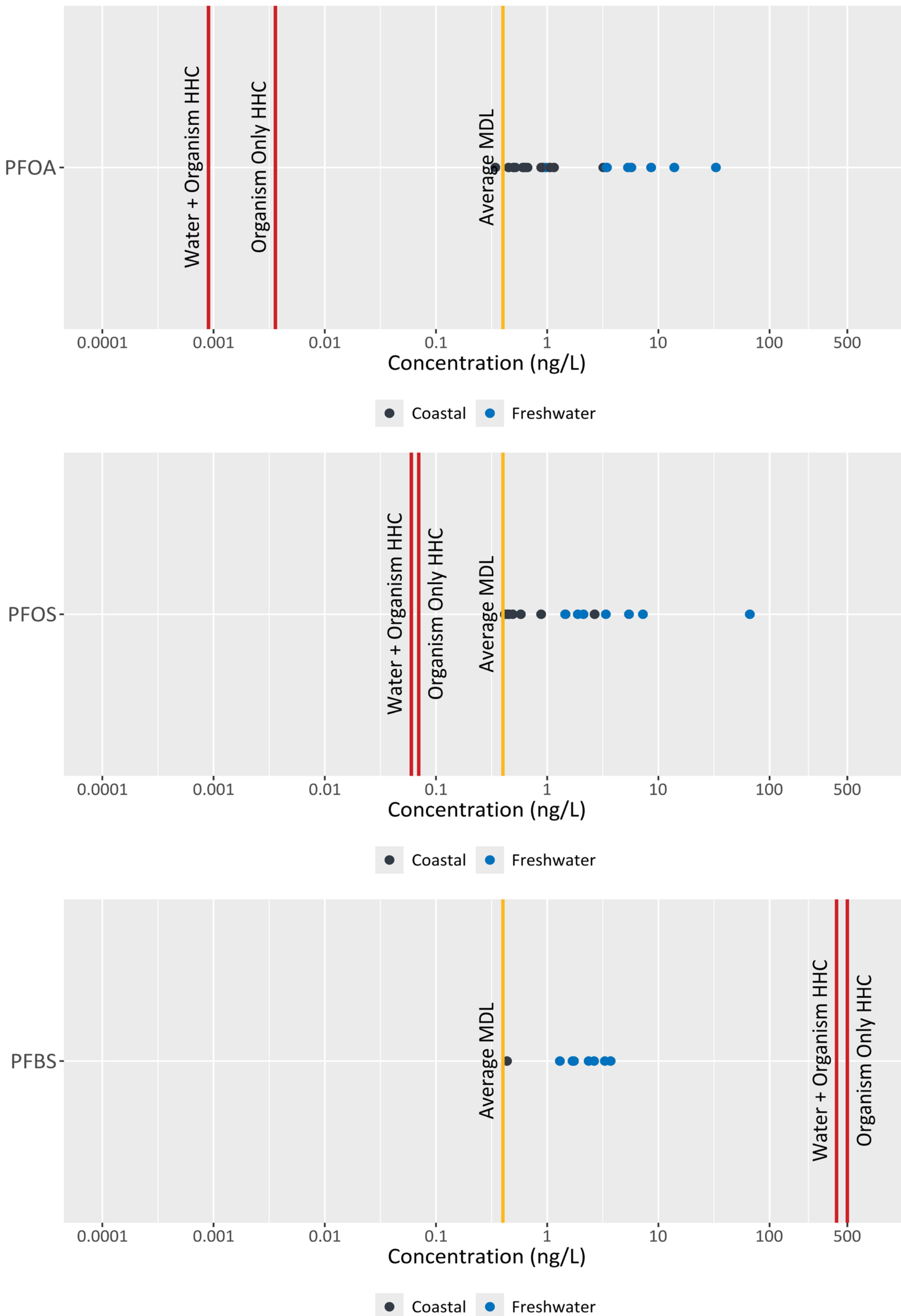
In 2024, EPA published draft Human Health Criteria (HHC) recommendations for three PFAS: PFOA, PFOS, and PFBS (EPA, 2024d, 2024e, 2024f). These criteria are designed to protect human health from adverse effects associated with the ingestion of water, fish, and shellfish from inland and coastal waterbodies. For each PFAS, EPA derived two types of values: 1) a “water + organism” HHC, based on the consumption of both water and fish and/or shellfish, and 2) an organism-only HHC, which is based on the consumption of fish and/or shellfish alone. These draft HHC values apply to surface waters, depending on the primary exposure pathways (Table 19).

Table 19. EPA Draft Human Health Criteria Recommendations for Three PFAS

PFAS	Water + Organism HHC (ng/L)	Organism Only HHC (ng/L)
PFOA	0.0009	0.0036
PFOS	0.06	0.07
PFBS	400	500

Notably, EPA’s draft HHC values for PFOA and PFOS are lower than current detection limits for most commercial laboratories, including SGS AXYS. As such, any detection of PFOA or PFOS would exceed EPA’s draft HHC recommendations (Figure 15). PFOA was detected at 24 out of 30 locations, and PFOS was detected at 18 of the 30 locations. The detection limits for these three PFAS in this study ranged from 0.379 to 0.457 ng/L. PFBS did not exceed either of the draft HHC at any of the sampled waterbodies (Figure 15).

Figure 15. Surface Water Compared to EPA Draft Human Health Criteria for Three PFAS



4.5. Comparison of PFAS Results to EPA Aquatic Life Criteria Recommendations

In 2024, EPA published final recommended aquatic life AWQC for PFOA and PFOS, and aquatic life benchmark values for eight other PFAS with less toxicity information. For PFOA and PFOS, EPA established acute and chronic freshwater criteria, as well as acute saltwater benchmarks. Acute freshwater benchmarks were also developed for eight PFAS with more limited data, including PFBA, PFHxA, PFNA, PFDA, PFBS, PFHxS, 8:2 FTUCA, and 7:3 FTCA. These values represent the highest pollutant levels in surface water that support the health and reproduction of aquatic life. Additionally, EPA developed chronic criteria expressed as tissue-based concentrations to help protect aquatic life from PFOA or PFOS bioaccumulation. An overview of these recommended criteria is provided in Table 20.

Table 20. EPA Aquatic Life Criteria or Benchmarks for PFAS

EPA aquatic life criteria or benchmark	PFOA	PFOS
Freshwater acute water column[a]	3,100,000 ng/L	71,000 ng/L
Freshwater chronic water column[b]	100,000 ng/L	250 ng/L
Estuarine/marine acute water column[c]	7,000,000 ng/L	550,000 ng/L
Freshwater chronic invertebrate, whole-body[d]	1,180 ng/g ww	28 ng/g ww
Freshwater chronic fish, whole-body[d]	6,490 ng/g ww	201 ng/g ww
Freshwater chronic fish, muscle[d]	133 ng/g ww	87 ng/g ww

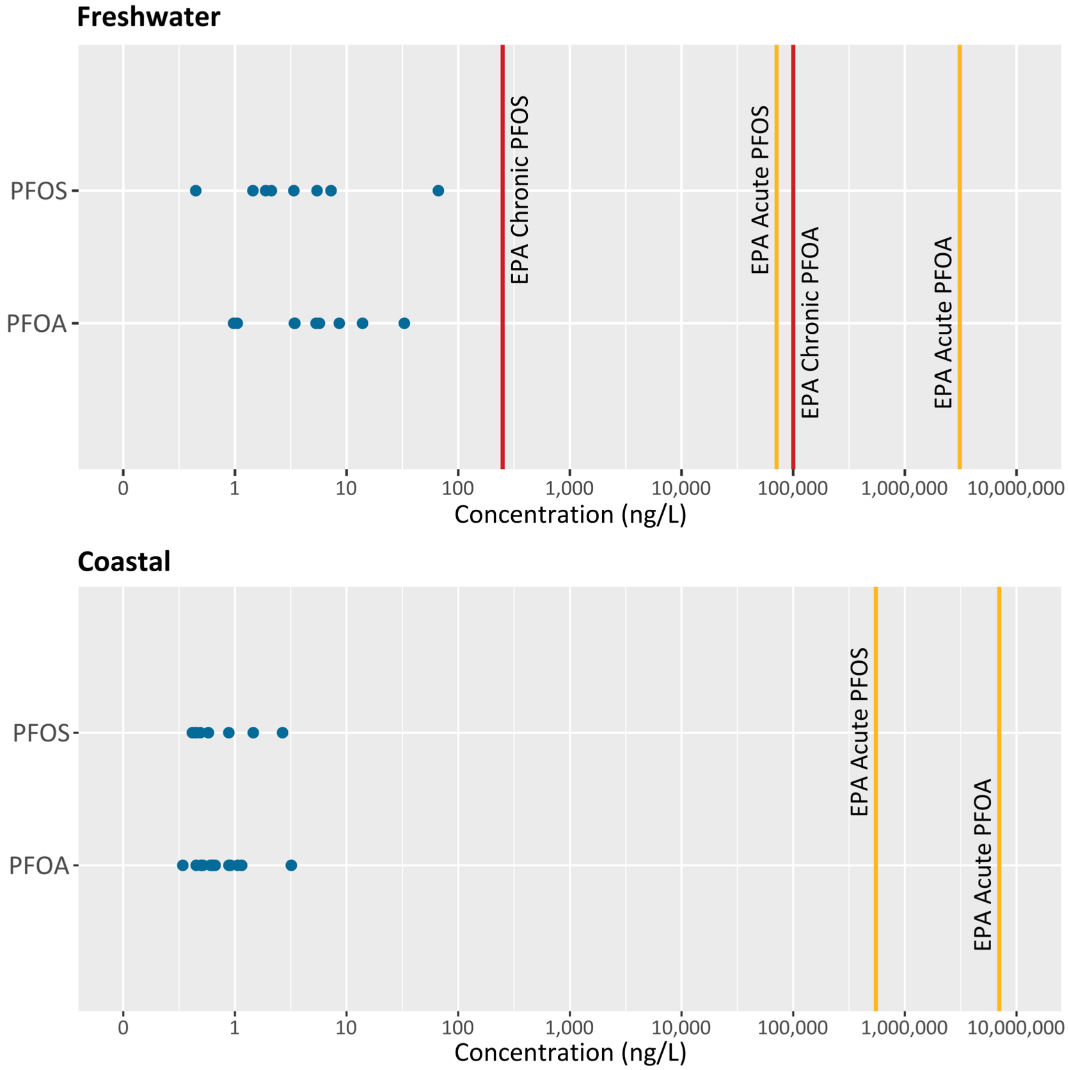
- Additional acute freshwater surface water benchmarks (not shown in table) were developed for PFBA (5,300,000 ng/L), PFHxA (4,800,000 ng/L), PFNA (650,000 ng/L), PFDA (500,000 ng/L), PFBS (5,000,000 ng/L), PFHxS (210,000 ng/L), 8:2 FTUCA (37,000 ng/L), and 7:3 FTCA (12,000 ng/L).

[a] Criterion Maximum Concentration: 1-hour average, not to be exceeded more than once in three years.
[b] Criterion Continuous Concentration: 4-day average, not to be exceeded more than once in three years.
[c] Acute benchmark (not a criterion): 1-hour average, not to be exceeded more than once in three years.
[d] Criterion: Instantaneous, not to be exceeded anytime.

4.5.1. Surface Water

Although surface water samples for this project were collected at a single point in time, we compared the results to both acute and chronic aquatic life criteria recommendations from EPA. At all freshwater locations, PFOA and PFOS concentrations were below EPA's recommended aquatic life AWQC for both acute and chronic exposure (maximum PFOA: 32.9 ng/L; maximum PFOS: 66.4 ng/L) (Figure 16). Maximum detected concentrations of other PFAS—PFBA (10.8 ng/L), PFHxA (20.6 ng/L), PFNA (3.63 ng/L), PFDA (0.922 ng/L), PFBS (3.72 ng/L), and PFHxS (27.6 ng/L) —were also well below EPA's acute freshwater benchmarks, by several orders of magnitude. As for the other two PFAS with freshwater benchmarks, 7:3 FTCA was not detected in our surface water samples and 8:2 FTUCA was not analyzed by EPA Method 1633A. A similar trend was observed at coastal sites, with all maximum concentrations falling one to two orders of magnitude below the applicable marine benchmarks.

Figure 16. Surface Water Compared to EPA's Aquatic Life Ambient Water Quality Criteria Recommendations

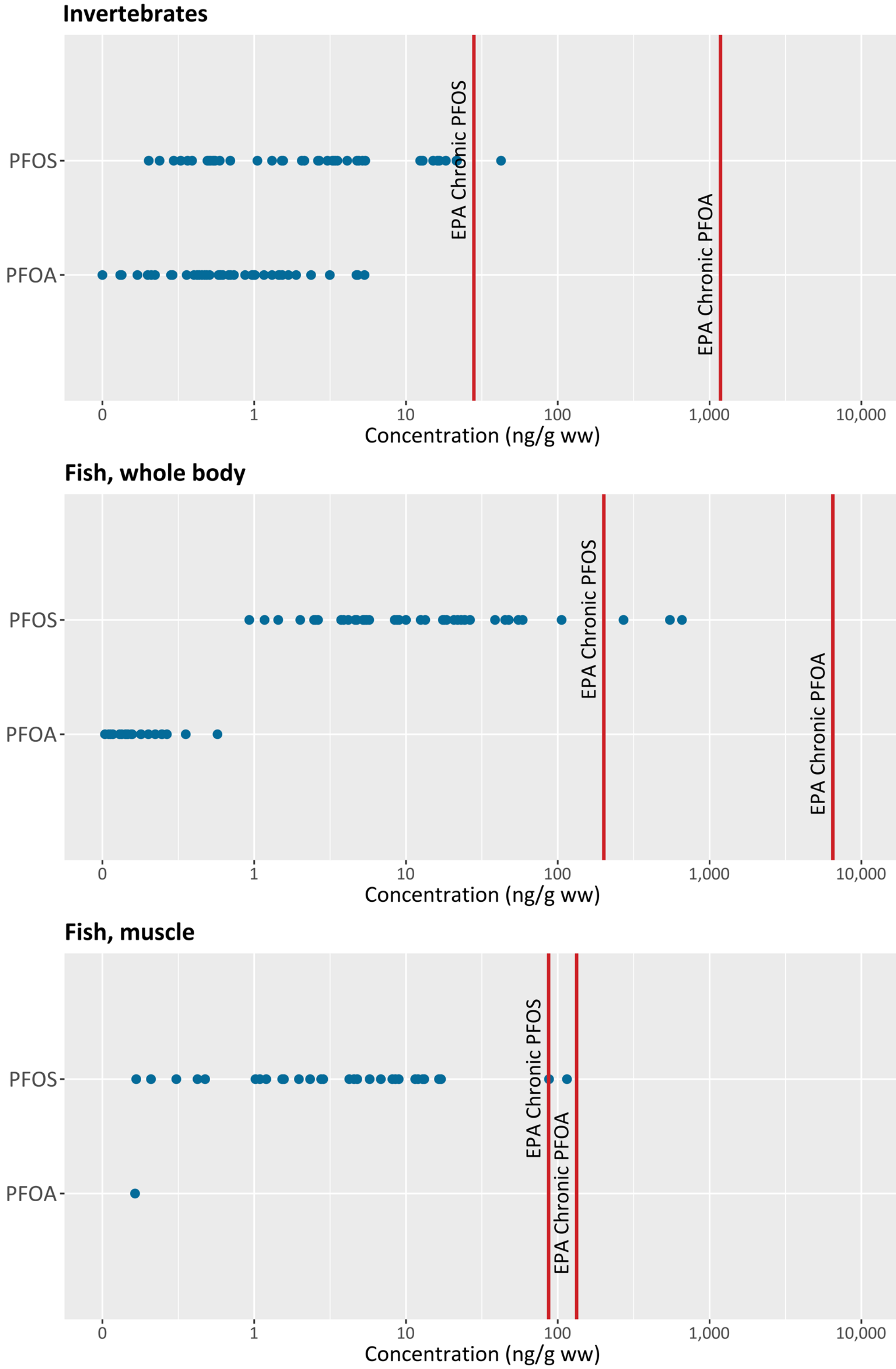


- *Only detected observations are shown.*

4.5.2. Tissue

All freshwater invertebrate tissue results were below EPA's recommended freshwater chronic criterion for PFOA (Figure 17). This was not the case for PFOS. EPA's invertebrate criterion for PFOS is 28 ng/g, which was exceeded at one location: Studleys Pond. At this site, PFOS was detected in a sample of gastropods from at a concentration of 42.3 ng/g. The other six invertebrate samples from Studleys Pond were below the criterion. PFOS concentrations in invertebrate samples from all other sites were below the recommended freshwater chronic criterion.

Figure 17. Freshwater Tissue Compared to EPA's Aquatic Life Criteria Recommendations



- *Only detected observations are shown. In several cases, multiple results are stacked on top of one another in this figure (e.g., the point for PFOA represents 23 detected results all within a very small range). EPA has not derived criteria or benchmarks applicable to coastal fish or shellfish.*

A similar trend was observed in freshwater whole-body fish. All detected PFOA concentrations were below EPA's recommended chronic criterion, whereas PFOS exceeded the criterion in three samples. Specifically, PFOS was detected above the threshold in two bluegill and one largemouth bass sample from Studleys Pond. The next highest concentrations were observed in the Charles River (e.g., a yellow perch at 106 ng/g), all of which were below the criterion. For freshwater fish muscle tissue, PFOA was detected in only one sample—an American eel from Powdermill Brook—at a concentration of 0.164 ng/g, well below EPA's chronic criterion. PFOS, on the other hand, was detected above EPA's criterion (87 ng/g) in two bluegill samples from Studleys Pond, at concentrations of 87.5 ng/g and 115 ng/g. All other results were below the criterion.

4.6. Limitations

This study provides a broad overview of PFAS across a wide range of aquatic organisms, tissue types, and co-located surface water in Massachusetts. While the findings offer valuable insights, there are several limitations to this study that are important to consider when interpreting the results. These limitations also highlight key considerations for the design of future studies.

Organisms were collected based on species availability at each site, resulting in variation in species sampled across waterbodies. Because PFAS profiles vary by location, this limits the ability to statistically compare PFAS concentrations across species while accounting for site-specific differences. In some cases, logistical constraints required collecting fish and shellfish from sites that were farther apart than intended, which further complicated cross-media comparisons. Coastal comparisons were particularly challenging due to the dynamic nature of marine environments, including ocean currents and the mobility and migratory behavior of many marine fish species. As a result, PFAS concentrations in fish may not reflect PFAS contamination at their collection sites.

Sample size was another important limitation. In many cases, the number of samples within a given waterbody, species, or media type was too small to support robust statistical analyses. This also constrained the ability to conduct multivariable analyses that could account for multiple factors at once—such as fish weight, species, and location.

While this study generated a robust dataset of PFAS measurements, the number of freshwater sites included was small (10). When combined with the freshwater results from the 2022 study, however, the surface water and fish tissue results collected in freshwater in 2024 add to the growing knowledgebase of the range of PFAS concentrations found in MA rivers and lakes.

Similarly, although efforts were made to sample a variety of organisms, species were selected based on local availability and do not represent the full range of species or taxonomic groups present across the state. Coastal sampling included a limited number of fish and shellfish species, and as with freshwater sites, the results should not be generalized to other unsampled species or regions.

Analytical uncertainties also affected interpretation. Specifically, NEtFOSE was frequently detected at low levels, above the MDL but below the reporting limit, in laboratory method blanks associated with tissue samples, likely due to matrix interference. This was not observed for water samples. As a result, NEtFOSE tissue concentrations above 20 ng/L were qualified, and tissue concentrations below 20 ng/L were censored across all tissue samples. More information on this issue is available in Appendix K. This precluded comparisons across sample types and between coastal and freshwater tissues and limited the exploration of BAFs for this compound. It also introduced uncertainty when comparing total PFAS concentrations across surface water and tissue samples, as PFAS sums in surface water included 40 analytes, while PFAS sums in tissue included 39 analytes.

Additionally, many PFAS were not detected above the MDL. These compounds may still have been present at low concentrations; therefore, for statistical analyses, a substitution approach was applied by assigning values equal to one-half the MDL. While this method is consistent with standard analytical practices, it introduces a degree of uncertainty into the resulting statistical estimates.

Site classification also presented some complexity. At coastal sites, the study design included locations presumed to have low PFAS concentrations (i.e., reference sites). However, due to limited data on PFAS in aquatic ecosystems along the coastline, there was some uncertainty in this classification.

Finally, additional limitations resulted from data collections and analyses that could not be included in this study:

- Assessment of the temporal variability of PFAS concentrations within individual waterbodies by sampling the same locations and media repeatedly.
- Attributing PFAS contamination to specific PFAS sources, the mitigation of which is a MassDEP priority.
- Sampling for additional analytes beyond PFAS40. Although the study included analyses of 40 PFAS using EPA Method 1633, thousands of other PFAS are known to exist and were not captured by the analytical method.
- Collecting samples of all species that exist in Massachusetts; thus, conclusions about all fish, invertebrates, or shellfish species found in the region are not possible.
- Collection of sediment samples or foam samples, each of which are commonly contaminated with PFAS and contribute to PFAS exposure pathways for many of the species sampled (particularly benthic species).

5. Conclusion

PFAS have raised increasing concern due to their widespread presence in aquatic environments across the country. This study investigated PFAS contamination in various media, including surface water, fish filets, whole-body fish, invertebrates, and shellfish, collected from 10 freshwater sites and 26 coastal locations across Massachusetts. A broad range of PFAS was detected, with notable differences observed by location, media, and species.

In **freshwater environments**, the types and frequencies of PFAS detections varied across media. PFOA was the most frequently detected PFAS in surface water and was found at relatively high concentrations compared to other compounds. In fish filets, whole fish, and invertebrates, PFOS, PFDoA, and PFUnA were detected most frequently (see Table 8, Table 9, Table 10, Table 11). Among these, only PFOS was also consistently detected in surface water. In addition, while PFOA was not commonly detected in fish tissue, it was detected at low concentrations in most invertebrate samples. In general, a broader range of PFAS analytes were detected in invertebrates than both fish tissue or surface water, suggesting that invertebrates may accumulate a wider variety of these compounds and may be sensitive indicators of PFAS contamination. Many invertebrates may also be more frequently exposed to PFAS contained in sediments leading to different PFAS profiles than fish. BAFs calculated for freshwater fish and invertebrates were consistent with values reported in the scientific literature (see Table 12). PFOS had the highest BAFs, indicating a strong potential for bioaccumulation, and PFOA had the lowest BAFs. Whole-body fish exhibited higher BAFs than fish filets of the same species for a given PFAS. Notably, Studleys Pond emerged as an outlier among the freshwater sites, with the highest PFAS concentrations across all sample types.

In **coastal environments**, PFAS were detected less frequently and at lower concentrations. PFOA was the most commonly detected compound in surface water samples along the coast, while PFOSA, a PFOS precursor, was most frequently found in both fish filets and shellfish (see Table 13, Table 14, Table 15). Among shellfish species, quahogs had a bioaccumulation factor of 2.3 log(L/kg), which is consistent with values reported elsewhere. Due to low detection frequencies, BAFs were not calculated for other coastal species. Note that dilution, tidal flushing, and salinity are among the potential reasons for lower PFAS concentrations at coastal sites compared to freshwater sites. Notably, though concentrations were lower at coastal sites compared to freshwater sites, the relative contributions of PFCAs and PFSAs to ∑PFAS40 were similar.

Overall, the study's findings have implications for human health, particularly in relation to fish consumption. Fish from 26 of 30 locations, including three reference locations, were above MA DPH’s fish action level (see Table 18), suggesting the potential need for site-specific risk assessments by MA DPH to determine appropriate fish consumption advisories. PFOS was the compound most frequently exceeding this health-based guideline.

NOTE: All references to MA DPH PFAS guidance and action levels are for general comparison or discussion purposes only and are not intended to imply or recommend human health-based advisories, which are the purview of the MA DPH.

Surface water samples from both freshwater and coastal locations were well below EPA's acute aquatic life criteria recommendations and benchmarks for PFAS. EPA also provides tissue-based criteria recommendations for PFOS and PFOA in invertebrates, whole-body fish, and fish muscle. PFOS levels exceeded these criteria at only one location, Studleys Pond—further emphasizing this site's significance as a potential PFAS hotspot.

These findings support important insights into how different PFAS affect aquatic ecosystems, such as bioaccumulation. The results show that PFAS contamination is widespread, with notable differences between freshwater and coastal environments, as well as between species. Given the persistence and prevalence of PFAS in environmental media, the data support the need for continued monitoring, focused risk assessment, and targeted strategies to mitigate PFAS sources and exposure to both human and ecological communities.

5.1. Areas for Future Work

Although this study addressed many questions and produced a broad dataset on PFAS in freshwater and coastal media, it also underscores the need for further data collection and analysis on this emerging contaminant. Potential areas of future investigation are listed below.

- *A probabilistic survey to estimate the extent of fish tissue contamination in freshwater throughout the Commonwealth.*
    - This type of study, designed to randomize site selection within Massachusetts, would provide representative statistical estimates of PFAS across Massachusetts and enable inferential conclusions within certain confidence limits. Such a study could also standardize the target species across locations to facilitate cross-waterbody comparisons within species.
- *Co-located collection of sediment samples, surface water, and aquatic organisms.*
    - Studies of PFAS in aquatic environments in Massachusetts have focused on PFAS in aquatic organisms and surface water. PFAS are known to accumulate in sediments depending on their physico-chemical properties, which may be an important (legacy) source of PFAS exposure for aquatic life, particularly benthic species. This type of sampling could also provide additional context on bioaccumulation for PFAS commonly found in aquatic organisms but not in surface water and would contribute to our knowledge of PFAS profiles in sediments.
- *An interlaboratory study to compare results for EPA Method 1633A between a commercial laboratory and the MassDEP state laboratory (Wall Experiment Station).*
    - Comparing results for selected split field samples for surface water and fish tissue, as part of a larger PFAS sampling study, would strengthen and enhance MassDEP's analytical capabilities for measurement of PFAS.

- *Continue collecting PFAS data at targeted locations in lakes, rivers, and coastal areas to expand geographic coverage across Massachusetts*.
    - Coupled with additional analytical methods that characterize total organic fluorine, nontarget analyses, and/or additional precursor sampling, this type of sampling effort would improve PFAS data availability and help address knowledge gaps, ultimately supporting greater public awareness and targeted mitigation efforts in areas of PFAS contamination.
- *Analyze PFAS in foam at freshwater locations (e.g., beaches) and seafoam along coastal areas*.
    - PFAS concentrations have been shown to be higher in foams in aquatic ecosystems due to their surfactant properties, which reduce surface tension and stabilize air bubbles in water. Exposure to PFAS through contact with surface foams on waterbodies has not yet been characterized in Massachusetts, and therefore conducting a study would provide further insight.
- *Monitor PFAS concentrations over time at sites with known PFAS contamination* (such as Studleys Pond), similar to other studies (e.g., MacGillivray, 2020; Walsh et al. 2025).

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Appendix A: Additional Details on Sampling Locations

Table A1. Coordinates for Sampling Locations

Site ID[a]	Waterbody Name	Latitude	Longitude
Freshwater Locations			
001	Charles River	42.15832	-71.3329
002	Merrimack River	42.64954	-71.3845
003	Johns Pond	41.90669	-70.7850
004	Sheomet Pond	42.6786	-72.2823
010	Lake Gardner	42.86285	-70.9422
011	Spectacle Pond	42.51248	-71.6822
013	Studleys Pond	42.11966	-70.9207
016	Green River	42.66740	-72.6349
017	Powdermill Brook	42.13733	-72.7404
019	Canoe River	41.97307	-71.1368
Coastal Locations[b]			
005	Boston Harbor (near Deer Island)	42.35393	-70.9683
006 F	Great Pond	41.54748	-70.5817
006 SF	Bournes Pond	41.56528	-70.5532
007	Pine Creek	42.72199	-70.7857
008 F	Annisquam River	42.61694	-70.6794
008 SF	Mill River	42.63348	-70.6767
009	Wareham River	41.74799	-70.7060
012	Plum Island Sound	42.69648	-70.7872
014 F	Atlantic Ocean	42.48359	-70.8405
014 SF	Marblehead Harbor	42.50431	-70.8456
015	Boston Harbor (near Castle Island)	42.33938	-71.0087
018	Hingham Bay	42.27332	-70.9334
020	Cape Cod Bay	41.85518	-70.5245
021	Plymouth Harbor	41.96683	-70.6616
022 F	Duxbury Bay	42.03029	-70.6392
022 SF	Back River	42.05000	-70.6576
023	Cole River	41.72844	-71.2240
024	Apponagansett Bay	41.58164	-70.9464
025	Little Harbor	41.72618	-70.6797
026	Megansett Harbor	41.65754	-70.6296
027	Barnstable Harbor	41.71619	-70.2879
028	Rock Harbor Creek	41.80085	-70.0098
029	Popponesset Bay	41.58660	-70.4532
030	Bass River	41.65176	-70.1965
031	Westport River	41.51650	-71.0815
032	Lewis Bay	41.63050	-70.2522
033	Allens Harbor	41.66292	-70.0891
034F	Cohasset Narrows	41.74242	-70.6286

Site ID[a]	Waterbody Name	Latitude	Longitude
034 SF	Buttermilk Bay	41.75395	-70.6303
035	Mill Creek	41.67523	-70.0201
037	Sesuit Harbor	41.75608	-70.1545

a. Each waterbody was assigned a unique ID during sample collection. Note that the site originally designated as ID 036 was not sampled.

b. In several instances, fish and shellfish were collected from separate areas within the same general location for a given coastal site. These cases are shown as two separate rows in this table, with "SF" or "F" added to the sample ID to indicate which coordinates apply to the location of shellfish sample collection and which apply to the location of fish tissue sample collection. These sites include Great Pond-Bournes Pond (ID 006), Annisquam River-Mill River (ID 008), Marblehead Harbor-Atlantic Ocean (ID 014), Duxbury Bay-Bay River (ID 022), and Buttermilk Bay-Cohasset Narrows (ID 034). These locations are plotted in Figure A1 below, as well as in the CZM specific maps that follow (Figure A2 through Figure A6). The freshwater locations are also shown.

Figure A1. Map of Project Sampling Locations

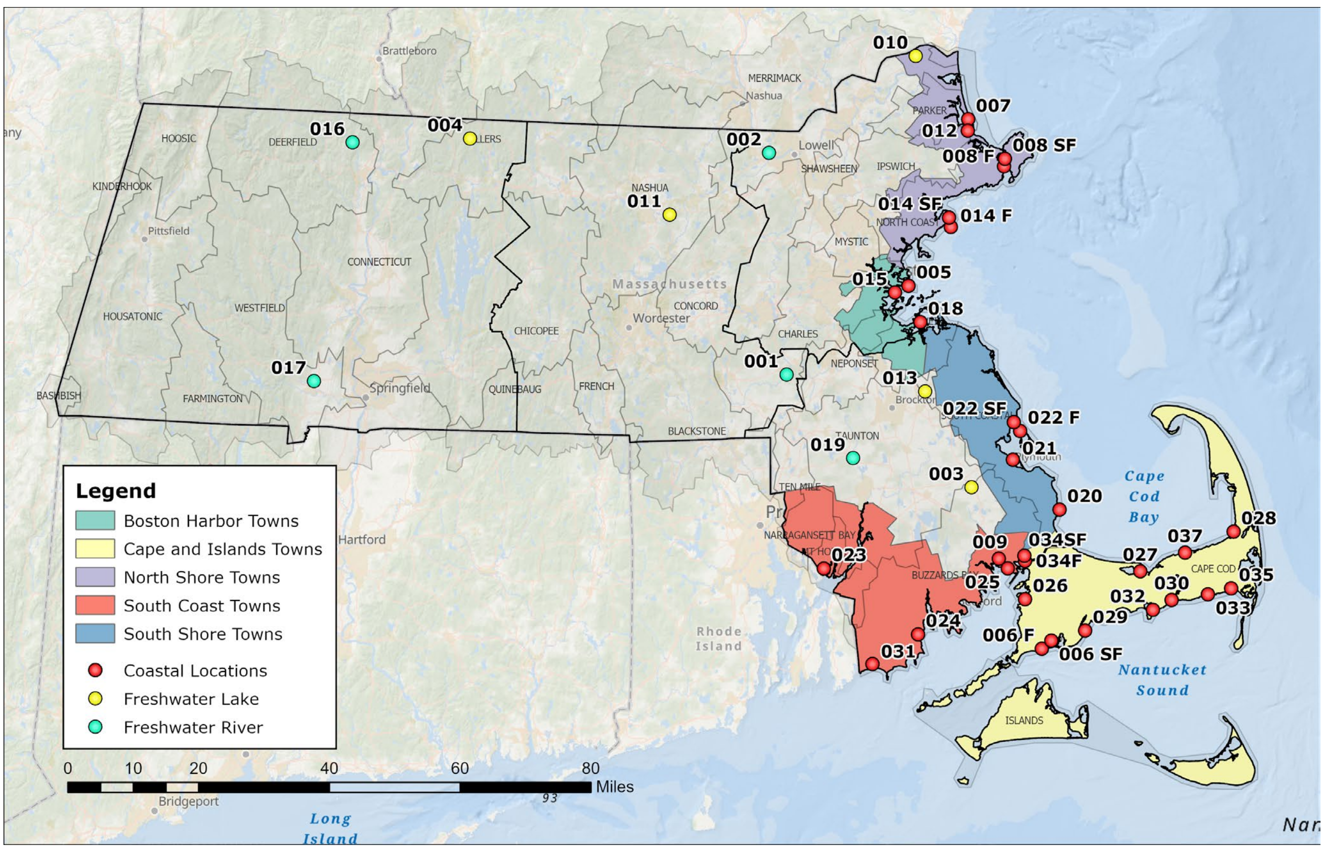


Figure A2. Map of Coastal Sites in North Shore CZM Region

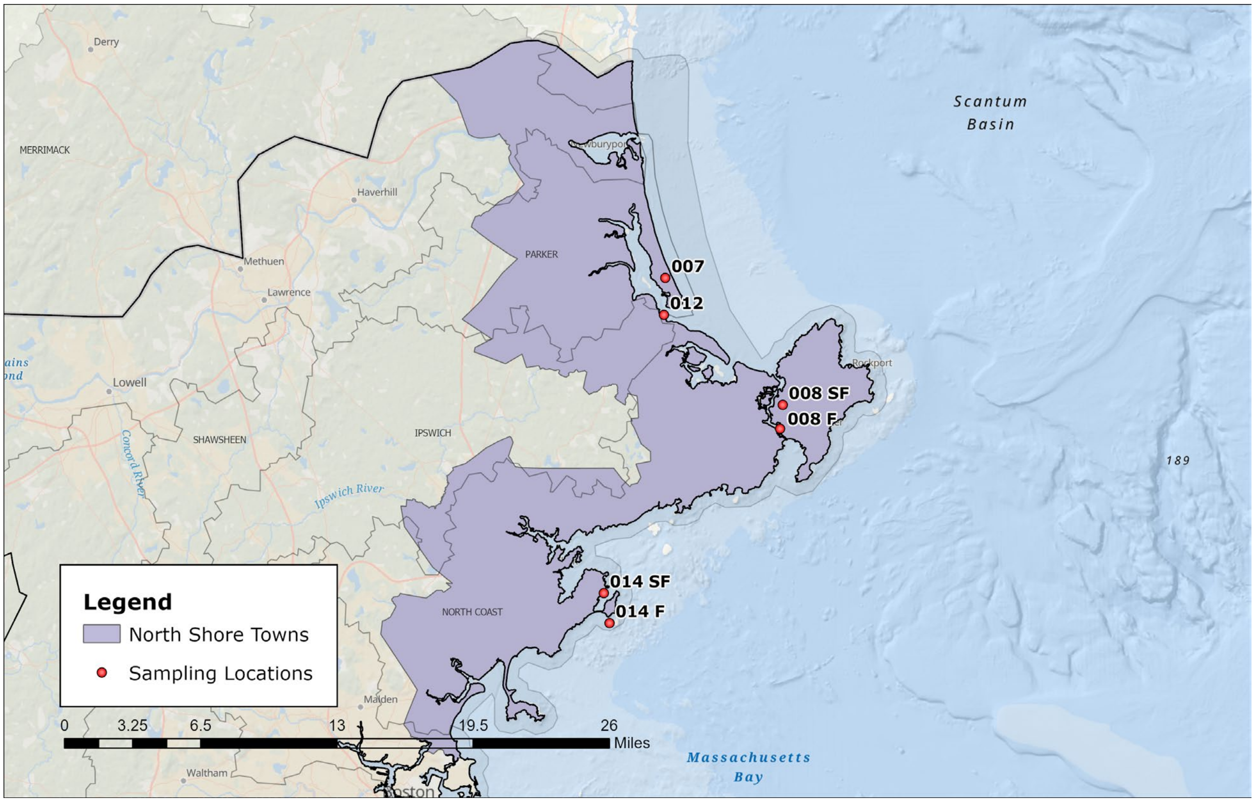


Figure A3. Map of Coastal Sites in Boston Harbor CZM Region

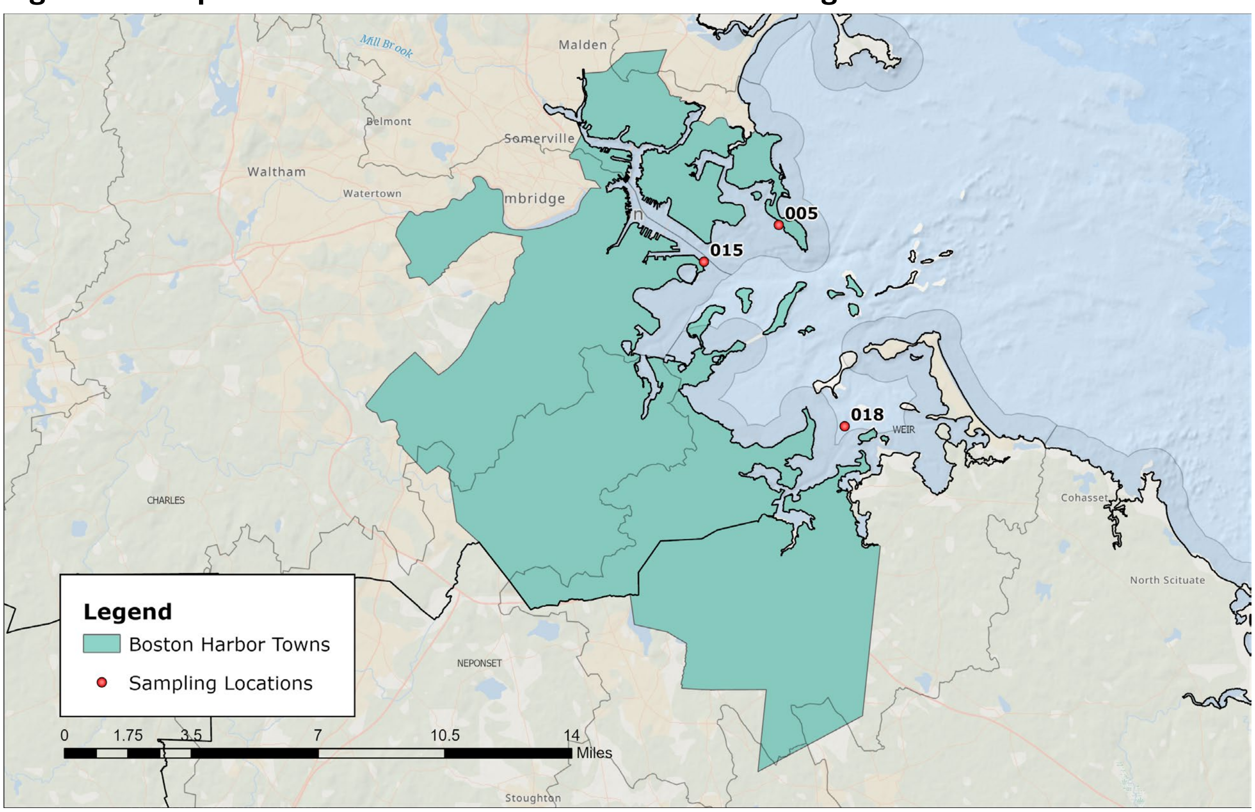


Figure A4. Map of Coastal Sites in South Shore CZM Region

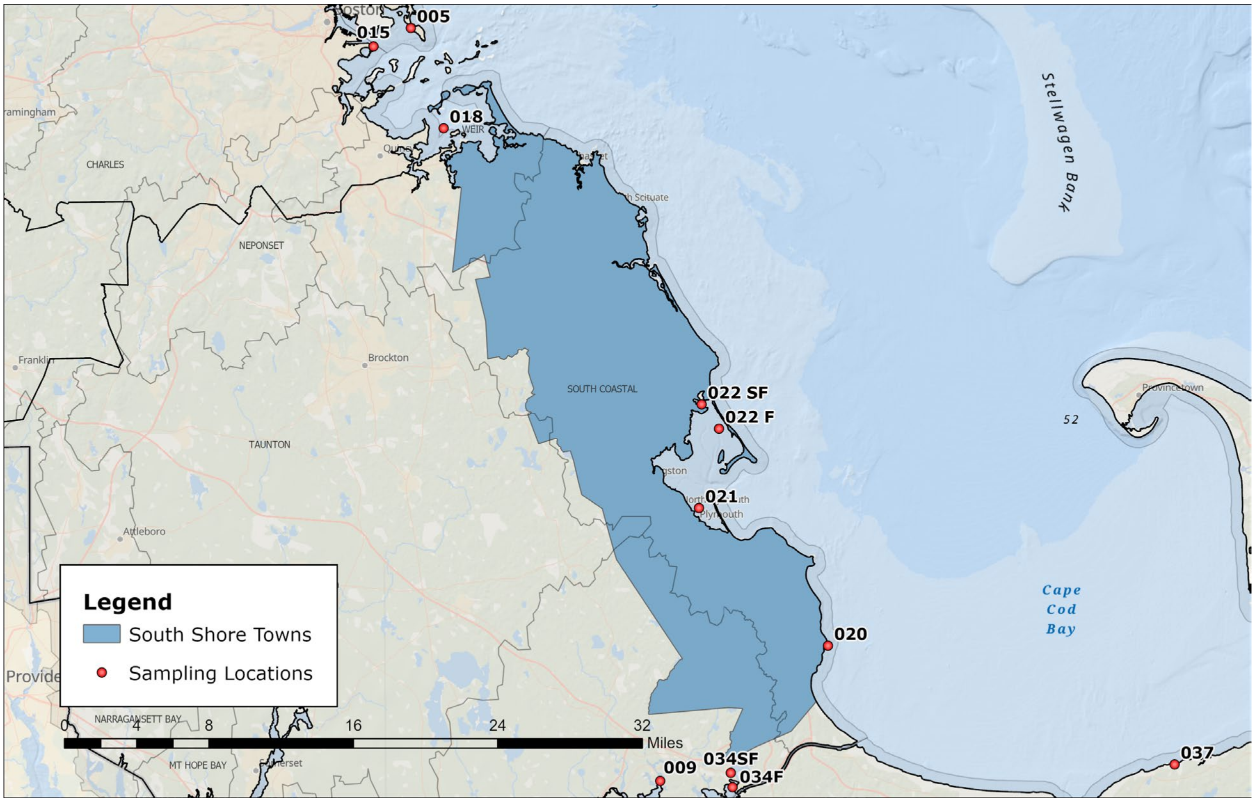


Figure A5. Map of Coastal Sites in Cape Cod and Islands CZM Region

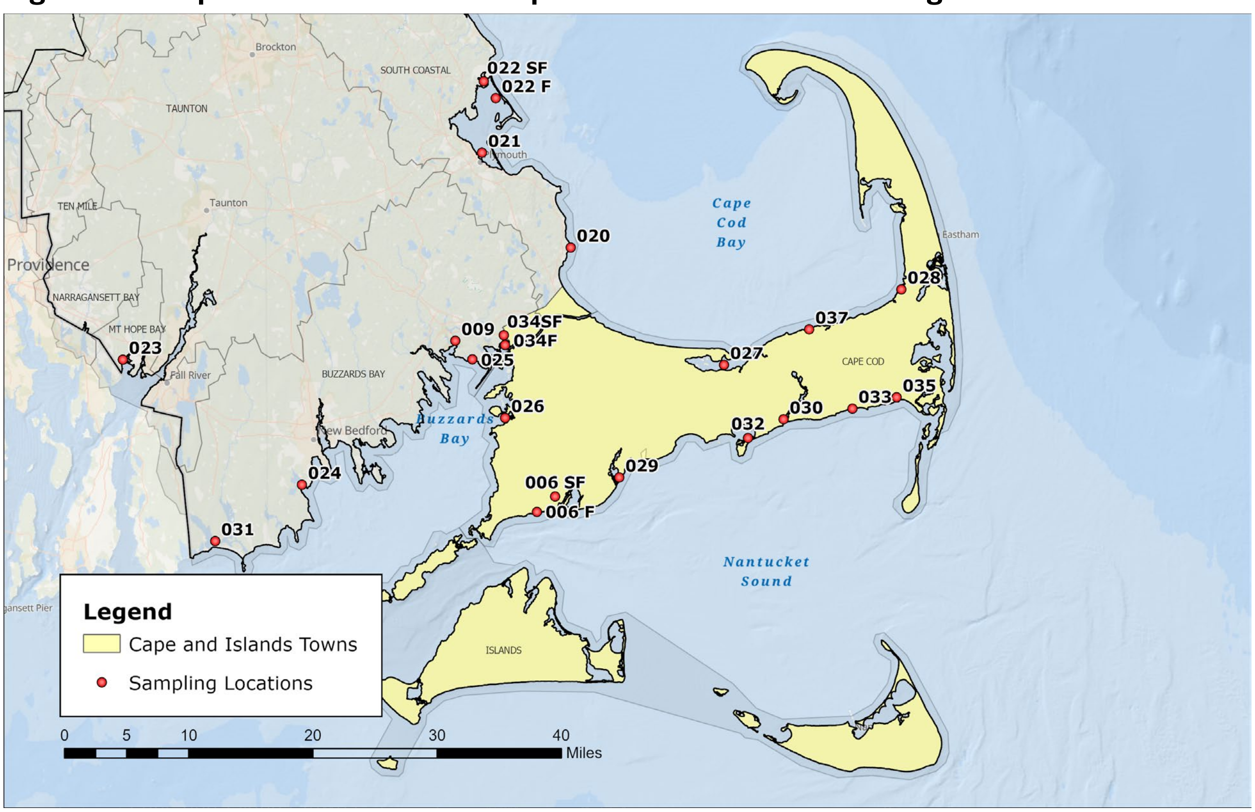
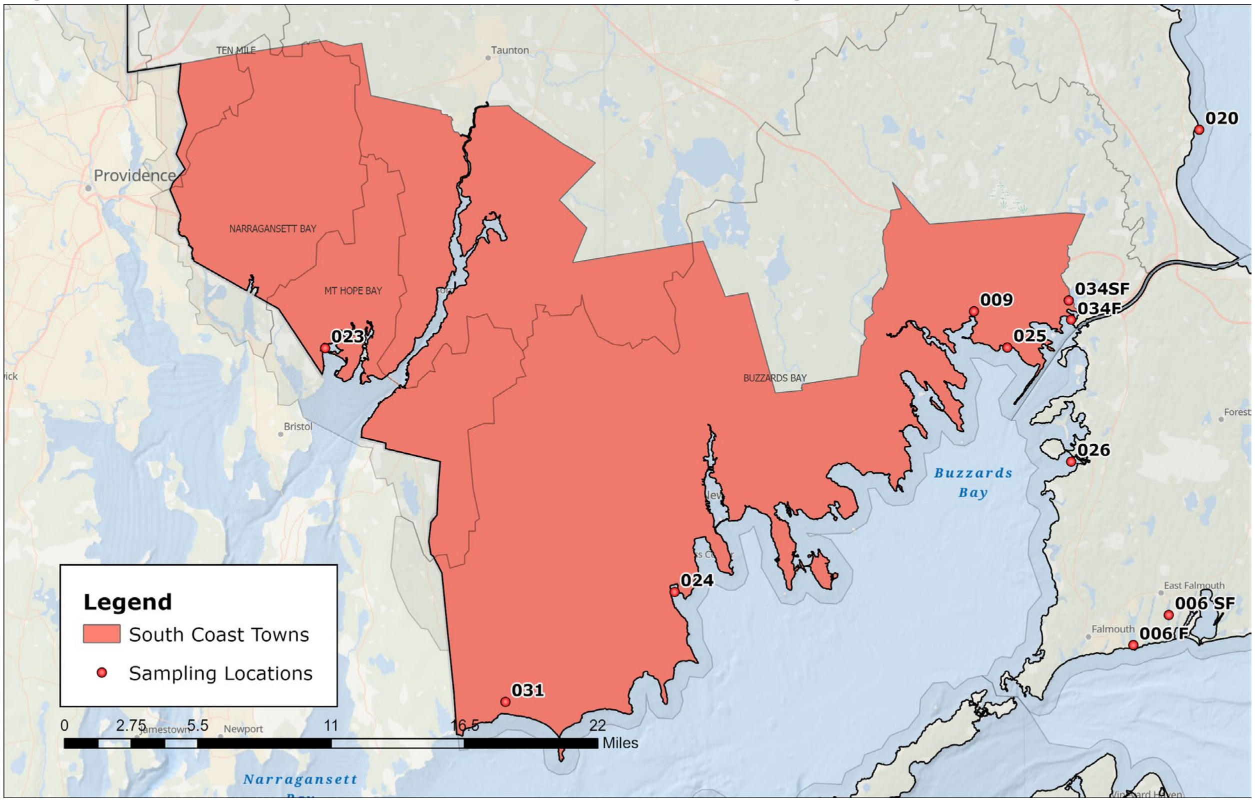


Figure A6. Map of Coastal Sites in South Coast CZM Region



Appendix B: Samples Collected by Location

ID	Waterbody Name	# of Water Samples	# of Inv Samples	Types of Inv Samples[a]	# of Whole Fish Samples	# of Fish Filet Samples	Species of Fish[b]	# of Shellfish Collected	# of Shellfish Composite Samples	Types of Shellfish Samples[c]
Freshwater Locations										
001	Charles River	1	3	BI, CBI	4	2	B, RT, YP	--	--	--
002	Merrimack River	1	6	CBI, CRU	4	4	SMB, WS	--	--	--
003	Johns Pond	1	1	CBI	3	3	B, BB, YP	--	--	--
004	Sheomet Pond	1	3	CBI, CRU	5	4	BB, WS, YP	--	--	--
010	Lake Gardner	1	6	CBI, GAS	4	4	P, YP	--	--	--
011	Spectacle Pond	1	6	CBI, GAS, IN	4	3	B, LMB, P	--	--	--
013	Studleys Pond	1	7	CRU, GAS, INS	3	2	BG, LMB	--	--	--
016	Green River	1	6	CRU, GAS, INS	6	3	CB, EBT, LD, RT	--	--	--
017	Powdermill Brook	1	4	INS	4	4	AE, BT	--	--	--
019	Canoe River	1	3	INS	4	4	BG, YP	--	--	--
Coastal Locations										
005	Boston Harbor, near Deer Island	1	--	--	--	2	SK	--	--	--
006	Great Pond-Bournes Pond	2	--	--	--	7	SB, SC	15	3	Q
007	Pine Creek	1	--	--	--	0	--	15	3	SSC
008	Annisquam River-Mill River	1	--	--	--	2	SB	15	3	BM
009	Wareham River	1	--	--	--	4	PB, SC	15	3	Q
012	Plum Island Sound	1	--	--	--	7	AM, SB	15	3	BM

ID	Waterbody Name	# of Water Samples	# of Inv Samples	Types of Inv Samples[a]	# of Whole Fish Samples	# of Fish Filet Samples	Species of Fish[b]	# of Shellfish Collected	# of Shellfish Composite Samples	Types of Shellfish Samples[c]
014	Marblehead Harbor-Atlantic Ocean	1	--	--	--	5	AM	15	3	BM
015	Boston Harbor, near Castle Island	2	--	--	--	4	SH	--	--	--
018	Hingham Bay	2	--	--	--	0	--	NA	--	--
020	Cape Cod Bay	2	--	--	--	1	C	20	4	BM
021	Plymouth Harbor	1	--	--	--	3	SF	9	3	BM
022	Back River - Duxbury Bay	1	--	--	--	7	BF, CN, SB	15	3	Q
023	Cole River	1	--	--	--	5	DF, SS	15	3	Q
024	Apponagansett Bay	1	--	--	--	10	AB, BSB, SC, SS	15	3	Q
025	Little Harbor	1	--	--	--	9	BF, BSB, SC, SF, SS	20	5	CW, Q
026	Megansett Harbor	1	--	--	--	6	BSB, SC, SS	15	3	Q
027	Barnstable Harbor	1	--	--	--	4	BSB, SB	15	3	BM
028	Rock Harbor Creek	1	--	--	--	1	BSB	20	4	Q
029	Popponesset Bay	1	--	--	--	6	BSB, DF, SC, SF	15	3	Q
030	Bass River	1	--	--	--	5	BSB, SC, SS, SF	15	3	O
031	Westport River	1	--	--	--	5	BSB, T	20	5	O, Q
032	Lewis Bay	1	--	--	--	0	--	17	4	O, Q
033	Allens Harbor	1	--	--	--	0	--	20	4	O

ID	Waterbody Name	# of Water Samples	# of Inv Samples	Types of Inv Samples[a]	# of Whole Fish Samples	# of Fish Filet Samples	Species of Fish[b]	# of Shellfish Collected	# of Shellfish Composite Samples	Types of Shellfish Samples[c]
034	Buttermilk Bay-Cohasset Narrows	1	--	--	--	1	AM	10	3	Q
035	Mill Creek	1	--	--	--	0	--	22	5	O, Q
037	Sesuit Harbor	1	--	--	--	0	--	25	5	BM, O

[a] Invertebrate types listed include BI=bivalves, CBI=combined macroinvertebrates, CRU= crustaceans, INS=insects, and GAS=gastropods.

[b] Fish species listed include AB = Atlantic bonito, AE = American eel, AM = Atlantic mackerel, B = bluegill, BB = brown bullhead, BF = bluefish, BSB = black sea bass, BT = brown trout, CB = creek chub, CN = cunner, DF = smooth dogfish, EBT = eastern brook trout, LD = longnose dace, LMB = largemouth bass, P=pumpkinseed, PB = Atlantic menhaden, RT = rainbow trout, SB = striped bass, SC = scup, SF = summer flounder, SH = silver hake, SK = little skate, SMB = smallmouth bass, SS = striped searobin, T = tautog, WS = white sucker, and YP=yellow perch.

[c] Shellfish types listed include BM=blue mussel, CW=channel whelk, O=oyster, Q=quahog, and SSC=soft shell clam.

Appendix C: Additional Freshwater Surface Water Results

Table C1. Surface Water Results for Select PFAS by Waterbody

Table C1. Surface Water Results for Select PFAS by Waterbody

Site Name	SiteID	PFBA	PFBS	PFHpA	PFHxA	PFHxS	PFNA	PFOA	PFOS	PFOSA	PFPeA	ΣPFAS40
Charles River	001	3.53 J	2.64	1.84	3.88	2.32	0.780 J	5.33	7.26	<0.421	3.69	31.3
Merrimack River	002	<1.69	1.30 J	1.30 J	2.31	0.795 J	<0.422	3.45	1.885	<0.422	1.83 J	12.9
Johns Pond	003	2.87 J	<0.379	0.709 J	0.585 J	<0.435	0.316 KJ	0.974 J	0.446 J	<0.379	<0.757	5.90
Sheomet Pond	004	<1.58	<0.395	<0.395	<0.395	<0.455	<0.395	<0.395	<0.395	<0.395	<0.791	NA
Lake Gardner	010	2.86 J	1.69 J	2.72	2.815	0.747 J	0.708 J	8.605	3.37 J	<0.442	2.73	26.2
Spectacle Pond	011	3.11 J	1.74 J	4.56	3.73	0.595 J	<0.457	13.9	1.45 J	<0.457	3.59 J	32.7
Studleys Pond	013	10.8	3.72	13.7	20.6	27.7	3.63	32.9	66.4	1.88	29.8	261
Green River	016	<1.77	<0.443	<0.443	<0.443	<0.510	<0.443	1.05 J	<0.443	0.607 J	<0.887	1.66
Powdermill Brook	017	2.13 J	2.36	0.974 J	2.19	3.37	<0.411	3.41	2.12	0.504 J	2.29 J	19.3
Canoe River	019	4.81 J	3.30	1.97	3.86	2.30	0.864 J	5.71	5.44	<0.420	4.64	32.9

- MDL values are sample-specific.
- All results are in ng/L.
- ΣPFAS40 excludes non-detect results.
- PFAS shown represent the 10 most frequently detected in surface water.
- Data qualifiers are included for results in this table.

Appendix D: Additional Freshwater Fish Results

Table D1. Fish Filet Mean Concentrations for Select PFAS by Waterbody and Species

Site Name	Site ID	Species	Mean Length (mm)	Mean Weight (g)	N	NEtFOSAA	PFDA	PFDS	PFDoA	PFNA	PFOS	PFOSA	PFTeDA	PFTrDA	PFUnA	ΣPFAS39
Charles River	001	B	201.5	193.9	2	<0.101	0.280	0.283	0.293	<0.101	7.90	<0.101	0.167	0.260	0.427	9.92
Merrimack River	002	SMB	320	393.5	2	0.255	0.940	0.230	1.64	<0.0985	15.1	1.15	0.902	1.19	1.57	23.0
Merrimack River	002	WS	455.5	1138	2	0.139	0.324	<0.0976	0.425	<0.0976	2.15	0.462	0.312	0.418	0.423	7.19
Johns Pond	003	B	220	225.7	1	<0.100	0.152	<0.0995	0.422	<0.0995	1.02	<0.0995	<0.105	0.762	0.824	3.18
Johns Pond	003	BB	346	614.9	1	<0.100	<0.0995	<0.0995	0.248	<0.0995	<0.0995	<0.0995	0.277	0.639	0.288	1.45
Johns Pond	003	YP	253	191.2	1	<0.100	0.169	<0.100	0.381	<0.100	0.475	<0.100	0.217	0.650	0.535	2.43
Sheomet Pond	004	BB	205.5	103.3	2	<0.101	<0.101	<0.101	0.0975	<0.101	0.130	<0.101	<0.101	0.227	0.190	0.619
Sheomet Pond	004	YP	194.5	82.7	2	<0.100	<0.0998	<0.0998	0.194	<0.0998	0.365	<0.0998	0.151	0.264	0.288	1.26
Lake Gardner	010	P	174.5	104.9	2	<0.100	0.315	<0.100	0.404	<0.100	10.1	0.213	0.432	0.587	0.590	12.6
Lake Gardner	010	YP	227.5	147.8	2	<0.100	0.609	<0.100	0.450	0.207	14.7	0.262	0.327	0.638	0.984	18.2
Spectacle Pond	011	B	219	194.5	2	<0.101	0.556	<0.101	0.891	<0.101	2.15	<0.101	0.708	1.11	1.08	6.50
Spectacle Pond	011	P	212	185.2	1	<0.100	0.442	<0.0995	0.762	<0.0995	1.57	<0.0995	0.192	0.595	1.14	4.70
Studleys Pond	013	B	201.5	145.1	2	<0.0976	0.571	0.402	0.787	<0.0976	101	3.22	1.093	0.948	0.644	146
Green River	016	CB	144	35.7	2	<0.0993	0.214	<0.0993	0.239	<0.0992	2.19	<0.0993	0.265	0.327	0.455	3.76
Green River	016	RT	396	644.9	1	<0.0962	<0.0962	<0.0962	<0.0769	<0.0962	0.167	<0.0962	<0.104	<0.0962	<0.0962	0.167
Powdermill Brook	017	AE	355	76.2	2	<0.0957	0.152	0.139	0.435	<0.0957	4.39	<0.0957	0.870	1.03	0.270	7.36
Powdermill Brook	017	BT	353.5	432.4	2	<0.0964	<0.0964	<0.0964	<0.0771	<0.0964	1.15	<0.0964	<0.110	0.107	0.0972	1.44
Canoe River	019	B	197.5	138.6	2	<0.0990	0.506	<0.0990	0.280	<0.0990	10.0	<0.0990	<0.110	0.272	0.623	11.7
Canoe River	019	YP	241.5	150.3	2	<0.0983	0.369	<0.0983	0.218	<0.0983	5.27	<0.0983	<0.199	0.209	0.476	6.58

- MDLs represent the average MDL for each site and species combination for freshwater filets. In some cases, averages represent the average of a detection and a non-detection, with MDL/2 used as a substitute for the non-detection. In these cases, if the average result was below the average of the MDLs, the average is reported in the table as <MDL.
- All concentrations are in ng/g.
- ΣPFAS39 excludes non-detect results and NEtFOSE results.
- Data qualifiers are not included for averaged results.

Table D2. Whole Body Fish Mean Concentrations for Select PFAS by Waterbody

Site Name	Site ID	Species	Mean Length (mm)	Mean Weight (g)	N	PFDA	PFDS	PFDoA	PFNA	PFOA	PFOS	PFOSA	PFTeDA	PFTrDA	PFUnA	ΣPFAS39
Charles River	001	B	188.5	160.4	2	1.02	1.66	0.996	<0.0971	<0.0971	32.5	0.345	0.663	0.868	1.16	42.0
Charles River	001	RT	357	447.8	1	0.371	1.44	0.401	0.240	<0.0769	13.4	0.167	0.262	0.282	0.544	18.0
Charles River	001	YP	255	239.3	1	2.78	2.48	3.07	1.44	0.354	106	0.435	3.29	3.09	2.95	144
Merrimack River	002	SMB	351	513	2	3.25	0.806	5.35	<0.0836	<0.0836	56.9	2.78	2.24	2.74	5.20	85.8
Merrimack River	002	WS	449	1047	2	1.10	0.170	1.59	0.281	0.110	7.13	3.78	0.810	1.12	1.35	28.4
Johns Pond	003	B	199	162.5	1	0.663	0.122	0.874	0.100	<0.0826	2.54	<0.0826	0.371	1.09	1.49	7.25
Johns Pond	003	BB	344	655.1	1	0.128	0.115	0.527	<0.0862	<0.0862	2.48	<0.0862	0.564	0.821	0.586	5.22
Johns Pond	003	YP	228	142.6	1	0.730	0.165	1.61	0.235	<0.0855	2.63	0.0940	0.597	2.05	2.26	10.4
Sheomet Pond	004	BB	186	74.4	2	<0.0880	<0.0880	0.381	<0.0880	<0.0880	1.73	<0.0880	0.312	0.669	0.493	3.63
Sheomet Pond	004	WS	356	501.3	1	0.217	<0.0791	0.872	<0.0791	<0.0791	0.928	<0.0791	0.548	1.79	0.679	7.18
Sheomet Pond	004	YP	160.5	48	2	0.550	<0.0954	1.17	0.141	<0.0954	2.67	<0.0954	0.672	1.61	1.74	9.30
Lake Gardner	010	P	146	65.3	2	1.27	<0.0969	1.20	0.187	0.143	24.2	0.607	0.472	0.985	2.03	31.1
Lake Gardner	010	YP	199.5	89.9	2	1.54	<0.0883	1.01	0.197	0.119	29.7	0.385	0.424	0.790	1.84	36.1
Spectacle Pond	011	B	192	141.2	2	2.14	0.108	3.65	0.141	0.257	7.19	0.0964	1.41	3.40	3.84	25.3
Spectacle Pond	011	LMB	300	304.3	1	3.94	0.168	5.97	0.249	0.179	18.5	0.116	3.84	4.98	6.44	44.5
Spectacle Pond	011	P	196	161.1	1	3.54	<0.100	3.75	0.486	0.573	4.74	0.425	1.25	2.74	4.62	24.7
Studleys Pond	013	B	179.5	105.8	2	2.59	0.731	2.52	0.199	0.183	410	6.80	2.33	2.76	1.85	809

Site Name	Site ID	Species	Mean Length (mm)	Mean Weight (g)	N	PFDA	PFDS	PFDoA	PFNA	PFOA	PFOS	PFOSA	PFTeDA	PFTrDA	PFUnA	ΣPFAS39
Studleys Pond	013	LMB	360	645.8	1	4.62	1.88	4.67	0.424	<0.0939	658	10.2	3.21	4.05	3.40	1337
Green River	016	CB	95	8.75	2	0.510	<0.0924	0.428	0.145	<0.0924	4.51	<0.0924	0.327	0.702	0.850	7.69
Green River	016	EBT	107.5	11.4	2	0.357	<0.0948	0.210	0.179	0.0971	4.80	<0.0948	0.107	0.289	0.520	6.51
Green River	016	LD	99	10.3	2	0.989	<0.0863	0.525	0.410	0.100	7.32	<0.0863	0.243	0.766	1.13	11.5
Powdermill Brook	017	AE	345	77.5	2	0.323	0.304	0.614	0.162	0.179	10.5	<0.0835	0.990	1.16	0.427	16.6
Powdermill Brook	017	BT	272	201.8	2	0.339	0.194	0.406	0.203	0.143	11.6	0.186	0.528	0.544	0.448	16.7
Canoe River	019	B	175.5	93.6	2	1.59	<0.0828	0.776	<0.0828	0.0990	34.7	<0.0828	0.462	0.725	1.57	40.0
Canoe River	019	YP	228.5	136.1	2	1.62	<0.0846	0.824	0.393	0.119	23.7	<0.0846	0.672	1.14	1.27	33.1

- MDLs represent the average MDL for each site and species combination for freshwater filets. In some cases, averages represent the average of a detection and a non-detection, with MDL/2 used as a substitute for the non-detection. In these cases, if the average result was below the average of the MDLs, the average is reported in the table as <MDL.
- All concentrations are in ng/g.
- ΣPFAS39 excludes non-detect results and NEtFOSE results.
- Lab qualifiers are not included for averaged results.

Table D3. Fish Filet Results by Reference and Non-reference Locations

Analyte	Reference (n= 7 Fish)			Non-Reference (n=26 fish)			p-value
	FOD	Maximum	Median	FOD	Maximum	Median	
PFDA	28.6%	0.273	<MDL	88.5%	1.09	0.362	<0.001
PFDoA	85.7%	0.270	0.173	96.2%	1.78	0.402	0.002
PFOS	85.7%	2.85	0.307	96.2%	115	5.27	0.001
PFTeDA	57.1%	0.343	0.145	73.1%	1.26	0.248	0.040
PFTrDA	85.7%	0.381	0.245	100.0%	1.37	0.617	0.009
PFUnA	85.7%	0.523	0.247	96.2%	1.69	0.559	0.012

- Comparisons between fish filet results at reference and non-reference locations were calculated for PFAS detected at 50% or more of waterbodies.
- All results are in ng/g.
- Statistical testing is the result of an ANOVA (equivalent to a t-test, when performed with only two groups) conducted on log-transformed individual fish results.

Table D4. Whole body Fish Results by Reference and Non-reference Locations

Analyte	Reference (n= 11 Fish)			Non-Reference (n=30 fish)			p-value
	FOD	Maximum	Median	FOD	Maximum	Median	
PFDA	90.9%	1.22	0.406	100.0%	4.62	1.42	<0.001
PFDS	0%	<MDL	<MDL	73.3%	2.48	0.165	NA
PFDoA	100.0%	1.63	0.383	100.0%	5.97	1.17	<0.001
PFNA	72.7%	0.414	0.149	83.3%	1.44	0.1895	0.356
PFOA	27.3%	0.147	<MDL	66.7%	0.573	0.1235	0.017
PFOS	100.0%	10.0	3.88	100.0%	658	19.6	<0.001
PFOSA	0%	<MDL	<MDL	73.3%	10.2	0.2435	NA
PFTeDA	90.9%	0.749	0.367	100.0%	3.84	0.7025	<0.001
PFTrDA	100.0%	2.13	0.700	100.0%	4.98	1.115	0.021
PFUnA	100.0%	2.51	0.749	100.0%	6.44	1.58	0.010

- Comparisons between surface water results at reference and non-reference locations were calculated for PFAS detected at 50% or more of waterbodies.
- We did not conduct tests for statistical significance for PFAS that were not detected at all in reference locations.
- All results are in ng/g.
- Statistical testing is the result of an ANOVA (equivalent to a t-test, when performed with only two groups) conducted on log-transformed individual fish results.

Table D5. Descriptive Statistics for ΣPFAS39 by Species in Fish Filets

Species	Mean Length (mm)	Mean Weight (g)	Sample Count	Mean ΣPFAS39 (ng/g)
American eel	355.0	76.2	2	7.36
Bluegill	206.6	174.4	9	39.1
Brown bullhead	252.3	273.8	3	0.896
Brown trout	353.5	432.4	2	1.44
Creek chub	144.0	35.7	2	3.76
Pumpkinseed	187.0	131.6	3	9.97
Rainbow trout	396.0	644.9	1	0.167
Smallmouth bass	320.0	393.5	2	23.0
White sucker	455.5	1138.0	2	7.19
Yellow perch	225.7	136.1	7	7.78

- All concentrations are in ng/g.
- ΣPFAS39 excludes non-detect results and NEtFOSE results.
- Results are not weighted by waterbody.

Table D6. Descriptive Statistics for ΣPFAS39 by Species in Whole-body Fish

Species	Mean Length (mm)	Mean Weight (g)	Sample Count	Mean ΣPFAS39 (ng/g)
American eel	345.0	77.5	2	16.6
Bluegill	185.6	129.4	9	205
Brown bullhead	238.7	267.9	3	4.16
Brown trout	272.0	201.8	2	16.7
Creek chub	95.0	8.8	2	7.69
Eastern brook trout	107.5	11.4	2	6.51
Dace	99.0	10.3	2	11.5
Largemouth bass	330.0	475.1	2	691
Pumpkinseed	162.7	97.2	3	29.0
Rainbow trout	357.0	447.8	1	18.0
Smallmouth bass	351.0	513.0	2	85.8
White Sucker	418.0	865.1	3	21.3
Yellow Perch	207.5	116.2	8	38.9

- All concentrations are in ng/g.
- ΣPFAS39 excludes non-detect results and NEtFOSE results.
- Results are not weighted by the waterbody.

Table D7. Comparison of PFAS between species in freshwater fish filets

Analyte	Bluegill (n= 9)			Yellow Perch (n=7)			p-value
	FOD	Maximum	Median	FOD	Maximum	Median	
PFDA	100%	0.630	0.511	71.4%	0.633	0.347	0.14
PFDoA	100%	1.03	0.422	100%	0.493	0.2335	0.05
PFOS	100%	115	8.515	100%	16.5	4.775	0.14
PFTeDA	66.7%	1.26	0.218	71.4%	0.459	0.157	0.37
PFTrDA	100%	1.31	0.762	100%	0.709	0.363	0.28
PFUnA	100%	1.28	0.629	100%	1.00	0.535	0.27

- Comparisons between species were calculated for PFAS detected in 50% or more of samples.
- All concentrations are in ng/g.
- P-values represent the result of an ANOVA test of PFAS concentrations between species for fish filets.
- Statistical testing is the result of an ANOVA (equivalent to a t-test, when performed with only two groups) conducted on log-transformed individual fish results.

Table D8. Comparison of PFAS between species in freshwater whole fish

Analyte	Bluegill (n= 9)			Yellow Perch (n=8)			p-value
	FOD	Maximum	Median	FOD	Maximum	Median	
PFDA	100%	3.20	1.63	100%	2.78	1.38	0.39
PFDoA	100%	3.98	1.00	100%	3.07	1.036	0.42
PFDS	88%	1.99	0.122	25%	2.48	<MDL	0.12
PFNA	77%	0.205	0.119	100%	1.44	0.239	0.01
PFOA	77.8%	0.266	0.117	62.5%	0.354	0.100	0.51
PFOS	100%	548	24.4	100%	106	21.9	0.30
PFOSA	55.6%	8.54	0.145	62.5%	0.463	0.0930	0.43
PFTeDA	100%	3.48	0.916	100%	3.29	0.626	0.70
PFTrDA	100%	4.00	1.14	100%	3.09	1.16	0.86
PFUnA	100%	4.30	1.67	100%	2.95	1.825	0.84

- Comparisons between species were calculated for PFAS detected in 50% or more of samples.
- All concentrations are in ng/g.
- Statistical testing is the result of an ANOVA (equivalent to a t-test, when performed with only two groups) conducted on log-transformed individual fish results.

Table D9. Whole body Fish Results Compared to Fish Filet Results

Analyte	Whole-Body (n=41 Fish)			Filet (n=33 fish)			p-value
	FOD	Maximum	Median	FOD	Maximum	Median	
PFDA	97.6%	4.62	1.05	75.8%	1.09	0.309	<0.001
PFUnA	100%	6.44	1.49	93.9%	1.69	0.514	<0.001
PFDoA	100%	5.97	0.991	93.9%	1.78	0.355	<0.001
PFTrDA	100%	4.98	1.08	97.0%	1.37	0.427	<0.001
PFTeDA	97.6%	3.84	0.597	69.7%	1.26	0.218	<0.001
PFOS	100%	658	13	93.9%	115	3.54	<0.001

- Comparisons between results for filets and whole-body fish were calculated for PFAS detected in 50% or more of samples from freshwater water bodies.
- Tests for statistical significance were not conducted for PFAS that were not detected at all in either whole-body fish or in fish filets.
- All results are in ng/g.
- Statistical testing is the result of an ANOVA (equivalent to a t-test, when performed with only two groups) conducted on log-transformed individual fish results.

Appendix E: Additional Freshwater Invertebrate Results

Table E1. Invertebrate Results for Select PFAS by Waterbody

Table E2. Invertebrate Results by Reference and Non-reference Locations

Table E3. Comparison of PFAS between Species in Freshwater Whole Fish and Fish Filets

Table E1. Invertebrate Mean Concentrations for Select PFAS by Waterbody

Site Name	Site ID	Type of Invertebrate	N	PFDA	PFDoA	PFHxS	PFNA	PFOA	PFOS	PFOSA	PFTeDA	PFTrDA	PFUnA	ΣPFAS39
Charles River	001	BI	2	<0.0900	<0.0720	<0.104	<0.0900	<0.0900	0.501	0.103 J	<0.0900	<0.0900	<0.0900	0.604
Charles River	001	CBI	1	0.518	0.418	0.599	0.407	0.508	21.7	0.328	0.289	0.443	0.625	40.7
Merrimack River	002	CBI	4	0.216	0.279	<0.106	0.224	0.495	2.77	0.338	0.201	0.190	0.208	6.81
Merrimack River	002	CRU	2	0.256	0.386	0.132	0.195	0.711	1.43	0.343	0.219	0.345	0.340	9.99
Johns Pond	003	CBI	1	0.375	0.615	<0.114	0.309	0.210	0.593	0.107	0.155	0.750	1.02	6.54
Sheomet Pond	004	CBI	2	<0.104	0.111	<0.104	<0.0901	0.116	0.449	<0.0901	<0.0901	0.233	0.193	4.94
Sheomet Pond	004	CRU	1	<0.0957	0.265	<0.110	<0.0957	<0.0957	0.364	<0.0957	0.262	0.499	0.331	2.07
Lake Gardner	010	CBI	2	0.437	0.465	0.512	0.281	0.942	4.46	0.370	0.220	0.332	0.855	9.02
Lake Gardner	010	GAS	4	0.356	0.174	1.52	0.370	2.73	3.90	0.300	<0.120	<0.0905	0.427	10.5
Spectacle Pond	011	CBI	2	0.329	0.361	0.157	0.198	0.946	0.527	0.150	0.209	0.146	0.344	3.39
Spectacle Pond	011	GAS	3	0.141	0.260	<0.111	0.0988	0.664	0.478	0.121	<0.140	0.136	0.220	2.41
Spectacle Pond	011	INS	1	0.395	0.580	<0.108	0.216	0.592	1.05	0.118	0.256	0.443	0.651	4.30
Studleys Pond	013	CRU	1	0.626	1.36	2.24	0.680	1.68	12.4	15.2	0.637	0.967	0.590	236
Studleys Pond	013	GAS	5	0.743	0.490	5.82	0.761	2.62	20.5	10.1	0.290	0.236	0.370	208
Studleys Pond	013	INS	1	0.515	0.479	15.1	0.634	1.89	21.5	11.9	0.244	0.283	0.370	254
Green River	016	CRU	3	0.147	0.242	<0.0971	0.191	0.813	0.392	<0.0844	0.155	0.375	0.351	3.90
Green River	016	GAS	1	<0.0980	<0.0784	<0.113	<0.0980	0.134	0.238	<0.0980	<0.128	<0.0980	0.119	0.491
Green River	016	INS	2	0.177	0.456	<0.110	0.247	0.735	1.54	<0.0953	<0.0953	<0.0953	0.267	12.6
Powdermill Brook	017	INS	4	0.126	0.117	0.165	0.120	0.288	3.71	<0.0858	0.101	0.140	0.167	6.03
Canoe River	019	INS	3	1.27	0.667	0.441	0.768	0.742	15.9	0.173	0.206	0.607	1.23	22.2

- MDLs represent the average MDL for each site and group combination for invertebrates. In some cases, averages represent the average of a detection and a non-detection, with MDL/2 used as a substitute for the non-detection. In these cases, if the average result was below the average of the MDLs, the average is reported in the table as <MDL.
- All concentrations are in ng/g.
- ΣPFAS39 excludes non-detect results and NEtFOSE results.
- Data qualifiers are not included for averaged results.
- BI=Bivalves; CBI=Combined Benthic Invertebrates; CRU=Crustaceans; GAS=Gastropods; INS=Insects

Table E2. Invertebrate Results by Reference and Non-reference Locations

Analyte	Reference (n= 9)			Non-Reference (n=36)			p
	FOD	Maximum	Median	FOD	Maximum	Median	
PFDA	55.6%	0.223	0.099	94.4%	1.45	0.276	<0.001
PFDoA	77.8%	0.872	0.187	94.4%	1.36	0.350	0.061
PFHxS	0%	<MDL	<MDL	69.4%	18.6	0.158	NA
PFNA	66.7%	0.307	0.121	88.9%	1.42	0.266	0.017
PFOA	88.9%	1.16	0.487	94.4%	5.33	0.599	0.066
PFOS	100.0%	1.55	0.364	100.0%	42.3	3.38	<0.001
PFOSA	0%	<MDL	<MDL	88.9%	19.4	0.209	NA
PFTeDA	33.3%	0.262	<MDL	66.7%	0.637	0.198	0.032
PFTrDA	77.8%	0.499	0.324	72.2%	0.967	0.188	0.832
PFUnA	88.9%	0.449	0.301	91.7%	1.26	0.347	0.262

- Comparisons between invertebrate results at reference and non-reference locations were calculated for PFAS detected at 50% or more of waterbodies We did not conduct tests for statistical significance for PFAS that were not detected at all in reference locations.
- All concentrations are in ng/g.
- Statistical testing is the result of an ANOVA (equivalent to a t-test, when performed with only two groups) conducted on log-transformed individual invertebrate composite results.

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Table E3. Descriptive Statistics for ΣPFAS39 by Invertebrate Category

Invertebrate Category	N	ΣPFAS39
Bivalves	2	0.604
Combined macroinvertebrates	12	9.10
Crustaceans	7	38.6
Gastropods	13	83.9
Insects	11	34.0

- All concentrations are in ng/g.
- ΣPFAS39 excludes non-detect results and NEtFOSE results.
- Results are not weighted by waterbody.

Appendix F: Additional Coastal Surface Water Results

Table F1. Surface Water Results for Select PFAS by Waterbody

Table F1. Surface Water Results for Select PFAS by Waterbody

Site Name	Site ID	NEtFOSAA	PFBS	PFHpA	PFHxA	PFHxS	PFNA	PFOA	PFOS	PFOSA	PFPeA	ΣPFAS40
Boston Harbor (near Deer Island)	005	<0.411	<0.411	0.462J	0.657J	<0.473	<0.411	0.665J	0.421J	<0.411	0.926J	3.13
Bournes Pond	006	<0.414	0.435J	0.459J	0.895J	0.978J	<0.414	0.913J	1.46J	<0.414	<0.828	5.14
Great Pond	006	<0.405	<0.405	<0.405	<0.405	<0.466	<0.405	0.629J	0.453J	<0.405	<0.810	1.08
Pine Creek	007	0.467K J	<0.38	0.581J	0.669J	<0.437	0.510J	3.20	2.67	<0.380	<0.760	8.10
Annisquam River-Mill River	008	<0.456	<0.456	<0.456	<0.456	<0.525	<0.456	0.633J	0.416J	<0.456	<0.913	1.05
Wareham River	009	<0.411	<0.411	0.411J	0.87J	<0.472	<0.411	1.15J	0.578J	<0.411	1.06J	4.07
Plum Island Sound	012	<0.383	<0.383	<0.383	<0.383	<0.441	<0.383	0.884J	0.490J	0.397J	<0.766	1.77
Marblehead Harbor-Atlantic Ocean	014	<0.407	<0.407	<0.407	<0.407	<0.468	<0.407	<0.407	<0.407	<0.407	<0.814	0
Boston Harbor (near Castle Island)	015	<0.383	<0.383	<0.383	<0.383	<0.441	<0.383	<0.383	<0.383	<0.383	<0.766	0
Hingham Bay	018	<0.390	<0.390	<0.390	0.694J	<0.448	<0.39	0.450J	0.443J	<0.390	<0.780	1.59
Cape Cod Bay	020	<0.390	<0.390	<0.390	<0.39	<0.448	<0.39	<0.390	<0.390	<0.390	<0.779	0
Plymouth Harbor	021	<0.379	<0.379	<0.379	<0.379	<0.435	<0.379	<0.379	<0.379	<0.379	<0.757	0
Back River - Duxbury Bay	022	<0.395	<0.395	<0.395	<0.395	<0.454	<0.395	<0.395	<0.395	<0.395	<0.790	0
Cole River	023	<0.395	<0.395	<0.395	0.667J	<0.454	<0.395	1.06J	0.882J	<0.395	<0.790	2.61
Apponagansett Bay	024	<0.397	<0.397	<0.397	<0.397	<0.457	<0.397	<0.397	<0.397	<0.397	<0.795	0
Little Harbor	025	<0.390	<0.390	<0.390	<0.390	<0.448	<0.390	0.342K J	<0.390	<0.390	<0.779	0.342
Megansett Harbor	026	<0.380	<0.380	<0.380	<0.380	<0.437	<0.380	<0.380	<0.380	<0.380	<0.760	0
Barnstable Harbor	027	<0.400	<0.400	<0.400	<0.40	<0.460	<0.400	<0.400	<0.400	<0.400	0.832J	0.832
Rock Harbor Creek	028	<0.381	<0.381	<0.381	<0.381	<0.438	<0.381	0.517J	<0.381	<0.381	<0.762	0.517
Popponesset Bay	029	<0.399	<0.399	<0.399	<0.399	<0.459	<0.399	<0.399	<0.399	<0.399	<0.798	0
Bass River	030	<0.382	<0.382	<0.382	<0.382	<0.439	<0.382	0.619J	<0.382	<0.382	<0.764	0.619
Westport River	031	<0.386	<0.386	<0.386	<0.386	<0.444	<0.386	<0.386	<0.386	<0.386	<0.772	0
Lewis Bay	032	<0.390	<0.390	<0.390	0.474J	<0.449	<0.390	0.500J	0.579J	<0.390	<0.78	1.55
Allen Harbor	033	<0.394	<0.394	<0.394	<0.394	<0.453	<0.394	0.612J	<0.394	<0.394	<0.788	0.612
Buttermilk Bay-Cohasset Narrows	034	<0.388	<0.388	<0.388	<0.388	<0.447	<0.388	0.497J	<0.388	<0.388	<0.777	0.497
Mill Creek	035	<0.388	<0.388	<0.388	0.416J	<0.446	<0.388	0.604J	0.451J	<0.388	<0.775	1.47
Sesuit Harbor	037	<0.387	<0.387	<0.387	<0.387	<0.445	<0.387	<0.387	<0.387	<0.387	<0.774	0

- MDL values are sample-specific. - All results are in ng/L. - ΣPFAS40 excludes non-detect results.

Appendix G: Additional Coastal Fish Results

Table G1. Fish Filet Results for Select PFAS by Waterbody (landscape)

Table G2. Fish Filet Results by Reference and Non-reference Locations

Table G3. Fish Filet Results by CZM Region

Table G4. Descriptive Statistics for ΣPFAS39 by Species in Fish Filets

Table G1. Fish Filet Mean Concentrations for Select PFAS by Waterbody

Site Name	Site ID	Species	Mean Length (mm)	Mean Weight (g)	N	NEtFOSAA	PFDA	PFDoA	PFHpA	PFNA	PFOA	PFOS	PFOSA	PFTeDA	PFTrDA	PFUnA	ΣPFAS39
Boston Harbor (near Deer Island)	005	SK	298.5	687.5	2	<0.0951	<0.0951	0.251	<0.0951	<0.0951	0.220	0.789	0.136	0.407	0.547	0.292	2.75
Great Pond	006	SB	283	201.3	1	<0.101	0.169	0.387	0.154	<0.101	<0.101	1.83	1.96	0.416	0.522	0.303	5.94
Great Pond	006	SC	286.3	344.1	6	<0.100	<0.100	<0.0800	<0.100	<0.100	<0.100	<0.100	0.153	<0.101	0.153	<0.100	0.400
Annisquam River-Mill River	008	SB	474	1191	2	0.117	0.145	0.150	<0.0998	<0.0998	<0.0998	1.39	0.606	0.155	0.234	0.256	3.05
Wareham River	009	PB	288.5	220	2	<0.0962	<0.0962	<0.0769	<0.0962	<0.0962	<0.0962	0.274	<0.0962	<0.0962	<0.0962	0.111	0.488
Wareham River	009	SC	277	351.8	2	<0.0949	<0.0949	<0.0760	<0.0949	<0.0949	<0.0949	<0.0949	<0.0949	0.109	0.153	<0.0949	1.88
Plum Island Sound	012	AM	316.8	248.2	6	<0.0993	<0.0993	<0.0794	<0.0993	<0.0993	<0.0993	0.239	0.171	<0.0993	0.132	0.136	0.749
Plum Island Sound	012	SB	461	890.9	1	0.416	0.107	0.130	<0.101	0.124	<0.101	1.31	1.61	<0.237	0.123	0.273	4.09
Marblehead Harbor-Atlantic Ocean	014	AM	272.4	147.5	5	<0.0974	<0.0974	<0.0779	<0.0974	<0.0974	<0.0974	0.105	0.121	<0.109	<0.100	<0.0974	0.566
Boston Harbor (near Castle Island)	015	SH	271.8	125.6	4	<0.0975	<0.0975	<0.0780	<0.0975	<0.0975	<0.0975	0.158	0.252	<0.117	<0.0975	0.101	0.524
Cape Cod Bay	020	CN	190	106	1	<0.100	<0.100	<0.0800	<0.100	<0.100	<0.100	<0.100	1.27	<0.225	0.116	<0.100	1.38
Plymouth Harbor	021	SF	258	165.0	3	<0.100	<0.100	<0.0800	<0.100	<0.100	<0.100	0.198	0.189	<0.109	<0.100	0.159	0.552
Back River - Duxbury Bay	022	BF	596	1451.5	1	<0.0971	0.130	0.107	<0.0971	<0.0971	<0.0971	1.04	0.573	0.111	0.280	0.231	2.59
Back River - Duxbury Bay	022	CN	196.5	120.4	2	<0.0990	<0.0990	<0.0792	<0.0990	<0.0990	<0.0990	<0.0990	0.338	<0.0990	<0.0990	<0.0990	0.338
Back River - Duxbury Bay	022	SB	606	2682	1	<0.0990	0.108	0.163	<0.0990	<0.0990	<0.0990	1.02	0.971	0.169	0.308	0.247	2.99
Cole River	023	DF	657.7	1175	4	<0.0973	<0.0973	0.395	<0.0973	<0.0973	<0.0973	0.4225	<0.09725	0.500	1.59	0.151	3.09
Cole River	023	SS	400	715	1	<0.0948	0.110	0.425	<0.0948	<0.0948	<0.0948	0.971	1.52	0.423	1.32	0.297	5.07
Apponagansett Bay	024	AB	523	1580.8	1	<0.0976	<0.0976	0.110	<0.0976	<0.0976	<0.0976	0.689	0.502	<0.0976	0.275	0.202	1.78
Apponagansett Bay	024	BSB	264	239.1	3	<0.0976	<0.0976	<0.0781	<0.0976	<0.0976	<0.0976	0.107	<0.0976	<0.115	<0.0977	<0.0976	0.141
Apponagansett Bay	024	SC	255.3	243.2	4	<0.0975	<0.0975	<0.0780	<0.0975	<0.0975	<0.0975	<0.0975	0.140	<0.0975	0.113	<0.0975	1.37
Apponagansett Bay	024	SS	285.5	270.5	2	<0.0976	0.110	0.145	<0.0976	<0.0976	<0.0976	0.797	0.628	<0.117	0.329	0.281	2.29
Little Harbor	025	BF	418	736	1	<0.101	<0.101	<0.0804	<0.101	<0.101	<0.101	0.390	0.247	<0.132	<0.101	0.132	0.769
Little Harbor	025	BSB	385	696.4	3	<0.0993	<0.0993	<0.0795	<0.0993	<0.0993	<0.0993	0.125	<0.0993	<0.187	<0.0993	<0.0993	0.203
Little Harbor	025	SC	276	310.3	1	<0.100	<0.100	<0.0800	<0.100	<0.100	<0.100	<0.100	<0.100	<0.118	0.119	<0.100	0.119
Little Harbor	025	SF	232	112	1	<0.101	<0.101	<0.0804	<0.101	<0.101	<0.101	0.127	0.119	<0.101	<0.101	<0.101	0.246
Little Harbor	025	SS	288	273.4	1	<0.101	<0.101	0.103	<0.101	<0.101	<0.101	0.567	0.558	<0.101	0.294	0.311	1.83
Megansett Harbor	026	BSB	272.5	290.0	2	<0.0993	<0.0993	<0.0794	<0.0993	<0.0993	<0.0993	0.106	<0.0993	<0.153	<0.0993	<0.0993	0.150

Site Name	Site ID	Species	Mean Length (mm)	Mean Weight (g)	N	NEtFOSAA	PFDA	PFDoA	PFHpA	PFNA	PFOA	PFOS	PFOSA	PFTeDA	PFTrDA	PFUnA	ΣPFAS39
Megansett Harbor	026	SC	272	289.9	3	<0.100	<0.100	<0.0799	<0.100	<0.100	<0.100	<0.100	0.140	<0.116	0.101	<0.100	0.207
Megansett Harbor	026	SS	285	251.6	1	<0.0995	0.219	0.208	<0.0995	<0.0995	<0.0995	1.30	0.938	<0.123	0.314	0.470	3.45
Barnstable Harbor	027	BSB	399	912.5	1	<0.0995	<0.0995	<0.0796	<0.0995	<0.0995	<0.0995	0.189	0.493	<0.0995	<0.0995	<0.0995	0.682
Barnstable Harbor	027	SB	452.7	1003.4	3	<0.100	<0.100	<0.0801	<0.100	<0.100	<0.100	0.290	0.336	<0.100	<0.100	<0.100	0.663
Rock Harbor Creek	028	BSB	197	123.5	1	<0.0995	<0.0995	<0.0796	<0.0995	<0.0995	<0.0995	<0.0995	0.233	<0.107	<0.0995	0.138	0.371
Popponesset Bay	029	BSB	349	490.5	2	<0.100	<0.100	<0.0798	<0.100	<0.100	<0.100	0.103	0.108	<0.124	<0.100	<0.100	0.221
Popponesset Bay	029	DF	1143	3175.2	1	<0.100	<0.100	0.107	<0.100	<0.100	<0.100	0.171	<0.100	0.134	0.468	<0.100	0.88
Popponesset Bay	029	SC	293	382.1	2	<0.100	<0.100	<0.0800	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	0.127	0.118	0.321
Popponesset Bay	029	SF	264	181.5	1	<0.100	<0.100	<0.0800	<0.100	<0.100	<0.100	0.154	<0.100	<0.100	<0.100	<0.100	0.154
Bass River	030	BSB	314	407.2	1	<0.0990	<0.0990	<0.0792	<0.0990	<0.0990	<0.0990	0.217	0.191	<0.0990	<0.0990	0.153	0.561
Bass River	030	SC	243	223.9	2	<0.101	<0.101	<0.0802	<0.101	<0.101	<0.101	<0.101	<0.101	<0.101	<0.101	0.114	0.233
Bass River	030	SF	405	555.8	1	<0.0990	0.104	0.093	<0.0990	<0.0990	<0.0990	0.363	0.152	<0.0990	<0.0990	0.192	0.904
Bass River	030	SS	324	469.1	1	<0.0985	<0.0985	0.0790	<0.0985	<0.0985	<0.0985	0.346	0.849	<0.0985	0.122	0.188	1.58
Westport River	031	BSB	466.3	1046.9	4	<0.0975	<0.0975	<0.0780	<0.0980	<0.0980	<0.0980	<0.0980	0.0981	0.0992	0.162	<0.0975	0.331
Westport River	031	T	283	480.8	1	<0.0990	<0.0990	<0.0792	<0.0990	<0.0990	<0.0990	<0.0990	<0.0990	<0.0990	<0.0990	<0.0990	0.086
Buttermilk Bay-Cohasset Narrows	034	AM	355	380.3	1	<0.100	<0.100	<0.0800	<0.100	<0.100	<0.100	0.780	0.418	<0.100	0.168	0.183	1.61

- MDLs represent the average MDL for each site and species combination for coastal filets. In some cases, averages represent the average of detections and non-detections, with MDL/2 used as a substitute for the non-detection. In these cases, if the average result was below the average of the MDLs, the average is reported in the table as <MDL.
- All concentrations are in ng/g.
- ΣPFAS39 excludes non-detect results and NEtFOSE results.
- Data qualifiers are not included for averaged results.

Table G2. Fish Filet Results by Reference and Non-reference Locations

Analyte	Reference (n=9 fish)			Non-Reference (n=80 fish)			p
	FOD	Maximum	Median	FOD	Maximum	Median	
PFOS	66.7%	1.31	0.250	58.8%	1.83	0.131	0.661
PFOSA	88.9%	1.61	0.233	66.3%	1.96	0.130	0.104
PFTrDA	77.8%	0.221	0.123	57.5%	1.91	0.110	0.775

- Comparisons between fish filet results at reference and non-reference locations were calculated for PFAS detected at 50% or more of waterbodies.
- All results are in ng/g.
- Statistical testing is the result of an ANOVA (equivalent to a t-test, when performed with only two groups) conducted on log-transformed individual fish results.

Table G3. Fish Filet Results by CZM Region

Analyte	Boston Harbor (n=6)			Cape Cod and Islands (n=30)			North Shore (n=14)			South Coastal (n=31)			South Shore (n=8)			p
	FOD	Maximum	Median	FOD	Maximum	Median	FOD	Maximum	Median	FOD	Maximum	Median	FOD	Maximum	Median	
PFOS	83.3%	0.800	0.218	46.7%	1.83	<MDL	71.4%	1.75	0.267	61.3%	0.971	0.123	62.5%	1.04	0.157	0.437
PFOSA	100%	0.338	0.201	70.0%	1.96	0.154	78.6%	1.61	0.161	48.4%	1.52	<MDL	100%	1.27	0.355	0.016
PFTrDA	66.7%	0.711	0.101	46.7%	0.522	<MDL	78.6%	0.266	0.128	67.7%	1.91	0.126	37.5%	0.308	<MDL	0.190

- Comparisons between fish filet results across CZM regions were calculated for PFAS detected at 50% or more of waterbodies.
- P-values represent the result of an ANOVA among groups.
- All results are in ng/g.
- ANOVA testing was conducted on log-transformed individual water sample results.

Table G4. Descriptive Statistics for ΣPFAS39 by Species in Fish Filets

Species	Mean Length (mm)	Mean Weight (g)	N	ΣPFAS39
Atlantic bonitos	523.0	1580.8	1	1.78
Atlantic mackerel	301.5	217.2	12	0.744
Bluefish	507.0	1093.8	2	1.68
Black sea bass	350.9	588.1	17	0.277
Cunner	194.3	115.6	3	0.685
Dogfish	754.7	1575.0	5	2.65
Atlantic menhaden	288.5	220.0	2	0.488
Striped bass	457.0	1145.8	8	2.64
Scup	272.9	306.6	20	0.674
Summer flounder	279.2	224.0	6	0.493
Silver hake	271.8	125.6	4	0.524
Skate	298.5	687.5	2	2.75
Sea robin	311.3	375.0	6	2.75
Tautog	283.0	480.8	1	0.0858

- All concentrations are in ng/g.
- ΣPFAS39 excludes non-detect results and NEtFOSE results.
- Results are not weighted by waterbody.

Appendix H: Additional Coastal Shellfish Results

Table H1. Shellfish Results for Select PFAS by Waterbody)

Table H2. Descriptive Statistics for ΣPFAS39 by Species in Shellfish

Table H1. Shellfish Mean Concentrations for Select PFAS by Waterbody

Site Name	Site ID	Species	N	NEtFOSAA	NMeFOSAA	PFDoA	PFHxS	PFOA	PFOS	PFOSA	PFPeA	PFTeDA	PFTrDA	ΣPFAS39
Great Pond-Bournes Pond	6	Q	3	<0.0850	<0.0850	<0.0680	<0.0978	<0.0850	0.103	<0.0850	0.190	<0.0850	<0.0936	0.288
Pine Creek	7	SSC	3	<0.0887	<0.0887	<0.0734	<0.102	<0.0887	<0.0887	<0.0887	<0.177	<0.282	<0.108	0.0970
Annisquam River-Mill River	8	BM	3	<0.0834	<0.0834	0.0672	<0.0959	<0.0834	0.126	0.733	<0.167	<0.0964	<0.0834	1.040
Wareham River	9	Q	3	<0.0826	<0.0826	<0.0661	<0.0950	<0.0826	<0.0826	<0.0826	<0.165	<0.101	<0.0826	0.0327
Plum Island Sound	12	BM	3	<0.0775	<0.0775	<0.0636	<0.0891	<0.0775	<0.0775	0.698	<0.155	<0.143	<0.0869	0.755
Marblehead Harbor-Atlantic Ocean	14	BM	3	<0.0838	<0.0838	<0.0706	<0.0964	<0.0838	0.120	0.381	<0.168	<0.0950	0.0914	0.632
Cape Cod Bay	20	BM	4	<0.0964	<0.0964	<0.0772	<0.111	<0.0964	<0.0964	0.260	<0.193	<0.119	<0.0964	0.300
Plymouth Harbor	21	BM	3	<0.0970	<0.0970	<0.0776	<0.111	<0.0970	<0.0970	0.219	<0.194	<0.0970	<0.105	0.219
Back River - Duxbury Bay	22	Q	3	<0.0799	<0.0799	<0.0639	<0.0919	<0.0799	<0.0799	<0.0799	<0.160	<0.118	<0.0799	0
Cole River	23	Q	3	<0.0904	<0.0904	<0.0723	<0.104	<0.0904	<0.0904	<0.0904	<0.181	<0.107	<0.0904	0.0337
Apponagansett Bay	24	Q	3	<0.0872	<0.0872	<0.0777	<0.100	<0.0872	<0.0872	<0.0872	<0.174	<0.170	<0.0895	0
Little Harbor	25	CW	2	<0.0926	<0.0926	<0.0741	<0.107	<0.0926	<0.0926	<0.0926	<0.185	<0.0963	<0.0926	0
Little Harbor	25	Q	3	<0.0807	<0.0807	<0.0645	<0.0929	<0.0807	<0.0807	<0.0807	<0.161	<0.110	<0.0807	0.0413
Megansett Harbor	26	Q	3	<0.0913	<0.0913	<0.0731	<0.105	<0.0913	<0.0913	<0.0913	<0.183	<0.232	<0.0926	0.0690
Barnstable Harbor	27	BM	3	<0.0946	<0.0946	<0.0757	<0.109	<0.0946	<0.0946	0.173	<0.189	<0.0946	<0.0946	0.215
Rock Harbor Creek	28	Q	4	<0.0883	<0.0883	<0.0706	<0.1014	<0.0883	<0.0883	<0.0883	<0.177	<0.0883	<0.0883	0
Popponesset Bay	29	Q	3	<0.0902	<0.0902	<0.0721	<0.104	<0.0902	<0.0902	<0.0902	<0.180	<0.0902	<0.0902	0.0723
Bass River	30	O	3	<0.0840	<0.0840	<0.0672	<0.0967	<0.0840	<0.0840	0.116	<0.168	<0.148	<0.111	0.148
Westport River	31	O	2	<0.0900	0.252	<0.0720	<0.104	<0.0900	<0.0900	0.847	<0.180	<0.145	<0.124	1.15
Westport River	31	Q	3	<0.0900	<0.0900	<0.0721	<0.104	<0.0900	<0.0900	<0.0900	<0.180	<0.0900	<0.0900	0
Lewis Bay	32	O	3	<0.0956	<0.0956	<0.0765	<0.110	0.109	<0.0956	0.177	<0.191	<0.325	<0.110	0.253
Lewis Bay	32	Q	1	<0.0957	<0.0957	<0.0772	<0.110	0.225	<0.0957	<0.0957	0.706	<0.220	<0.165	0.931
Allen Harbor	33	O	4	<0.0880	<0.0880	<0.0704	<0.101	0.127	<0.0880	0.277	<0.176	<0.377	<0.154	0.461

Site Name	Site ID	Species	N	NEtFOSAA	NMeFOSAA	PFDoA	PFHxS	PFOA	PFOS	PFOSA	PFPeA	PFTeDA	PFTrDA	ΣPFAS39
Buttermilk Bay-Cohasset Narrows	34	Q	3	<0.0934	<0.0934	<0.0761	<0.108	0.0980	<0.0934	<0.0934	<0.187	<0.147	<0.113	0.0817
Mill Creek	35	O	3	<0.0788	<0.0788	<0.0631	<0.0907	<0.0788	<0.0788	0.233	<0.157	<0.247	<0.108	0.258
Mill Creek	35	Q	2	<0.0908	<0.0908	<0.0727	<0.105	0.105	<0.0908	<0.0908	<0.182	<0.122	<0.0908	0.0805
Sesuit Harbor	37	BM	4	<0.0904	<0.0904	<0.0724	<0.104	<0.0904	<0.0904	0.208	<0.181	<0.176	<0.101	0.253
Sesuit Harbor	37	O	1	<0.0858	<0.0858	<0.0725	<0.0987	<0.0858	<0.0858	0.259	<0.172	<0.269	<0.0858	0.259

- MDLs represent the average MDL for each site and species combination for shellfish. In some cases, averages represent the average of detections and non-detection, with MDL/2 used as a substitute for the non-detection. In these cases, if the average result was below the average of the MDLs, the average is reported in the table as <MDL.
- All concentrations are in ng/g.
- ΣPFAS39 excludes non-detect results and NEtFOSE results.
- Data qualifiers are not included for averaged results.
- Q=Quahog; BM=Blue mussel; O=Oyster.

Table H2. Descriptive Statistics for ΣPFAS39 by Species in Shellfish

Species	N	ΣPFAS39
Blue mussel	23	0.469
Channel whelk	2	0
Oyster	16	0.399
Quahog	37	0.0797
Soft shell clam	3	0.0970

- All concentrations are in ng/g.
- ΣPFAS39 excludes non-detect results and NEtFOSE results.
- Results are not weighted by waterbody.

Appendix I: Quality Assurance Program Plan

Available on MassDEP's PFAS in Surface Water and Fish Tissue webpage.

Appendix J: Sampling and Analysis Plan

Available on MassDEP's PFAS in Surface Water and Fish Tissue webpage.

Appendix K: Summary of MassDEP Data Validation Process & Results

Summary of MassDEP Data Validation Process & Results

The following summary provides an overview of the data validation approach, methods[1] and results for the MassDEP 2024/2025 PFAS (per- and polyfluoroalkyl substances) monitoring project investigating PFAS levels at selected freshwater and coastal locations. The data validation decision-making process used by the MassDEP Watershed Planning Program (WPP), in consultation with an external contractor, Eastern Research Group (ERG), resulted in final, quality-assured data suitable for data analysis and decision-making.

Planning for Quality Assurance

Prior to sample collection, a Quality Assurance Project Plan (QAPP) was prepared and approved by MassDEP. A separate Sampling and Analysis Plan (SAP) was also developed to provide a greater level of detail on sampling procedures and logistics. These planning documents provided specific information related to ensuring data quality for both field and laboratory data generated by the Normandeau field team and the SGS-AXYS environmental testing laboratory. This included the SGS-AXYS laboratory SOP for EPA method 1633A for non-potable water and biological tissues.

Field and Lab Qualifications

The project team consisted of MassDEP, ERG, Normandeau Associates, and the SGS-AXYS laboratory. MassDEP and staff from ERG's Environmental and Occupational Health (EOH) unit managed the overall effort. ERG's EOH staff routinely design and oversee environmental sampling programs across all media (i.e., soil, drinking water, groundwater, surface water, sediment, fish, and other biota) and for a broad range of substances, including PFAS. Normandeau staff are experienced in environmental sampling, including fish, shellfish and benthic macroinvertebrates. Normandeau conducted all the field sampling and sample preparation. The SGS-AXYS lab routinely performs analysis of waters, solids, and tissues using state-of-the-art analytical methods. SGS-AXYS developed and finalized the EPA 1633A method following EPA's multi-lab validation procedure. The SGS-AXYS lab is accredited for EPA Method 1633A for the US Department of Defense under QSM 5.4 Table B-24 for all 40 PFAS for water, solids and tissue matrices.

Use of EPA Analytical Method 1633A

Per MassDEP's request, the SGS-AXYS laboratory utilized the final EPA Method 1633A (PFAS by 1633A). Method 1633A is an EPA-developed method to test for 40 PFAS in non-potable water and other matrices, such as solids and tissue. This method employs isotope dilution to achieve lower reporting limits and reduce matrix-

[1] *Data validation approach adapted from Appendix H – Data Review Guidelines for Analysis of PFAS in Non-Potable Waters and Solids of the NYDEC's Sampling, Analysis and Assessment of Per- and Polyfluoroalkyl Substances (PFAS), Under NYSDEC's Part 375 Remedial programs (November 2022).*

influenced bias. The final version of the 1633A method for all eight environmental matrices (wastewater, surface water, groundwater, soil, biosolids, sediment, landfill leachate, and tissue) was published in December 2024 (w/ minimal adjustments).

Overview of Data Validation Approach

In coordination with ERG and following MassDEP's receipt of project field and analytical laboratory data, WPP quality assurance staff reviewed the information as part of the data validation requirement of the project QAPP and with the objective of finalizing the data. This included qualifying or censoring individual datum wherever necessary based on comparison to the data quality objectives contained in the project QAPP and applying the following approach and criteria. These guidelines are applicable to both the non-potable water and tissue (i.e., fish, invertebrates and shellfish) PFAS data and therefore were applied to the review of both water sample and tissue sample analytical PFAS results from the SGS-AXYS laboratory.

The project team's validation of PFAS data included analysis of the following primary deliverables and related materials:

- SGS-AXYS lab SOP for EPA 1633A
- SGS-AXYS lab reports and completed COCs
- SGS-AXYS lab EDDs
- Fieldsheets and fish sample preparation information from the field sampling contractor (Normandeau Associates)
- Master data spreadsheet, sample tracking and crosswalk tables prepared by the lead contractor (ERG)
- ERG data summaries providing periodic preliminary analysis of the field QC sample results (e.g., field blanks, equipment rinsate blanks, field duplicates) results
- Laboratory corrective actions (as needed)
- Project QAPP (for relevant data quality objectives and performance criteria)

General Validation Procedures and Criteria

1. WPP qualifiers were applied as necessary dependent on the QC issue to qualify (usable data with caveat) or censor (not usable data) individual datum based on severity. Standard WPP qualifiers symbols are defined in Tables 1 and 2 below (and differ from the lab qualifiers used; see #3).
2. The data quality objectives for the project as defined in the PFAS project QAPP and in this guidance, both of which are generally consistent with WPP's standard procedures for data validation, were applied when evaluating data quality.
3. Per standard WPP practice, lab qualifiers for lab-reported data are generally carried forward where appropriate for the final data. Due to differences between the

qualifier symbols used by the SGS-AXYS Lab and WPP for the specific issues identified, the symbols were adjusted as necessary while retaining the original meaning, per Table 1 below.

4. If qualifiers have not already been applied by the lab to the related sample results based on identified lab QC issues, best professional judgement (BPJ) was exercised to extend the lab qualification decisions to sample data (for detected and non-detected analytes) in associated sample batches or jobs, if considered appropriate.
5. The following additional, non-analytical WPP data qualifiers are also used if/when applicable (Table 2).

Table 1. Translation table for data qualifiers

ISSUE	SGS-AXYS LAB QUALIFIER	LAB DEFINITION	WPP (FINAL) DATA QUALIFIER	WPP DEFINITION
Holding time violation	H	Sample was prepped or analyzed beyond the specified holding time	h	holding time violation (usually indicating possible bias low)
Lab QC outside acceptance limits	N	Authentic recovery is not within method control limits.	a	accuracy as estimated at SGS-AXYS Lab via matrix spikes, PT sample recoveries, internal check standards and lab-fortified blanks did not meet project data quality objectives for program or QAPP.
Lab QC outside acceptance limits	V	Surrogate recovery is not within method control limits.	a	Same as above.
Lab QC outside acceptance limits	NQ	Data not quantifiable.	a	Same as above.
Between MDL and RL	J	Concentration less than practical limit of quantitation.	j	‘estimated’ value for lab-related issues where certain lab QC criteria are not met. Also, where the sample concentration is less than the ‘reporting’ limit or RDL and greater than the method detection limit or MDL (MDL < x < RDL).

ISSUE	SGS-AXYS LAB QUALIFIER	LAB DEFINITION	WPP (FINAL) DATA QUALIFIER	WPP DEFINITION
Estimated value	K	Peak detected but did not meet quantitation criteria; result reported represents the estimated maximum possible concentration.	j	Same as above.
Blank contamination	B	Analyte found in sample and associated blank.	b	blank contamination in lab reagent blanks and/or field blank samples (indicating possible bias high and false positives).
Duplicate precision (reproducibility)	---	---	d	= precision of field duplicates (or lab duplicates) did not meet project data quality objectives identified for program or in QAPP. Batched samples may also be affected.
Non-detects	U/ND(R)J	Not Detected or analyte found in sample by error	---	No qualifier applied. Less than method reporting limit (MRL) results indicate a sample result that went undetected using a specific analytical method or was detected but the result is less than the allowable reporting limit. The actual, numeric MRL is specified when reporting the results.
Sample-specific information related to validity of results	---	Refer to Case Narrative for further detail	---	Apply appropriate WPP qualifier dependent on case narrative description

Table 2. Additional Potential WPP data qualifiers

ISSUE	WPP (FINAL) DATA QUALIFIER	WPP DEFINITION
Samples improperly preserved or stored prior to analysis	p	samples not preserved per SOP or analytical method requirements.

ISSUE	WPP (FINAL) DATA QUALIFIER	WPP DEFINITION
Field and/or lab method not followed	m	method SOP not followed, only partially implemented or not implemented at all, due to complications with sample matrix (e.g. sediment in sample, floc formation), lab error (e.g. Cross-contamination between samples), additional steps taken by the lab to deal with matrix complications, lost/unanalyzed samples, use of expired reagents and missing data.
Sample representativeness	r	data may not be representative due to circumstances and/or conditions at the time of sampling, including the possibility of "outlier" data

Sample Representativeness

All field sheet metadata for water and tissue (fish, invertebrates and shellfish) samples collected by the Normandeau field crews were reviewed for any notes or comments indicating that the samples may not be representative of "average" conditions (e.g., poorly collected water sample, tissue or water sample taken from an isolated pool, weather-related effects on water sample contents, possible PFAS-contamination of sample, etc.). Apply "r" qualifier as necessary to qualify or censor the data depending on severity.

ISSUE	WPP DECISION FOR SAMPLE DATA
Sample may not be representative of average site conditions	Use professional judgement to qualify (or censor) detects and non-detects with "r" for noted and significant comments related to representativeness

Sample Preservation

Water and tissue samples were generally preserved on ice to a temperature of less than 6°C following collection and then frozen ASAP following surveys and sample preparation. Samples stored in the analytical lab were generally protected from light and held at a temperature of ≤-20°C until extraction (or chilled with a lesser holding time). Apply "p" qualifier as necessary to qualify or censor the data depending on severity.

ISSUE	WPP DECISION FOR SAMPLE DATA
Sample temperature greatly exceeds 6°C at any time at the field lab or analytical lab	Use professional judgement to qualify (or censor) detects and non-detects with "p" for noted and significant preservation problems

Sample Holding Time

Tissue samples were generally extracted within 90 days or as soon as possible. Extracts were generally analyzed within 28 days after extraction. Extracts were stored in the refrigerator. Deviations from required holding time protocols may be cause for data qualification or censoring for affected samples (on a sample-by-sample basis, based on lab jobs/batches, related to field trip samples, and/or other as appropriate). Apply "h" qualifier as necessary to qualify or censor the data depending on severity.

ISSUE	WPP DECISION FOR SAMPLE DATA
Holding time exceeding 90 days (frozen) to extraction and/or 28 days to analysis of extract	Use professional judgement to qualify (or censor) detects and non-detects with "h" if holding time is significantly exceeded

Field and Equipment Blanks

In addition to lab method blanks run by SGS-AXYS, ambient field blank water samples (in the field during water sampling) and equipment rinsate blanks (during tissue sample prep in the field lab) were collected by field crews at 10 percent of the sampled waterbodies to assess the potential for PFAS cross contamination introduced during the sampling and sample preparation process. There should be no detections in any of the blanks above the detection limits. Results for field equipment/rinsate blanks, ambient field blanks, etc. are evaluated to identify detections above the MDLs and RLs. QC results that exceed the upper limits and are associated with non-detect samples are qualified but further narration by the lab was not required since the bias is high and does not change a non-detect result. Further narration was also not required with QC blank detection when the associated sample concentration is non-detect or more than ten times the level in the blank. Apply "b" qualifier as necessary to qualify or censor the data depending on severity and as described below.

BLANK RESULT (WATER)	ASSOCIATED SAMPLE RESULT (WATER OR TISSUE)	WPP DECISION FOR SAMPLE DATA
Any analyte detection (>MDL)	<Reporting limit	Use professional judgement to qualify or censor with "b" for that analyte for samples within the associated lab batch, job, analysis date, collection date, or waterbody
Any analyte detection (>MDL)	>Reporting limit and <10X the blank result	Use professional judgement to qualify or censor (as described above)
Any analyte detection (>MDL)	>Reporting Limit and >10x the blank result	No qualification

Lab Blanks/Method Blanks

For each batch of samples, at a minimum frequency of one per batch, or one per 20 samples for larger sets, analysts evaluated method blanks. No analyte can be detected > ½ LOQ or >1/10th the amount measured in field samples in the batch, whichever is greater. If any results exceeded the laboratory's QA/QC limits, SGS AXYS re-extracted and re-analyzed the affected samples and, when necessary, applied data qualifiers.

BLANK RESULT (WATER)	WPP DECISION FOR SAMPLE DATA
Lab or method blank detected above lab QC limits and reported w/ lab qualifier	Carry forward lab qualifier using professional judgement to qualify or censor with "b" for that analyte for samples within the associated lab batch, job, analysis date, collection date, or waterbody

Field Duplicates

A field duplicate is a second sample collected from the same location at the same time and placed under identical circumstances as the parent field sample, and that is then treated the same throughout laboratory procedures. These QC samples evaluate the reproducibility of results, accounting for potential variability in field collection and laboratory analysis processes. Sequential (i.e., one immediately after the other) field duplicates were collected for surface water samples at approx. About 25 percent of the sampled waterbodies. During fish filet processing, duplicate fish tissue samples were collected at approx. 25 percent of the sampled waterbodies by filleting both sides of the same fish during compositing (parent=all right-side filets; duplicate=all left-side filets). Field duplicate samples were not collected for whole fish, invertebrates, or shellfish (lab and field precision were determined from the field replicate samples [with the exception of shellfish]). For individual duplicate results, if the concentration is ≥ 5 times the MDL, the RPD must be ≤ 40 percent. If the concentration is < 5 times the MDL, RPD must be ≤100 percent. Per WPP convention, the first or prior sequential sample ID # is the sample result, and the second-in-order sample is the duplicate. Apply "d" qualifier as necessary to qualify or censor the data depending on severity and as described below.

ASSOCIATED SAMPLE RESULT	DUPLICATE PAIR RPD	WPP DECISION FOR SAMPLE DATA
≥ 5 times the MDL	<40% RPD	No qualification
≥ 5 times the MDL	>40% RPD	Use professional judgement to qualify or censor with "d" for that analyte for samples within the associated lab batch/job/analysis date/collection date
< 5 times the MDL	<100%RPD	No qualification
< 5 times the MDL	>100%RPD	Use professional judgement to qualify or censor with "d" for that analyte for samples within the associated lab batch/job/analysis date/collection date

Signal to Noise Ratio

Per the SGS-AXYS SOP, the signal to noise (S:N) ratio for the Instrument Sensitivity Check (ISC) must be at least 3:1. No samples can be analyzed until the instrument sensitivity meets acceptance criteria. Apply the "a" qualifier as necessary to qualify or censor the data depending on severity and as described below.

DESCRIPTION IN LAB REPORT	WPP DECISION FOR SAMPLE DATA
Case narrative indicates problems or issues related to the instrumentation sensitivity that did not result in lab qualification	Use professional judgement to qualify detects and non-detects with “a” for noted and significant S/N ratio or other sensitivity problems

Initial Calibration

Per the SGS-AXYS SOP for EPA 1633A, a minimum of six calibration standards is required when using an average or linear curve fit. A minimum of seven calibration standards is required for a second order (quadratic) curve fit. The relative standard deviation (RSD) for all analytes must be less than 20%. Each calibration point is calculated back against the curve. The back calculated concentration for each calibration point should be within ±30% of its true value. A check standard prepared from a second source (ICV) is injected to confirm the validity of the calibration curve/standard. The calculated amount for each analyte must be within ±30% of the true value. Apply the “a” qualifier as necessary to qualify or censor the data depending on severity and as described below.

DESCRIPTION IN LAB REPORT	WPP DECISION FOR SAMPLE DATA
Lab data qualified with “E”	Carry lab qualifier forward for subject analyte(s) associated with the same batch/job/analysis date and translate to WPP qualifier using “a” for non-detects and detects
Case narrative indicates problems or issues related to calibration that did not result in lab qualification	Use professional judgement to qualify detects and non-detects with “a” for noted and significant calibration problems

Continuing Calibration Verification

Per the SGS-AXYS SOP for EPA 1633A, continuing calibration verification (CCV) checks should be analyzed at a frequency of one per 10 field samples. The calculated amount for each compound (native and surrogate standard concentrations) in the CCV standard must be within ±30% of the true value. Samples that are not bracketed by acceptable CCV analyses must be reanalyzed. The exception to this would be if the CCV recoveries are high, indicating increased sensitivity, and there are no positive detections in the associated samples, the data may be reported with a qualifying comment. Recovery standard analyte concentrations must be within 50-200% of their true value. Ion ratios must be within 50-150% of the ratios determined from I-CAL CAL E. If the CCV criterion is not met, an instrument re-calibration is performed. The absolute areas of the injection internal standards should be greater than 30% of the average areas measured during the initial calibration. Apply the “a” qualifier as necessary to qualify or censor the data depending on severity and as described below.

DESCRIPTION IN LAB REPORT	WPP DECISION FOR SAMPLE DATA
Lab data qualified with “E”	Carry lab qualifier forward for subject analyte(s) associated with the same batch/job/analysis date and translate to WPP qualifier using “a” for non-detects and detects
Case narrative indicates problems or issues related to calibration that did not result in lab qualification	Use professional judgement to qualify detects and non-detects with “a” for noted and significant calibration problems

Lab Control Sample/Lab Control Sample Duplicate

Lab control samples and spikes (LCS/LCSD) should be analyzed with each extraction batch or one for every twenty samples. The LCS should contain all compounds of interest. Analyte recoveries should be between 46% - 161% (water samples) and 10% - 300% (tissue samples) (SGS-AXYS SOP acceptance limits). Apply the “a” qualifier as necessary to qualify or censor the data depending on severity and as described below.

DESCRIPTION IN LAB REPORT	WPP DECISION FOR SAMPLE DATA
Lab data qualified with “ *+ ”	Carry lab qualifier forward for subject analyte(s) associated with the same batch/job/analysis date and translate to WPP qualifier using “a” for non-detects and detects
Case narrative and/or lab QC data indicate problems or issues related to the LCS/LCSD that did not result in lab qualification	Use professional judgement to qualify detects and non-detects with “a” for noted and significant LCS/LCSD problems

Matrix Spike/Matrix Spike Duplicate

One matrix spike (MS) and matrix spike duplicate (MSD) should be collected at a rate of one per twenty samples. Analyte recoveries should be between 46% - 161% (water samples) and 10-300% (tissue samples) (SGS-AXYS SOP acceptance limits). Apply the “a” qualifier as necessary to qualify or censor the data depending on severity and as described below.

DESCRIPTION IN LAB REPORT	WPP DECISION FOR SAMPLE DATA
Case narrative and/or lab QC data indicate problems or issues related to the MS/MSD that did not result in lab qualification	Use professional judgement to qualify detects and non-detects with “a” for noted and significant MS/MSD problems

Extracted Internal Standards (Isotope Dilution Analytes)

Analyte recoveries for extracted internal standards (EIS) should be between 70% - 130% (SGS-AXYS SOP acceptance limits). Per SGS-AXYS standard practice, surrogate and/or isotope dilution analyte recoveries (if applicable) which are outside of the QC window are confirmed unless attributed to a dilution or otherwise noted in the narrative. Apply the “a” qualifier as necessary to qualify or censor the data depending on severity and as described below.

DESCRIPTION IN LAB REPORT	WPP DECISION FOR SAMPLE DATA
Lab data qualified with " *5+ " (high bias) or " *5- " (low bias), indicating >150% or <20%, respectively.	Carry lab qualifier forward for subject analyte(s) associated with the same batch/job/analysis date and translate to WPP qualifier using "a" for non-detects and detects
Case narrative and/or lab QC data indicate problems or issues related to the EIS or the non-extracted internal standards (NIS) that did not result in lab qualification	Use professional judgement to qualify detects and non-detects with "a" for noted and significant EIS/NIS problems

Estimated Results

Per the SGS-AXYS SOP, data reported as estimated maximum possible concentrations due to detected but unquantifiable peak are qualified with "K". Apply the "j" qualifier as necessary to qualify or censor the data depending on severity and as described below.

DESCRIPTION IN LAB REPORT	WPP DECISION FOR SAMPLE DATA
Lab data qualified with " K "	Carry lab qualifier forward for subject analyte(s) associated with the same batch/job/analysis date and translate to WPP qualifier using "j" for non-detects and detects

Results Between the MDL and RL

Per the SGS-AXYS SOP, data values between the Method Detection Limit (MDL) and the Reporting Limit (RL) are reported with the "J" qualifier. Apply the "j" qualifier as described below. [Note: for "<MDL" results qualified by the lab with "U", no WPP qualifier is applied.]

DESCRIPTION IN LAB REPORT	WPP DECISION FOR SAMPLE DATA
Lab data qualified with " J "	Carry lab qualifier forward for subject analyte(s) associated with the same batch/job/analysis date and translate to WPP qualifier using "j".

Performance Evaluation Samples

Performance evaluation (PE) of SGS-AXYS lab results for QC samples (water matrix) prepared by MassDEP using purchased Certified Reference Material, CRM (ERA, Golden, CO) and submitted to the lab double-blind (i.e., as regular samples) was completed. Purchased CRM was diluted to three levels (1/20, 1/10 and 1/5) and prepared in duplicate by an organic chemist at the MassDEP Wall Experiment Station (WES) lab. Reagent water blanks were also submitted to the lab. Aqueous PE samples were kept frozen following preparation until analysis. Estimates of accuracy (as % recovery) and precision (as Relative Percent Difference, RPD) were compared to typical data quality objectives for organic chemistry analyses (e.g., % recoveries 60-140%; RPDs <30%) as specified in the project QAPP.

LAB RESULT	WPP DECISION FOR SAMPLE DATA
Lab data for PE samples show consistent bias or inaccuracy for specific analyte(s), in comparison to "true" values for diluted CRM.	Similar to the evaluation of internal lab QC results for accuracy and precision, use BPJ to qualify or censor sample results for one or more analytes using "a".
Lab data for PE samples show poor duplicate precision for specific analyte(s).	Use BPJ to qualify or censor sample results for one or more analytes using "a" (poor lab accuracy/precision).

Overall Results of Project Data Quality Review

Overall Conclusion

The project sampling and analyses generated a total of 2640 individual analyte results for water quality and 9680 individual analyte results for tissue (fish, invertebrates and shellfish). Based on the analysis of field QC and laboratory QC results, and with minor exceptions as noted below, the project data collected for both water and tissue are considered valid and usable for decision-making. With one exception, MassDEP determined that all project data are acceptable (i.e., with and without qualification) for decision-making. The one exception was that all NEtFOSE results in tissue below a concentration of 20 ng/g were censored and removed from the final data analysis. This analyte exhibited blank sample interference in the tissue matrix, resulting in unreliable low-level results. The same did not occur with surface water NEtFOSE analyses. By WPP convention, any qualified data are considered usable for decision-making, albeit with general caveat to the data user. Censored data, however, should not be used.

Sample Precision

To evaluate repeatability of sampling results, field duplicates for both water and tissue were collected at an approx. frequency of 25% of sites. Relative percent difference (RPD) between parent and duplicate sample results was evaluated against measurement performance criteria in the QAPP.

For water samples, a total of 14 individual analyte sample results were qualified and one individual analyte sample result was censored. For fish tissue samples, a total of 24 individual analyte sample results were qualified. Most of the qualifications for both water and tissue were for PFOS.

Sample Cross-Contamination

To evaluate the potential for sample contamination and cross-contamination between samples, field blanks (water) and equipment rinsate blanks (tissue; de-ionized PFAS-free water used to rinse equipment when processing the tissue samples) were collected at an approx. frequency of 10% of sites. For blanks, WPP's Barnstead reagent DIW system was initially tested and found to be PFAS-free and a suitable source for use in preparing blank QC samples throughout the project. Any detected PFAS in blanks were flagged and associated sample results qualified as indicated in the criteria above and per the data quality objectives in the QAPP.

For water samples, only 3 individual analyte sample results were qualified due to blank results. For fish tissue samples, a total of 36 individual analyte sample results were qualified. Most of the qualifications for fish tissue were for PFOS.

Sample Bias/Accuracy and Analytical Precision (including Holding Time violations)

To evaluate the accuracy and precision of laboratory analyses, the lab reports were reviewed to verify internal lab quality control sampling was performed, to assess any exceedances of lab acceptance limits and to examine the case narratives for information related to the validity of results that may not have been flagged via the lab qualifiers applied to individual samples. As part of this review, questions were clarified by the lab (and revised lab reports reissued as needed) prior to data finalization.

For water samples, a total of 236 individual analyte sample results were qualified due lab-related QC results (as flagged by the lab). For fish tissue samples, a total of 989 individual analyte sample results were qualified due lab-related QC results (as flagged by the lab), including 240 results for holding time violations (i.e., >90 days). No additional qualifiers were needed for both water and fish tissue results, based on project data validation review, and no samples were censored based on laboratory QC results.

Corrective Actions

No corrective actions related to sample collection, pre-processing, storage, delivery, processing, or laboratory analysis were necessary during the project.

Performance Evaluation

For double-blind QC samples containing diluted reference material for 40 PFAS analytes that were submitted to the lab, the results were generally acceptable and met expectations for data quality (accuracy and precision). Both of the reagent water blank samples were "<MDL" for all 40 analytes. For each dilution (1/20, 1/10 and 1/5) series, the results for each analyte were acceptable with percent recoveries between 60-140% and duplicate RPDs <30%, with minor exception. Exceptions included poor percent recoveries and precision for NEtFOSA, NEtFOSE, NMeFOSA, NMeFOSE, and PFDoS at all dilution levels. Conversion of certain perfluoro sulfonamide, sulfonamide ethanols and sulfonic acids has been observed after 7 days without freezing. For example, NMeFOSE and NEtFOSE may undergo transformation to NMeFOSAA and NEtFOSAA respectively when stored at 0 - 6 ºC, but not when stored at or below -20 ºC. Poor recoveries of NMeFOSE, NEtFOSA, NMeFOSA, PFDoS and NEtFOSE in PE samples submitted to the lab could be explained by degradation when thawed and returned to the aqueous state prior to analysis

(PE samples were kept frozen following preparation at MassDEP's Wall Experiment Station laboratory until analysis at the SGS-AXYS laboratory). Non-frozen conditions are even more likely in real samples (e.g., following collection in the field prior to storing frozen before transport/shipping). Regardless of the cause for poor recovery, these five analytes were qualified for all water and tissue samples.

The NEtFOSE exhibited blank sample interference in the tissue matrix, resulting in unreliable low-level results. The same did not occur with surface water NEtFOSE analyses. All NEtFOSE results in tissue below a concentration of 20 ng/g were censored and removed from the final data analysis.

Sample Representativeness

To evaluate any anomalies that may have affected sample representativeness, sample metadata including fieldsheets, COC records and related documentation were reviewed and corrections made as needed. Based on this review, no sample results were qualified or censored due to unrepresentativeness.

Outliers

To evaluate if any PFAS values might be unusually high or larger than expected, the full dataset was reviewed to identify any potential outliers that could be considered invalid and not appropriate for further data analyses. The highest observed water analyte result was 66.4 ng/l (PFOS, Studley Pond; within range of other surface water results observed in freshwater and coastal waters). The maximum tissue result was 658 ng/g (PFOS, Studley Pond) with 4 other PFOS/7:3 FTCA results ranging from 548-272 ng/g (mostly in Studley Pond). The elevated levels of PFAS at Studleys Pond likely trace back to the former South Weymouth Naval Air Station's past use of AFFF. The site, active from 1944 to 1997, is now an EPA Superfund location. Based on this non-statistical review, no outlier values were identified.

Data Management and Reporting

Final decisions on data censoring or qualification were added to the master data spreadsheet using a unique project qualifier field (*ProjectQual* column), in addition to the laboratory qualifier (*Lab Qual* column). Each project qualifier that was added was explained in the *ResComm* field (column). All project qualifiers applied during validation will be included in the batch upload to the WPP EQuIS database. By standard practice, project qualifiers are attached to results and are included with the numeric results in any/all WPP data presentations.

Appendix L: Project Fact Sheet – Freshwater

Available on MassDEP's PFAS in Surface Water and Fish Tissue webpage

Appendix M: Project Fact Sheet – Coastal

Available on MassDEP's PFAS in Surface Water and Fish Tissue webpage