PFAS Concentrations in Surface Water and Fish Tissue at Selected Rivers and Lakes in Massachusetts

Prepared for:
Watershed Planning Program
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ACRONYMS AND ABBREVIATIONS

AFFF	aqueous film forming foam
BAF	bioaccumulation factor
cFAL	candidate Fish Action Level
CMC	Criterion Maximum Concentration
DIW	Deionized water
DoD	U.S. Department of Defense
DQO	data quality objective
EJ	environmental justice
EPA	U.S. Environmental Protection Agency
ERG	Eastern Research Group, Inc.
Eurofins	Eurofins Lancaster Laboratories Environment Testing
EQuIS	Environmental Quality Information System
FOD	frequency of detect
g	gram
JBCC	Joint Base Cape Cod
kg	kilogram
KYDEP	Kentucky Department of Environmental Protection
L	liter
LC-MS/MS	liquid chromatography tandem mass spectrometry
MassDEP	Massachusetts Department of Environmental Protection
MassWildlife	Massachusetts Division of Fisheries and Wildlife
MDCR	Massachusetts Department of Conservation and Recreation
MDPH	Massachusetts Department of Public Health
MCL	maximum contaminant level
MDL	method detection limit
mL	milliliter
mm	millimeter
MPCA	Minnesota Pollution Control Agency
NCCA	National Coastal Condition Assessment
ND	Non-detect
NHDES	New Hampshire Department of Environmental Services
NJDEP	New Jersey Department of Environmental Protection
Normandeau	Normandeau Associates, Inc.
NRSA	National Rivers and Streams Assessment
ng	nanogram
ORS	MassDEP Office of Research and Standards
ρ	Spearman rank correlation coefficient
PFAS	per- and polyfluoroalkyl substances
PFCA	perfluoroalkyl carboxylic acid
PFSA	perfluoroalkyl sulfonic acid
PG	PG Environmental
ppb	Part per billion (equivalent to ng/g)
ppt	Part per trillion (equivalent to ng/L)
QA	quality assurance
QAPP	quality assurance project plan

QC	quality control
RL	reporting limit
RPD	relative percent difference
SAP	sampling and analysis plan
SD	standard deviation
SERDP	Strategic Environmental Research and Development Program
SOP	standard operating procedure
TOF	Total Organic Fluorine
TOP	Total Oxidizable Precursors
USGS	U.S. Geological Survey
VTDEC	Vermont Department of Environmental Conservation
WIDNR	Wisconsin Department of Natural Resources
WPP	Watershed Planning Program
Σ	Sigma/Sum
<	Less than
>	Greater than
%	percent
/	per
ΣPFAS40	sum of all 40 PFAS that the laboratory measured
PFAS6	sum of PFOS, PFOA, PFHxS, PFNA, PFHpA, and PFDA

EXECUTIVE SUMMARY

Per- and polyfluoroalkyl substances (PFAS) are a large class of fluorinated synthetic chemicals that tend to break down slowly and can accumulate in humans, wildlife, and the environment. They are highly persistent and toxic and have been found in numerous drinking water supplies, as well as in fish tissue and other environmental media. In response, environmental and public health agencies across the country and at all government levels have been investigating the nature and extent of PFAS contamination and its effects on human health and the environment.

In the ongoing effort to better understand the environmental burden and human exposure to PFAS in Massachusetts, the Watershed Planning Program (WPP) within the Massachusetts Department of Environmental Protection (MassDEP) funded a study to characterize PFAS concentrations in surface water and edible tissue of commonly consumed freshwater fish from lakes, ponds, and rivers across the state. A secondary objective of the study was to characterize bioaccumulation of PFAS in fish. An additional secondary objective was to use fish tissue sampling data to inform fish consumption use, including human health risk and potential for setting advisories by data sharing with other agencies.

In the summer and fall of 2022, surface water and fish tissue samples were collected from 52 waterbodies throughout the state. While these efforts focused on waterbodies near known or suspected sources of PFAS and were therefore expected to have high levels of PFAS contamination, samples were also collected at six waterbodies in rural areas for comparison, referred to here as “reference” waterbodies. Co-located fish and surface water samples were collected at each waterbody, and additional surface water samples were collected at a subset of waterbodies near beach swimming areas. A maximum of 45 fish were collected at each waterbody, per the Scientific Collection Permit issued by the Massachusetts Division of Fisheries and Wildlife (MassWildlife). At lakes and ponds, up to three fish species were sampled, while at rivers and streams, up to two fish species were sampled. Skin-off fillets were prepared from each fish and combined into composite samples containing tissue from up to five similarly sized fish from the same waterbody and of the same species. In total, 66 surface water and 242 fish tissue composite samples (comprised of 948 fish) were analyzed for 40 PFAS using the draft EPA Method 1633. The sampling results were evaluated against the project’s data quality objectives (DQOs) contained in the Quality Assurance Project Plan (QAPP) and were validated by MassDEP.

Using the validated final data, descriptive statistics were calculated for surface water and fish tissue samples across waterbodies by PFAS analyte. Weighted statistics were used for fish tissue, with weights equal to the number of individual fish within a composite sample. Differences in PFAS concentrations were also explored for several variables, including type of waterbody (source-impacted or reference), proximity to environmental justice (EJ) census blocks, MassDEP-designated regions, and waterbody type (lakes and ponds versus rivers). Results are shown for individual PFAS analytes, as well as for the sum of detected concentrations for all 40 PFAS measured by the laboratory (ΣPFAS40) and the sum of detected results for the six PFAS analytes regulated in public drinking water sources in Massachusetts (i.e., PFOS, PFOA, PFHxS, PFNA, PFHpA, and PFDA – referred to here as PFAS6). Correlation was investigated between PFAS analytes within each media and across media, as well as between water samples collected at beach and open water locations within the same waterbody. Bioaccumulation factors (BAFs) were calculated for PFAS analytes detected in fish tissue, with a focus on the most frequently caught species (i.e., bluegill, pumpkinseed, yellow perch, and largemouth bass).

<u>Surface Water Results</u>

All waterbodies had detectable levels of at least two PFAS compounds in surface water. PFOA was detected in all waterbodies and at the highest concentrations, with a median concentration of 5.70

nanograms per liter (ng/L). PFOA contributed, on average, 27% of the ΣPFAS40 measured in surface water. Most waterbodies (80%) also had detectable concentrations of PFBS, PFHpA, and PFOS. The highest surface water concentrations of PFAS were observed at Ashumet Pond (ΣPFAS40 of 467 ng/L) and Studley Pond (ΣPFAS40 of 396 ng/L). Pelham Lake, which was selected for sampling as a reference waterbody, had the lowest ΣPFAS40 concentration (Σ2.15 ng/L). PFAS concentrations in surface water were not significantly different by proximity to EJ census tracts or by waterbody type. However, they were significantly higher in source-impacted waterbodies compared to reference waterbodies and in certain MassDEP regions.

None of the waterbodies had PFOA or PFOS concentrations in surface water approaching or exceeding EPA's draft recommended acute freshwater aquatic life ambient water quality criteria for PFOA and PFOS of 49 mg/L and 3.0 mg/L, respectively. Similarly, none of the waterbodies had surface water PFOA or PFOS concentrations approaching EPA's draft recommended chronic freshwater aquatic life ambient water quality criteria (0.094 mg/L and 0.0084 mg/L, respectively).

In relation to health-based criteria, 18 of the 52 waterbodies had PFAS6 concentrations above 20 ng/L, at which the Massachusetts Department of Public Health (MDPH) recommends public notification of the presence of PFAS confirmed by at least two rounds of sampling at permitted bathing beaches per the agency's draft Bathing Beach Operational PFAS Guidance (MDPH, interagency communication, September 2023). However, of these 18 waterbodies, only three included the collection of samples at permitted bathing beaches (in addition to open water locations). Samples not collected at permitted bathing beach locations are not subject to MDPH's Guidance. Beach samples (taken at locations representative of the point of exposure when bathing) collected at Crocker Pond (Westminster), Lake Cochituate (Natick), and Falls Pond (North Attleborough) had PFAS6 concentrations of 50 ng/l, 25 ng/l and 22 ng/l, respectively. One other waterbody with a permitted bathing beach, Nutting Lake (Billerica), also had PFAS6 concentrations above 20 ng/L. However, samples were not collected at the permitted bathing beach. While two waterbodies (Studley Pond in Rockland and Ashumet Pond in Mashpee) had concentrations of PFAS6 exceeding the Public Beach Action Level of 90 ng/L, these waterbodies do not warrant site-specific evaluation since Studley Pond does not have a permitted bathing beach and the PFAS samples at Ashumet Pond were not collected at the permitted bathing beach. Per the MDPH Guidance, confirmatory sampling at all aforementioned waterbodies except for Studley Pond is warranted to support future decision making for these permitted bathing beaches.

Fish Tissue Results

Similarly, all waterbodies had detectable levels of PFAS in at least one fish tissue composite sample that was analyzed. PFOS was detected in 99% of composite fish tissue samples and in at least one sample from each waterbody, including reference waterbodies. PFOS was also detected at the highest concentrations of all PFAS analytes in fish tissue, with a median concentration of 5.70 ng/g. Mirroring the surface water results, the highest summed PFAS concentrations in fish tissue were detected in Ashumet Pond (average ΣPFAS40 of 194.2 ng/g) and Studley Pond (average ΣPFAS40 of 109.0 ng/g). Within fish species, ΣPFAS40 varied considerably across waterbodies. However, within a waterbody, the profile of PFAS analytes was similar across species. PFAS concentrations were significantly higher in source-impacted waterbodies than in reference waterbodies, and they also exhibited significant differences across MassDEP regions. Concentrations did not differ significantly based on proximity to EJ census blocks or by waterbody type. ΣPFAS40 and PFAS6 concentrations in fish tissue were moderately correlated with concentrations of the same compounds in surface water samples from the same waterbody. In other words, where summed PFAS were high in surface water, summed PFAS were also high in fish tissue.

None of the fish tissue composite samples had concentrations above EPA's draft recommended aquatic life ambient water quality criteria for PFOA and PFOS in fish tissue muscle (125 ng/g and 2,910 ng/g, respectively). With respect to human health, at all 47 waterbodies where fish were collected, PFOS was detected in at least one composite sample at a concentration greater than MDPH's draft candidate Fish Action Level (cFAL) of 0.22 ng/g. In several waterbodies, PFOS concentrations were measured at concentrations that are approximately three orders of magnitude higher than this level.

The sampling data allowed for estimation of BAFs for different fish species and PFAS. For PFNA, estimated BAFs ranged from 1.88 log (liters per kilogram [L/kg]) for bluegill to 2.16 log (L/kg) for yellow perch, which is consistent with results reported in other studies and in the peer-reviewed literature. BAFs for PFOS ranged from 3.16 log(L/kg) for yellow perch to 3.45 log(L/kg), which is also consistent with results from other studies. The higher estimated BAFs for PFOS suggest a greater propensity for bioaccumulation.

Conclusions

The results of this study characterize the environmental burden and human exposure to PFAS in Massachusetts at targeted waterbodies selected based on the presence or absence of known or suspected contamination, with priority given to waterbodies with high fishing pressure and proximity to EJ communities. The descriptive statistics presented throughout this report pertain to PFAS contamination levels in the waterbodies sampled. One should not infer that these statistics represent average conditions in Massachusetts, because the study design did not involve randomized site selection of a statistical sampling population.

Although limited to freshwaters, findings from this study add to the growing body of evidence that PFAS are ubiquitous in the environment. PFAS were detected in all sampled waterbodies, including those in rural areas that are far from any known or suspected sources of PFAS contamination. However, the range of PFAS contamination found varied widely in both fish tissue and surface water. The PFAS analytes driving ΣPFAS40 concentrations also differed across media, with PFOA having the highest concentrations in surface water and PFOS having the highest concentrations in fish tissue. As expected, significant differences were found in concentrations of PFAS in water and fish tissue between reference (lower PFAS) and source-impacted (higher PFAS) areas and by region. Significant differences were not seen by waterbody type (lakes and ponds versus rivers) or proximity to EJ communities.

As found in many other states and countries, levels of PFAS contamination in surface water and fish tissue from freshwater waterbodies in Massachusetts continue to be of concern for human health and the environment. While PFOA and PFOS concentrations in surface waters and fish tissue were far below draft recommended EPA criteria for aquatic life, the immediate risk appears to be to human health from consuming fish with tissue concentrations exceeding MDPH's draft cFAL. Nearly all waterbodies had levels of PFAS in fish tissue that warrant further evaluation by MDPH on the necessity of fish consumption advisories. Additionally, some waterbodies had levels of PFAS in surface water (open water and beach locations) that may warrant confirmatory sampling at permitted bathing beaches and further evaluation by MDPH to determine the safety of recreational water use. Additionally, several of the waterbodies identified as potential sources of drinking water had ambient PFAS levels above MA standards and/or EPA's proposed standards for drinking water.

While this study answered many questions and generated a robust dataset on PFAS in freshwater fish and waterbodies across the state, it identified several data gaps. Possible areas for future WPP investigation may include a study to characterize PFAS in whole body freshwater fish and invertebrates; a study to characterize PFAS in brackish and saltwater areas; further investigation into PFAS in stocked

versus native trout; repeat monitoring to better understand temporal variability and improve comparisons to chronic aquatic life water quality criteria; analysis of samples for total oxidizable precursors (TOP) and/or total organic fluorine (TOF) as a better measure of “total” PFAS levels; and incorporating an interlaboratory study into future monitoring efforts to gather additional insight into laboratory data comparability and precision.

1.0 INTRODUCTION

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 overall goal of the project was to assess the occurrence and magnitude of PFAS in surface water and edible tissue of freshwater fish from lakes and rivers throughout the Commonwealth. To achieve that goal, samples were collected from over 50 waterbodies across the state, with a focus on those expected to have high levels of PFAS contamination. Sampling occurred in the summer and fall of 2022, and samples were analyzed for 40 unique PFAS analytes. This report summarizes the study design, sampling and analysis methods, and analytical results from the study.

The project team consisted of MassDEP, Eastern Research Group, Inc. (ERG), PG Environmental (PG), Normandeau Associates, Inc. (Normandeau), and the Eurofins Lancaster Laboratories Environment Testing (Eurofins). MassDEP and ERG managed the overall effort, PG assisted with the sampling design and sample processing protocol, and Normandeau conducted the field sampling and sample preparation. Eurofins analyzed the samples for PFAS using draft EPA Method 1633. Additionally, and as needed throughout the project period, WPP staff from MassDEP sought input from the department's Office of Research and Standards (ORS) and its environmental laboratory, Wall Experiment Station. MassDEP also consulted with state agency partners (i.e., MDPH, MassWildlife) on project details.

In addition to this report, information from the study and supplemental files is accessible on MassDEP's project website (https://www.mass.gov/info-details/pfas-in-surface-water-and-fish-tissue), which contains the following files:

- 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 resulting data are of a known and documented quality. It covers project management, schedule, goals and 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 (Appendix D of this report).
- Sampling and Analysis Plan (SAP): A document providing a greater level of detail on sampling procedures and logistics (Appendix E of this report).
- Analytical Results: A downloadable file with surface water analytical results, fish tissue analytical results, and relevant field data.
- PowerPoint presentation: A PDF with PowerPoint slides summarizing key findings.

The remainder of this report describes study methods and results. Section 2.0 provides general background information on PFAS and an overview of related prior studies, and Section 3.0 describes the study design. While Section 3.0 provides an overview of the sampling and analysis methods, the QAPP and SAP have further details. Section 4.0 summarizes the surface water and fish tissue analytical results and identifies limitations. Section 5.0 presents conclusions and recommendations for future work. References are documented in Section 6.0.

2.0 BACKGROUND

PFAS are a large class of fluorinated synthetic chemicals that have been widely used for decades to make consumer products that are resistant to water, grease, and strains (e.g., paper food packaging, non-stick cookware, textiles). The chemicals are also used in industrial processes and certain firefighting foams (e.g., aqueous film forming foam – AFFF). PFAS are a nationwide concern due to their toxicity and persistence in the environment. They have been found in numerous drinking water supplies, including many in Massachusetts; and the Centers for Disease Control and Prevention has reported that 98% of Americans have PFAS in their blood (CDC, 2023). Among the thousands of PFAS compounds, perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) are the most widely studied of these chemicals.

PFAS in surface water may originate from contaminated groundwater, stormwater runoff, or direct pollutant discharges, such as those from industrial facilities, landfills, or wastewater treatment plants. PFAS may also settle onto surface water from atmospheric deposition from local sources or through long range transport. Human exposure to PFAS in lakes, ponds, and rivers may occur from using the water as a drinking water source; dermal contact or incidental ingestion of the water during recreational activities such as swimming; or through fish consumption. Some PFAS are known to accumulate in fish and have been detected in freshwater fish tissue in many studies. PFAS also pose ecological concerns. Elevated concentrations of PFOA and PFOS in aquatic ecosystems can affect the growth and reproduction of aquatic organisms, and result in death. (EPA, 2022b).

In recent years, environmental and public health agencies at all government levels have investigated the nature and extent of PFAS contamination across environmental media and its effects on human health and the environment. At the federal level, the U.S. Environmental Protection Agency (EPA) proposed a National Primary Drinking Water Regulation in March of 2023 to establish legally enforceable levels (i.e., Maximum Contaminant Levels [MCLs]) for the following six PFAS in drinking water (EPA, 2023):

- PFOA
- PFOS
- Perfluorononanoic acid (PFNA)
- Hexafluoropropylene oxide dimer acid (HFPO-DA, also referred to as GenX Chemicals)
- Perfluorohexane sulfonic acid (PFHxS)
- Perfluorobutane sulfonic acid (PFBS)

In 2022, EPA released draft aquatic life ambient water quality criteria for PFOA and PFOS, reflecting the latest scientific knowledge on the effects of these chemicals on freshwater organisms (EPA 2022a). EPA's draft recommendations include acute and chronic criteria for freshwater as well as instantaneous criteria expressed as tissue-based concentrations to protect aquatic life from bioaccumulation. States will have the option of adopting either EPA's final criteria recommendations (anticipated late 2023) into their water quality standards or other scientifically defensible criteria based on local or site-specific conditions (EPA, 2022a).

In Massachusetts, state agencies have sought to characterize PFAS contamination and mitigate exposure through a combination of monitoring and regulatory efforts. In 2020, MassDEP published a drinking water standard (i.e., Massachusetts Maximum Contaminant Levels [MMCLs]) for the sum of six PFAS (i.e., PFOS, PFOA, PFHxS, PFNA, PFHpA, and PFDA) (MassDEP, 2020) in public drinking water supplies. MDPH has developed draft Operational Beach Guidance that includes health-based screening criteria for the same six PFAS compounds in recreational surface waters *(*MDPH, interagency communication, September 2023*).* If the sum of the six compounds exceeds 500 ng/L in surface water, MDPH

recommends no swimming; and if the sum ranges between 90 and 500 ng/L, MDPH initiates a site-specific evaluation. If the sum is between 20 ng/L and 90 ng/L, swimming may continue but a notice about the presence of PFAS should be posted. For fish tissue, MDPH compares individual concentrations of seven PFAS (i.e., PFBS, PFHxS, PFOA, PFOS, PFNA, GenX, and PFBA) to its cFAL of 0.22 ng/g to determine whether fish advisories may be warranted. In addition to these activities, MassDEP (in collaboration with the United States Geological Survey [USGS]) and MDPH have conducted separate studies to characterize PFAS in riverine surface water and fish tissue, respectively. These efforts are described briefly in Section 2.2 and incorporated into Section 4.0.

Other states have also developed surface water and/or fish tissue screening levels and guidelines for PFAS. These state activities, in combination with the federal activities mentioned above, are driven by data obtained from studies evaluating PFAS across different environmental media. A complete review of the regulatory and advisory frameworks of other agencies is beyond the scope of this study, but several examples of surface water quality initiatives in other states provide a brief, representative snapshot of the enormity of the PFAS problem:

- The Minnesota Pollution Control Agency and Wisconsin Department of Natural Resources (MPCA, 2023; WIDNR 2022) have developed water quality criteria for PFOS protective of fish consumption.
- The Great Lakes Consortium, Michigan Department of Health and Human Services, Maryland Department of the Environment, Connecticut Department of Public Health, Maine Centers for Disease Control and Prevention, New Jersey Department of Environmental Protection, and Kentucky Department for Environmental Protection have developed PFAS screening levels and/or fish advisories (Great Lakes Consortium, 2019; Maine CDC, 2022; NJDEP, 2018; KYDEP, 2022; MDHHS, 2016; CT DPH, 2018; MDE, 2021).

2.1 Prior Related PFAS studies

PFAS were first manufactured in the 1950s and gained widespread industrial and commercial use due to their stain-resistant, water-resistant, flame-retardant, and non-stick properties. Over the past 70 years, PFAS have accumulated in the environment, drinking water sources, and humans (MassDEP 2023). Today PFAS contamination is a topic of growing scientific interest and public concern. In this section, we describe recent studies of PFAS in fish and surface water across the U.S., as well as in Massachusetts.

Several national surveys have aimed to establish the extent of PFAS contamination in fish in the continental U.S. For example, during the 2013-2014 and 2018-2019 National Rivers and Streams Assessments (NRSA), EPA measured concentrations of 13 different PFAS compounds in fish tissue samples collected at nearly 500 different locations (Stahl et al., 2023). As part of the National Coastal Condition Assessment (NCCA) 2015 Great Lakes Human Health Fish Fillet Tissue Study, EPA quantified concentrations of the same set of 13 PFAS in fish tissue at 152 sites along the U.S. shoreline of the Great Lakes (EPA, 2023). Across these three surveys, which looked at thousands of fish divided into nearly 800 composite samples, only 15 samples had no detectable PFAS (Stahl et al., 2023; Barbo et al., 2023). Furthermore, Barbo et al. (2023), who analyzed data from both the 2015 Great Lakes Human Health Fish Fillet Tissue Study and 2013-2014 NRSA, reported a median summed PFAS concentration of 9.5 ng/g in fish tissue, leading authors to conclude that consuming freshwater fish is likely a significant source of exposure, especially for individuals who rely on subsistence fishing.

Due to the potential human health and ecological concerns, several states have also initiated their own fish sampling efforts. For example, Wisconsin was one of the first states to monitor PFAS in fish tissue. From 2006 to 2012, WI DNR quantified 17 PFAS in fish collected from Lake Superior, Lake Michigan, and

seven inland river systems, including the Mississippi River (WIDNR, 2019). Several New England states have also conducted exploratory studies. For example, in 2020, the New Hampshire Department of Environmental Services (NHDES) conducted a baseline study of PFAS in fish, surface water, and sediment at 12 target and two reference lakes in New Hampshire (NHDES, 2021). In 2021, the Vermont Department of Environmental Conservation (VTDEC) monitored PFAS in surface water at 19 sites, quantifying PFAS in fish tissue at eight of those sites as well as the effluents and locations upstream and downstream of three nearby wastewater treatment facilities (VTDEC, 2022).

Academic studies have also quantified and examined the relationship between fish and surface water PFAS concentrations. Pickard et al. (2022) measured 37 PFAS compounds in fish and surface water samples from nine freshwater ecosystems in southern New Hampshire. Goodrow et al. (2020) measured 13 PFAS compounds in surface water, sediments, and fish tissue samples from 11 waterbodies in New Jersey. Other noteworthy studies include those by Fair et al. (2019), who measured PFAS concentrations in edible fish from the Charleston Harbor (South Carolina) and its major tributaries; MacGillivray (2020), who examined temporal changes of PFAS concentrations in fish from the Delaware River; and Newstead et al. (2017), who analyzed spatial and temporal trends of PFAS concentrations in fish collected from the Upper Mississippi River. Section 4.0 discusses additional studies from the peer-reviewed literature.

Massachusetts agencies have also characterized the nature and extent of PFAS contamination in various environmental media. For surface waters, MassDEP and USGS recently completed a PFAS river sampling study where PFAS were detected in all 27 of the rivers sampled (USGS, 2021). The sum of 24 PFAS ranged between 0.30 and 399 ng/L. The highest concentrations were observed downstream of wastewater effluent discharges, but PFAS were also found in rivers upstream of these discharges. In 2021, MDPH measured PFAS in surface water collected from 16 lakes and ponds on Cape Cod (MDPH, 2021a). At five locations, MDPH also collected fish for PFAS analysis. This sampling resulted in MDPH issuing fish consumption advisories for all five waterbodies. More recently, in the summer of 2022, MDPH measured PFAS in fish at state parks operated by the Massachusetts Department of Conservation and Recreation (MDCR). This study led to fish consumption advisories at all 13 waterbodies where fish were collected, ranging from “one meal per week” to “do not eat any fish” (MDPH, 2023).

Although these efforts have resulted in important advances in our understanding of environmental PFAS contamination in the Commonwealth, they do not fully characterize the nature and extent of PFAS levels in freshwater fish throughout the state. This study was conducted to help fill that gap.

2.2 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 water and in edible tissues of freshwater fish from rivers and lakes across the Commonwealth in a manner that allows for assessment of public health risks associated with consuming freshwater fish. By design, sampling focused on waterbodies near known or suspected sources of PFAS (e.g., Superfund sites with reported PFAS detections, federal agency sites with known PFAS contamination, AFFF spills reported to the National Response Center, commercial airports, wastewater treatment plants, municipal waste landfills) and determined to have high fishing pressure. The study design provided data for waterbodies suspected to represent “worst case” conditions, though data were also generated at several “reference” locations for comparison. Emphasis was placed on waterbodies near EJ communities and on freshwater fish species that are commonly caught and consumed by recreational fishers.

A secondary objective of this study was to evaluate bioaccumulation of PFAS in fish from surface water. To that end, temporally and spatially paired surface water and fish tissue samples were collected and resulting data were used to evaluate patterns across media and to derive species-specific BAFs.

Additionally, and because the field sampling crews were already going to visit more than 50 waterbodies to meet the study's primary objective, MassDEP requested that a second surface water sample be collected at waterbodies with public or private beaches with high recreational use. At these locations, field crews collected near-shore surface water beach samples. Analytical results from these data may inform the need for further sampling by MDPH, relative to their evaluation of the public health implications associated with incidental ingestion of PFAS during recreational activities.

3.0 METHODS

This study was conducted in two phases. Phase 1 (hereafter referred to as the "pilot phase") was conducted between February 2022 and June 2022. During this phase, the project team developed an initial QAPP and SAP and collected and analyzed surface water and fish tissue samples at five waterbodies. Data and lessons learned gathered during this pilot phase were summarized in an interim report for MassDEP and then used to update the QAPP and SAP, as well as to guide the selection of sampling locations for the next phase. Phase 2 began in July 2022 and continued through June 2023. During this phase, the project team implemented the updated QAPP and SAP and collected samples at an additional 47 waterbodies from July to November, 2022. The project team developed a database that housed all analytical results provided by the laboratory along with field data (e.g., waterbody and fish characteristics, chain of custody forms). Note that the QAPP changes made between phases were largely minor clarifications and the project team considers the Phase 1 and Phase 2 data to be comparable.

The remainder of this section describes how waterbodies were selected for the study and which waterbodies were ultimately sampled (Section 3.1); how surface water and fish tissue samples were collected and processed in the field (Section 3.2); which laboratory analyses were performed on the samples (Section 3.3); how data quality was assessed (Section 3.4); and how the laboratory results and field data were processed and analyzed (Section 3.5). All study design decisions described here were made to ensure that PFAS measurement data met the project's principal objective – i.e., to characterize the nature and extent of PFAS contamination in water and edible tissues of freshwater fish from rivers and lakes in a manner that allows for the assessment of public health risks associated with consuming freshwater fish. Additional information on study methods and project timeline can be found in the QAPP and SAP, both of which are posted to the project website.

3.1 Sampling Locations

This study focused on freshwater lakes, ponds, and rivers in Massachusetts that have a high likelihood of PFAS contamination and where people are known to collect and consume fish, including in EJ communities. Waterbodies designated for "catch-and-release" fishing, with marine or brackish water, of a small size (less than five acres), or located on Martha's Vineyard and Nantucket were not considered. The project team used various resources and tools to select waterbodies located in areas with known or suspected PFAS releases into the environment (i.e., "source-impacted" areas) and in areas without known PFAS sources and with low population density (i.e., "reference" areas), as described below.

- For source-impacted waterbodies, this involved first compiling a universe of candidate waterbodies using MassWildlife's GoFishMA online tool and then narrowing down that list to a reasonable subset by ranking them based on potential impacts from known and suspected PFAS sources.[1] Selection of source-impacted areas was based on proximity to PFAS sources. For river locations, candidate sites were those located downstream from PFAS sources. For lake/pond locations, candidate sites were those with a PFAS source in the same sub-basin. For more information on the system used to rank source-impacted locations, refer to the project QAPP.

[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).

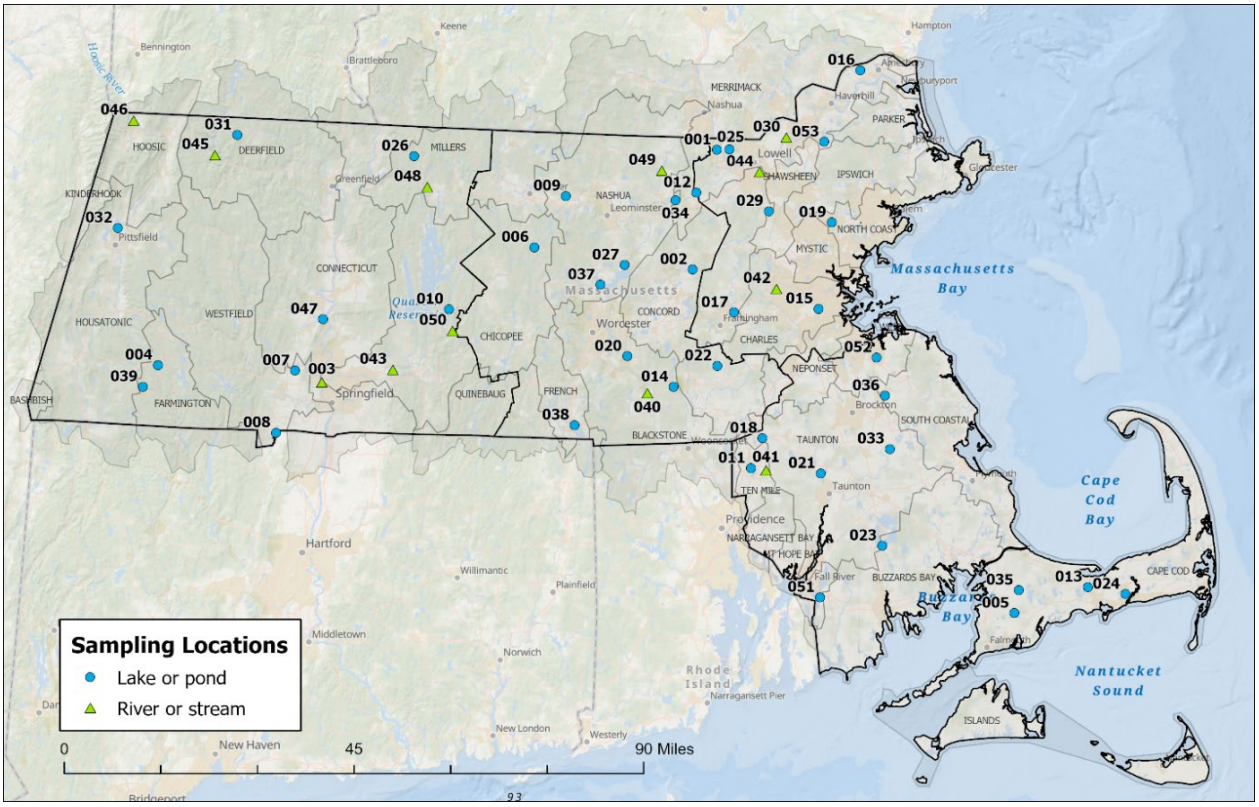
Suspected sources of PFAS included commercial airports, wastewater treatment plants, municipal solid waste landfills, sites accepting diverted food materials, and other sites in EPA's PFAS Analytic Tools website (i.e., historic manufacturers of PFAS and facilities that generate or receive Resource Conservation and Recovery Act [RCRA] waste contaminating PFAS).

- For reference areas, the project team evaluated and selected lakes and ponds from the same universe of waterbodies, but only considering those not located near any of the identified PFAS sources and focusing on waterbodies in areas with the lowest population density.

The targeted sampling locations identified with this systematic approach were then further reviewed to prioritize those with high fishing pressure and good boat access, enhance EJ inclusion, and ensure reasonable distribution across the state. Refer to Section 3.1.1 of the QAPP for more detail on the 50 waterbodies initially targeted for sample collection and how they were selected.

During the pilot phase, field teams collected samples at five waterbodies (i.e., the Connecticut River in Chicopee, Lake Boon, Ashumet Pond, Flint Pond, and Upper Spectacle Pond). During Phase 2, the original intent was to sample an additional 45 waterbodies. Two were found to have unfavorable sampling conditions and could not be sampled (e.g., low water levels, excessive vegetation); both were replaced with other waterbodies selected by MassDEP. The field crew was not able to collect fish from five of the waterbodies (i.e., Hathaway Ponds, South Meadow Pond (sampled as "Mossy Pond"), Norton Reservoir, Wachusett Reservoir, and the Bungay River); surface water was analyzed from samples collected at four of these waterbodies. Additionally, samples collected from three waterbodies were not able to be analyzed (i.e., Hopedale Pond, Falls Pond, and Nutting Lake). The field crew was able to resample two of these waterbodies for fish tissue, as well as collect samples at three additional waterbodies. These efforts provided surface water data for 52 waterbodies and fish tissue data for 47 waterbodies (see Figure 1 and Table 1).

Figure 1. Sampling Locations



Notes: Black boundaries indicate MassDEP regions and grey boundaries indicate watersheds. GIS layers for both were obtained from MassGIS (Bureau of Geographic Information) data (MassGIS June 2000; MassGIS May 2022). See Table 1 for the waterbody names and other waterbody features that correspond to the IDs shown here.

Table 1. Characteristics of Sampling Locations

ID*	Waterbody Name	Latitude	Longitude	Waterbody Type	Source-impacted or Reference Location	Region	Watershed	Within 1 mile of EJ Block
001	Flint Pond	42.67244304	-71.43064466	Lake/Pond	Source-impacted	Northeast	Merrimack	Yes
002	Lake Boon	42.40367618	-71.5019143	Lake/Pond	Source-impacted	Central	Concord	No
003	Connecticut River	42.14593145	-72.62085447	River	Source-impacted	West	Connecticut	Yes
004	Upper Spectacle Pond	42.18202796	-73.11790189	Lake/Pond	Reference	West	Farmington	No
005	Ashumet Pond	41.63165663	-70.53365288	Lake/Pond	Source-impacted	Southeast	Cape Cod	Yes
006	Asnacomet Pond	42.45634724	-71.98370922	Lake/Pond	Reference	Central	Chicopee	No
007	Buck Pond	42.17125347	-72.7025811	Lake/Pond	Source-impacted	West	Westfield	Yes
008	Congomond Lakes	42.02776575	-72.7569138	Lake/Pond	Source-impacted	West	Westfield	Yes
009	Crocker Pond	42.5717892	-71.88682286	Lake/Pond	Source-impacted	Central	Nashua	Yes
010	Hardwick Pond	42.31357389	-72.23959612	Lake/Pond	Source-impacted	West	Chicopee	No
011	Falls Pond	41.96308175	-71.32345644	Lake/Pond	Source-impacted	Southeast	Ten Mile	Yes
012	Forge Pond	42.57632819	-71.49009003	Lake/Pond	Source-impacted	Northeast	Merrimack	Yes
013	Hathaway Ponds	41.68438094	-70.31185138	Lake/Pond	Source-impacted	Southeast	Cape Cod	No
014	Hopedale Pond	42.13824772	-71.55052642	Lake/Pond	Source-impacted	Central	Blackstone	Yes
015	Jamaica Pond	42.31760085	-71.12054034	Lake/Pond	Source-impacted	Northeast	Charles	Yes
016	Lake Attitash	42.851	-70.983	Lake/Pond	Source-impacted	Northeast	Merrimack	No
017	Lake Cochituate	42.30499573	-71.37091248	Lake/Pond	Source-impacted	Northeast	Concord	Yes
018	Lake Mirimichi	42.02417861	-71.28808264	Lake/Pond	Source-impacted	Southeast	Taunton	No
019	Lake Quannapowitt	42.51777566	-71.07972922	Lake/Pond	Source-impacted	Northeast	North Coast	No
020	Lake Ripple	42.2135142	-71.69811636	Lake/Pond	Source-impacted	Central	Blackstone	Yes
021	Lake Sabbatia	41.94548974	-71.11099644	Lake/Pond	Source-impacted	Southeast	Taunton	Yes
022	Lake Winthrop	42.18816694	-71.42442914	Lake/Pond	Source-impacted	Central	Charles	No
023	Long Pond (Lakeville)	41.80214474	-70.94570757	Lake/Pond	Source-impacted	Southeast	Taunton	No
024	Long Pond (Yarmouth)	41.66952299	-70.1976405	Lake/Pond	Source-impacted	Southeast	Cape Cod	Yes
025	Mascuppic Lake	42.67712691	-71.38427937	Lake/Pond	Source-impacted	Northeast	Merrimack	Yes
026	Moores Pond	42.65678778	-72.34754271	Lake/Pond	Reference	West	Millers	No
027	South Meadow Pond	42.415147	-71.706389	Lake/Pond	Source-impacted	Central	Nashua	Yes
029	Nutting Lake	42.5356188	-71.27100893	Lake/Pond	Source-impacted	Northeast	Concord	Yes
030	Merrimack River	42.70144142	-71.21284322	River	Source-impacted	Northeast	Merrimack	Yes
031	Pelham Lake	42.699	-72.889	Lake/Pond	Reference	West	Deerfield	Yes
032	Pontoosuc Lake	42.4953931	-73.2486349	Lake/Pond	Source-impacted	West	Housatonic	Yes
033	Robbins Pond	42.00509695	-70.90663264	Lake/Pond	Source-impacted	Southeast	Taunton	No

ID*	Waterbody Name	Latitude	Longitude	Waterbody Type	Source-impacted or Reference Location	Region	Watershed	Within 1 mile of EJ Block
034	Sandy Pond	42.56207083	-71.55570102	Lake/Pond	Source-impacted	Central	Nashua	Yes
035	Snake Pond	41.68218024	-70.52035217	Lake/Pond	Source-impacted	Southeast	Cape Cod	Yes
036	Studley Pond	42.12007153	-70.92012246	Lake/Pond	Source-impacted	Southeast	South Coastal	Yes
037	Wachusett Reservoir	42.37089649	-71.77961084	Lake/Pond	Source-impacted	Central	Nashua	Yes
038	Webster Lake	42.04012562	-71.84598356	Lake/Pond	Source-impacted	Central	French	Yes
039	West Lake	42.13221533	-73.16345932	Lake/Pond	Reference	West	Farmington	No
040	Blackstone River	42.12894021	-71.63673824	River	Source-impacted	Central	Blackstone	No
041	Bungay River	41.95521	-71.2786	River	Source-impacted	Southeast	Ten Mile	Yes
042	Charles River	42.36291	-71.24547	River	Source-impacted	Northeast	Charles	Yes
043	Chicopee River	42.17912728	-72.4054951	River	Source-impacted	West	Chicopee	Yes
044	Concord River	42.62546	-71.29596	River	Source-impacted	Northeast	Concord	No
045	Deerfield River	42.65448949	-72.95556153	River	Reference	West	Deerfield	Yes
046	Hoosic River	42.72850018	-73.20572334	River	Source-impacted	West	Hoosic	Yes
047	Oxbow Pond-Easthampton	42.28996181	-72.63878752	Lake/Pond	Source-impacted	West	Connecticut	Yes
048	Millers River	42.58903	-72.30789	River	Source-impacted	West	Millers	Yes
049	Nashua River	42.6287	-71.59355	River	Source-impacted	Central	Nashua	No
050	Ware River	42.2662023	-72.22685496	River	Source-impacted	West	Chicopee	Yes
051	South Watuppa Pond	41.66854984	-71.12652642	Lake/Pond	Source-impacted	Southeast	Mt, Hope Bay	Yes
052	Whitman's Pond	42.20671324	-70.9355231	Lake/Pond	Source-impacted	Southeast	Weir	Yes
053	Lake Cochichewick	42.70332585	-71.09555365	Lake/Pond	Source-impacted	Northeast	Merrimack	No

* The original site #28 was not sampled.

As shown in Table 1, the 52 waterbodies sampled in this study include 40 lake or pond locations and 12 rivers. Six of the waterbodies are classified as reference locations, one of which is a river. The waterbodies cover all four MassDEP regions (23% in the Northeast, 25% in the Southeast, 23% in the Central, and 29% in the West) and 21 unique watersheds. 67% of the waterbodies are located within one mile of an EJ census block, as defined by the Massachusetts Executive Office of Energy and Environmental Affairs. That definition is based on household income, English language isolation, and percent minority population (MassGIS, 2021).

3.2 Sample Collection

Surface water and fish tissue samples were collected between May 31, 2022 and November 17, 2022. During this time, 66 surface water samples and 242 composite fish tissue samples (comprised of 948 fish from 16 different species were collected. Surface water samples were collected at all 52 waterbodies; the field team collected additional samples near beach areas at 12 of the waterbodies and an additional round of samples at two of the waterbodies. Fish tissue samples were collected at 47 waterbodies. At five locations, the field crew did not collect any fish after the designated sampling time, even after trying various approaches (e.g., electrofishing, trot lines, hook-and-line) and after using different bait. Table 2 summarizes the samples collected at each waterbody. (Note that these sample counts do not include various quality control samples collected during the study.)

Table 2. Samples Collected

ID[a]	Waterbody	Number of Surface Water Samples[b]	Number of Fish Caught	Species Caught[c]	Number of Fish Samples[d]
001	Flint Pond	1	42	B, LMB, YP	9
002	Lake Boon	1	45	B, LMB, WP	9
003	Connecticut River	1	21	SMB, YP	6
004	Upper Spectacle Pond	1	36	B, LMB, P	8
005	Ashumet Pond	1	45	LMB, WP, YP	9
006	Asnacomet Pond	2	4	B, LMB	2
007	Buck Pond	1	17	B, LMB, YP	6
008	Congomond Lakes	1	22	B, BB, P	6
009	Crocker Pond	2	30	BC, LMB, YP	6
010	Hardwick Pond	1	26	B, LMB, YP	6
011	Falls Pond	4	30	LMB, P, YP	6
012	Forge Pond	2	26	AE, BC, P	6
013	Hathaway Ponds	1	0	NA	NA
014	Hopedale Pond	2	18	B, BC, YP	6
015	Jamaica Pond	1	6	RT, YP	3
016	Lake Attitash	1	26	BB, P, YP	6
017	Lake Cochituate	2	26	BC, LMB, YP	6
018	Lake Mirimichi	1	27	B, LMB, YP	6
019	Lake Quannapowitt	1	12	WP, YP	3
020	Lake Ripple	1	28	B, BC, LMB	6
021	Lake Sabbatia	1	15	BC, LMB, YP	6
022	Lake Winthrop	2	20	BC, CP, YP	6
023	Long Pond (Lakeville)	1	25	LMB, P, YP	6
024	Long Pond (Yarmouth)	2	20	LMB, P	4
025	Mascuppic Lake	1	20	BB, CP, LMB	6
026	Moores Pond	1	13	B, LMB, P	4
027	South Meadow Pond	1	0	NA	NA

ID[a]	Waterbody	Number of Surface Water Samples[b]	Number of Fish Caught	Species Caught[c]	Number of Fish Samples[d]
029	Nutting Lake	1	0	NA	NA
030	Merrimack River	1	9	BB, LMB	4
031	Pelham Lake	2	16	P, YP	4
032	Pontoosuc Lake	1	24	BB, C, YP	6
033	Robbins Pond	1	26	B, CP, WS	6
034	Sandy Pond	2	21	B, YB, YP	5
035	Snake Pond	2	12	B, P, YP	4
036	Studley Pond	1	12	B, P, YP	5
037	Wachusett Reservoir	1	0	NA	NA
038	Webster Lake	2	14	BB, LMB, P	4
039	West Lake	1	27	BC, P, YP	6
040	Blackstone River	1	5	WP, YP	3
041	Bungay River	1	0	NA	NA
042	Charles River	1	12	B, BC, LMB	4
043	Chicopee River	1	16	B, LMB	4
044	Concord River	1	10	B	2
045	Deerfield River	1	1	RT	1
046	Hoosic River	1	6	BRT	2
047	Oxbow Pond-Easthampton	1	30	BB, P, YP	6
048	Millers River	1	5	P, RB, RT	3
049	Nashua River	1	16	BB, WS	4
050	Ware River	1	20	LMB, YP	4
051	South Watuppa Pond	1	30	B, P, YP	6
052	Whitman's Pond	1	18	B, P, YP	6
053	Lake Cochichewick	1	18	LMB, P, YP	6

Notes

NA = not applicable; no fish were caught in these waterbodies.

[a] IDs were assigned to each waterbody during sample collection and are displayed in this report's maps. Field sampling crews were not able to collect samples at one waterbody that was assigned an ID of 028.

[b] One routine surface water sample was collected at all waterbodies. At some waterbodies, an additional surface water sample was collected near recreational beaches. Two rounds of surface water samples were collected at Hopedale Pond and Fall Pond, as the waterbody was resampled to collect additional fish.

[c] Species listed include AE=American eel, B=bluegill, BB=brown bullhead, BC=black crappie, BRT=brown trout, C=common carp, CP=chain pickerel, LMB=largemouth bass, P=pumpkinseed, RB=redbreast sunfish, RT=rainbow trout, SMB=smallmouth bass, WP=white perch, WS=white sucker, YB=yellow bullhead, and YP=yellow perch.

[d] Individual fish were combined into composite samples of similar sized fish from the same waterbody and of the same species for PFAS measurements.

Sections 3.2.1 and 3.2.2 describe the surface water and fish sampling methodologies, respectively. Note that because of the ubiquitous nature of PFAS in common consumer products and in the equipment typically used to collect environmental samples, as well as the low method detection limits (MDLs) targeted for this project, special care was taken throughout sample collection and processing to minimize PFAS cross contamination. Additional information can be found in Section 3.1 of the QAPP and throughout the SAP.

3.2.1 Surface Water Sample Collection

Field crews collected one unfiltered surface water sample at each waterbody in the immediate vicinity of where the first productive fishing activities occurred, referred to throughout this report as the

"routine" surface water sample. Grab samples were collected boat-side at a depth of 1 to 1.5 feet beneath the surface. When collecting samples, field crews uncapped the sample bottles underwater to eliminate the potential for water from the surface layer to enter the sample. Data from these samples were used to derive species-specific BAFs.

Additional surface water samples were collected at a subset of lakes (not rivers) with primary beach areas that appeared to have moderate to high recreational use. At these waterbodies, field crews waded into the water and collected "beach" surface water samples within 20 feet of the shoreline at a depth of 0.5 to 1.0 feet. While this sample collection approach likely disturbed sediments, the approach is assumed to mimic the water quality conditions that a recreational user (e.g., a small child) might experience. "Beach" sample collection was the first activity completed by the field crew upon arrival to a waterbody; and to the extent possible, "beach" samples were collected during early morning hours when the beach areas were the least crowded. Data from these samples were used to inform potential health risks associated with incidental ingestion during recreational swimming.

All surface water samples were collected in sample bottles provided by the laboratory and immediately placed on ice inside a cooler (<6° C). Samples were then stored in a freezer until shipped fully frozen on ice to the laboratory within one week of being collected. Strict protocols were followed while samples were collected and during all sample handling to limit the potential for PFAS cross contamination.

3.2.2 Fish Tissue Sample Collection

At each lake, field crews collected a maximum of 45 fish from three different species; and at each river, field crews collected a maximum of 30 fish from two different species. Field crews did not keep any fish caught that people are not likely to take and consume (e.g., undersized fish).

Generally, field sampling crews chose fish species that were caught in the greatest numbers at a given waterbody. The rationale for this decision is that the fish species caught in greatest numbers, to a first and rough approximation, can be assumed to be the fish species most likely to be caught by recreational anglers. Provided these species were also likely to be consumed, field crews retained the fish from that species for analysis. In some instances, field crews did not keep the species caught in greatest numbers for analysis. This was done to increase the diversity of species sampled and to gather information on both pelagic and benthic species, including stocked fish (e.g., rainbow trout).

Fish were collected via electrofishing from a motorboat, whenever possible. This method was generally used for shallow waterbodies with good boat access and conductivity levels suitable for electrofishing. When conditions did not allow for electrofishing or specific species were sought, field sampling crews used hook and line fishing (i.e., setting fishing line in the water with baited hooks from a motorboat, canoe, or the shoreline) and/or trotlines. At many waterbodies, more than one technique was used. For example, at deeper waterbodies, field sampling crews began by using a combination of hook-and-line or trotlines for several hours of sampling, after which they switched over to electrofishing, if necessary. This helped ensure that the team collected a variety of species, including those from deeper waters.

Field teams only kept fish that met the state's minimum size requirements (i.e., 15 inches for chain pickerel and 12 inches for largemouth/smallmouth bass). Similarly sized fish of the same species were grouped together in the field, as these would later be processed into composite samples. Field sampling crews selected species and grouped fish to allow for composite samples comprised of between three and five similarly sized fish. In some cases, however, fewer than three fish of a species were collected and used for analysis.

In the study, 948 individual fish were collected from 47 waterbodies and kept for PFAS analysis. These fish represent 16 different species, a majority of which were yellow perch (24%), bluegill (19%), largemouth bass (17%), and pumpkinseed (14%). Table 2 lists the 16 species collected and presents the number of waterbodies where each species was caught. Yellow perch samples, for example, were collected at 28 of the 47 waterbodies sampled for fish.

After samples were collected for a given waterbody, the field sampling crews transported the fish on ice to Normandeau's offices in Bedford, New Hampshire, where they were processed. There, field sampling crews recorded the weight, length, and sex of the fish, and then skinned and filleted the specimens. Composite samples were prepared by grouping the skin-off right-side fillets of similarly sized fish of the same species. These grouped tissue samples were then double bagged in a PFAS-free zip-seal bag, labeled, and shipped frozen to the laboratory for homogenization and PFAS analysis. Note that composite samples provide a cost-effective and reliable estimate of PFAS analyte concentrations. Because each composite contains more than one fish, results are more likely to be representative of the average concentration of PFAS in the entire population and less likely to represent outliers. However, composite sampling does not provide information about PFAS concentrations in individual fish and the range of PFAS concentrations detected in individual fish may not be the same as the range of PFAS concentrations detected in composite samples.

242 fish tissue samples were sent to the laboratory for analysis: 10 were a fillet from an individual fish and 232 were composites from a waterbody. The number of fish per composite ranged from two fish (in 8% of the samples) to five fish (in 50% of the samples).

Table 3 summarizes the fish caught and analyzed for this study, including the average weight, average length, and sex ratio by species. Section 3.1 of the QAPP and the SAP provide additional details on fish sample collection and processing methods.

Table 3. Characteristics of Fish Caught

Family Name	Common Name	Scientific Name	Habitat[a]	Trophic Level[b]	Total Fish Caught (n=948)				
					# of Fish	Average Length (mm)	Average Weight (g)	Male to Female Ratio	# of Lakes or Rivers
Centrarchidae	Largemouth bass	*Micropterus salmoides*	benthopelagic	4	162	378	843	0.9:1	23
	Smallmouth bass	*Micropterus dolomieu*	benthopelagic	4	12	328	472	1.4:1	1
	Black crappie	*Pomoxis nigromaculatus*	benthopelagic	3	64	228	176	1.5:1	9
	Redbreast sunfish	*Lepomis auritus*	benthic	3	1	177	105	1:0	1
	Bluegill	*Lepomis macrochirus*	benthopelagic	3	181	176	110	0.9:1	20
	Pumpkinseed	*Lepomis gibbosus*	benthopelagic	3	137	169	110	0.9:1	18
Moronidae	White perch	*Morone americana*	benthopelagic	3	44	204	120	1.1:1	4
Percidae	Yellow perch	*Perca flavescens*	benthopelagic	3	232	219	133	0.4:1	28
Salmonidae	Brown trout	*Salmo trutta*	pelagic-neritic	4	6	271	173	1:0	1
	Rainbow trout	*Oncorhynchus mykiss*	benthopelagic	4	7	339	473	6:1	3
Ictaluridae	Brown bullhead	*Ameiurus nebulosus*	benthic	3	57	261	275	0.7:1	8
	Yellow bullhead	*Ameiurus natalis*	benthic	3	1	250	230	0:1	1
Esocidae	Chain pickerel	*Esox niger*	benthic	4	16	464	621	2.2:1	3
Cyprinidae	Common carp	*Cyprinus carpio*	benthopelagic	2	6	610	3,225	5:1	1
Anguillidae	American eel	*Anguilla rostrata*	benthic	4	6	602	537	2:1	1
Catostomidae	White sucker	*Catostomus commersonii*	benthic	3	16	414	800	1:1	2

Notes

a. Habitat classifications were obtained from FishBase (version 2/2023), 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 12 international organizations.

Benthic species: Live on or near the bottom and feed on benthic organisms like detritus, plankton, and small invertebrates.

Pelagic-neritic species: Live in midwaters and near the surface, as well as in nearshore ocean ecosystems (0-200 meter depth). Often consume plankton and other free-living organisms like small fish and crustaceans.

Benthopelagic species: Live and feed near the bottom, in midwaters, and near the surface. Opportunistically forage both free benthic and free-living organisms.

b. Trophic levels were obtained from VT DEC (2022), Goodrow et al. (2020), and KY DEP (2020). Trophic levels describe a species' position within a food chain or food web and is based on a species' diet (Kumar 1992).

Level 2: Grazers that consume algae, phytoplankton, or detritus.

Level 3: Carnivores that consume herbivorous fish and zooplankton.

Level 4: Carnivores that consume other carnivorous fish.

3.2.3 Field Quality Control Samples

In addition to the primary surface water and fish tissue samples described in Sections 3.2.1 and 3.2.2, numerous quality control samples were prepared and analyzed to enable data quality evaluation. The quality control sample types included field blanks, equipment blanks, and field duplicates. Field and equipment blanks were collected to assess for potential cross-contamination during any part of the data acquisition process (from field collection through laboratory analysis). Field blanks were prepared using PFAS-free de-ionized water (DIW) in the field. Equipment blanks were prepared at Normandeau's Bedford NH offices by running PFAS-free DIW over all the equipment used during fish processing (e.g., measuring board, knives, scale), after the equipment was cleaned and rinsed following study protocols. Note that before pilot phase sampling began, the project team sent test samples of the PFAS-free source water (from the DIW system at the MassDEP WPP laboratory; raw as dispensed from the DIW unit and from a cleaned carboy) to Eurofins for confirmatory analysis. None of the 40 PFAS measured under draft EPA Method 1633 (see section 3.2.4) were detected in these samples at concentrations above the laboratory MDL (i.e., all were non-detect).

At 25% of the waterbodies sampled, a surface water field blank was prepared in the field with PFAS-free DIW. Across all samples analyzed, there were only two detections in these blanks; PFOS was detected in one blank at a concentration of 0.6 ng/L (above the MDL but below the reporting limit [RL]) and PFOA was detected in another blank at 1.2 ng/L. Equipment blanks were prepared while processing fish samples from 14 of the 47 (30%) waterbodies where fish were collected. PFOS was detected at low levels (above the MDL but below the RL) in five of the blanks, and PFOA was detected at similarly low levels in one blank. In one of the equipment blanks, PFOS was detected at a concentration (2.5 ng/L) above the RL (1.9 ng/L). All results for quality control blanks were considered during project level data validation (Section 3.4 and Appendix A) when deciding whether to censor or qualify associated field survey, waterbody, or lab batch results due to cross contamination.

Field duplicates were collected to assess precision of the field sampling and laboratory analytical methods. The desired number of duplicate samples was specified in the QAPP; and 12 field duplicates were collected for surface water and 13 for fish tissue. The relative percent difference (RPD) was calculated across all PFAS measured in the duplicate pairs and compared to DQOs outlined in the QAPP. Nearly all of the 480 RPDs calculated for surface water and 521 RPDs calculated for fish tissue met DQOs. These results were considered during project level data validation when deciding whether to censor or qualify the final data due to poor repeatability.

Field QC sample results were reviewed on an ongoing basis as they were received from the laboratory. If results did not meet DQOs, ERG immediately reviewed study protocols with the field sampling crew.

3.3 Laboratory Analysis

After Normandeau processed the fish tissue and surface water samples, they were sent to the Eurofins-Lancaster Laboratory for analysis using draft EPA Method 1633 (EPA, 2021). Draft EPA Method 1633 is an EPA-developed method suitable for quantifying up to 40 unique PFAS compounds in non-potable water (e.g., wastewater, surface water, leachate) and other matrices (e.g., biosolids, fish tissue, soil). While EPA has developed and validated other methods for quantifying PFAS 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), draft EPA Method 1633 is currently the analytical method of choice for analyzing fish tissue samples. This method was selected for

this project because it could be used to analyze all samples collected (i.e., surface water and fish tissue) and because it quantifies concentrations of many PFAS compounds.

Draft EPA Method 1633 is a targeted Liquid Chromatography Tandem Mass Spectrometry (LC-MS/MS) method that involves preparing and extracting environmental samples and analyzing extracts in multiple reaction monitoring mode. It uses isotope dilution, considered the "gold standard for quantification of PFAS," in addition to extracted internal standard quantification with isotopically labeled compounds (EPA, 2021; Denly and Morin, 2022; Kuzniewski, 2022).

In September 2021, EPA's Office of Water, in collaboration with the U.S. Department of Defense's (DoD) Strategic Environmental Research and Development Program (SERDP), published the first draft of Method 1633 (EPA, 2021). The draft method has since undergone a multi-laboratory validation study. In June 2022, a second draft of EPA Method 1633 was published (EPA, 2022a), which is the basis for the Eurofins laboratory SOP used for this study. A third draft was published in December 2022 (EPA, 2022b) after this project's sampling was completed; and a final version, including QC acceptance criteria for all eight matrices, is anticipated to be published by the end of 2023.

Eurofins analyzed all surface water and fish tissue samples for the 40 PFAS shown in Table 4 following specifications of draft EPA Method 1633. Surface water sample results were reported in units of nanogram PFAS analytes per liter (ng/L). Fish tissue samples were homogenized prior to analysis and reported in units of nanogram PFAS analytes per gram of fish (ng/g, wet weight). All results were reported to concentrations equal to the laboratory MDL. Additional information on these methods can be found in Eurofins' SOP for draft EPA Method 1633, which is attached to the QAPP.

Table 4. PFAS Analytes for Surface Water and Fish Tissue

PFAS Analyte	Acronym	Number of Carbons	CAS Number
Perfluoroalkyl (PFCAs)			
Perfluorobutanoic acid	PFBA	4	375-22-4
Perfluoropentanoic acid	PFPeA	5	2706-90-3
Perfluorohexanoic acid	PFHxA	6	307-24-4
Perfluoroheptanoic acid	PFHpA	7	375-85-9
Perfluorooctanoic acid	PFOA	8	335-67-1
Perfluorononanoic acid	PFNA	9	375-95-1
Perfluorodecanoic acid	PFDA	10	335-76-2
Perfluoroundecanoic acid	PFUnA	11	2058-94-8
Perfluorododecanoic acid	PFDoA	12	307-55-1
Perfluorotridecanoic acid	PFTrDA	13	72629-94-8
Perfluorotetradecanoic acid	PFTeDA	14	376-06-7
Perfluoroalkyl Sulfonic Acids (PFSAs)			
Perfluorobutanesulfonic acid	PFBS	4	375-73-5
Perfluoropentansulfonic acid	PFPeS	5	2706-91-4
Perfluorohexanesulfonic acid	PFHxS	6	355-46-4
Perfluoroheptanesulfonic acid	PFHpS	7	375-92-8
Perfluorooctanesulfonic acid	PFOS	8	1763-23-1
Perfluorononanesulfonic acid	PFNS	9	68259-12-1
Perfluorodecanesulfonic acid	PFDS	10	335-77-3
Perfluorododecanesulfonic acid	PFDoS	12	79780-39-5
Fluorotelomer Sulfonic and Carboxylic Acids			
1H,1H, 2H, 2H-Perfluorohexane sulfonic acid	4:2FTS	6	757124-72-4
1H,1H, 2H, 2H-Perfluorooctane sulfonic acid	6:2FTS	8	27619-97-2

PFAS Analyte	Acronym	Number of Carbons	CAS Number
1H,1H, 2H, 2H-Perfluorodecane sulfonic acid	8:2FTS	10	39108-34-4
3-Perfluoropropyl propanoic acid	3:3FTCA	6	356-02-5
2H,2H,3H,3H-Perfluorooctanoic acid	5:3FTCA	8	914637-49-3
3-Perfluoroheptyl propanoic acid	7:3FTCA	10	812-70-4
Sulfonamides, Sulfomidoacetic Acids, and Sulfonamidoethanols			
Perfluorooctanesulfonamide	PFOSA	8	754-91-6
N-methyl perfluorooctanesulfonamide	NMeFOSA	9	31506-32-8
N-ethyl perfluorooctanesulfonamide	NEtFOSA	10	4151-50-2
N-methyl perfluorooctanesulfonamidoacetic acid	NMeFOSAA	11	2355-31-9
N-ethyl perfluorooctanesulfonamidoacetic acid	NEtFOSAA	12	2991-50-6
N-methyl perfluorooctanesulfonamidoethanol	NMeFOSE	11	24448-09-7
N-ethyl perfluorooctanesulfonamidoethanol	NEtFOSE	12	1691-99-2
Ether carboxylic acids and Other Compounds			
Hexafluoropropylene oxide dimer acid	HFPO-DA	6	13252-13-6
4,8-Dioxa-3H-perfluorononanoic acid	ADONA	7	919005-14-4
Perfluoro-3-methoxypropanoic acid	PFMPA	4	377-73-1
Perfluoro-4-methoxybutanoic acid	PFMBA	5	863090-89-5
Nonafluoro-3,6-dioxaheptanoic acid	NFDHA	5	151772-58-6
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid	9Cl-PF3ONS	8	756426-58-1
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid	11Cl-PF3OUdS	10	763051-92-9
Perfluoro(2-ethoxyethane)sulfonic acid	PFEESA	4	113507-82-7

3.4 Data Validation

Prior to delivering analytical results to the project team, Eurofins ensured that all data met quality assurance/quality control (QA/QC) criteria, as outlined in their SOP for draft EPA Method 1633 and their laboratory Quality Assurance Plan. At a rate of at least one per batch (or for larger batches, one per 20 samples), Eurofins analysts checked method blanks, MS/MSD, LCS/LLLCS, isotopically labeled extraction standards, and non-extracted internal standards against the SOP acceptance limits. When targets fell outside of the SOP's QA/QC acceptance limits, Eurofins re-extracted and re-analyzed samples, and, in some cases, added data qualifiers. The laboratory SOP for this method is attached to the QAPP.

ERG reviewed laboratory reports and electronic data deliverables (EDDs) as they were received from Eurofins for discrepancies and noted blank and duplicate sample results that fell outside of the project DQOs established in the project QAPP. Exceedances of QA/QC limits were discussed with the laboratory or field sampling team for appropriate action, including review of SOPs and increasing the frequency of blank sample collection. Data validation procedures implemented during sample collection and initial data review are described in further detail in the project QAPP.

Following MassDEP receipt of project field and analytical laboratory data, WPP staff reviewed the information with the objective of finalizing the data, including qualifying (or censoring if justified) individual datum wherever necessary based on comparison to the DQOs in the project QAPP. WPP's validation of project data included review of the following materials:

- Eurofins' laboratory SOP for draft EPA Method 1633
- Eurofins' laboratory reports and EDDs, as well as completed chain of custody forms
- Field sheets and fish sample preparation data from Normandeau field crews
- Project database, sample tracking, and crosswalk tables prepared by ERG

- ERG's interim data summaries of primary sample and field QC sample results (e.g., field blanks, equipment rinsate blanks, field duplicates)
- Eurofins' laboratory results for blind Performance Evaluation samples (provided by WPP)

WPP's data system qualifiers were applied as needed based on the criteria included in the MassDEP WPP PFAS Data Validation Protocol. By WPP convention, lab qualifiers were carried forward in the final data (and translated as needed to WPP's issue-specific qualifiers. As for all other WPP program data, qualified data are considered usable for decision making, albeit with caveat(s), to the data user related to the qualifiers applied. Only one result (for water) was censored (due to poor field precision) in the final dataset and was removed from further data analysis.

Based on this review of 2,640 individual analyte results for water quality and 9,680 individual analyte results for fish tissue results, MassDEP concluded that the project data collected for both media are acceptable for decision making (except for the censored sample noted above). Additional details on the results of the data validation process can be found in Appendix A.

WPP will manage the data resulting from this study in the Environmental Quality Information System (EQuIS) Data Management system. The study results will also be uploaded to the EPA's Water Quality Portal through EPA's Water Quality Exchange.

3.5 Data Processing and Statistical Analysis

This section describes how the validated project data were processed and analyzed. All analyses were conducted by ERG in either SAS (version 9.4) or R (version 4.2.2).

ERG compiled the analytical results from the 34 EDD files received from Eurofins and merged these data with information from the field (e.g., waterbody name, sample date, number of fish in composite, fish sample length and weight). Once MassDEP finished its data validation, ERG used the final project database for all analyses, with the following considerations:

- Field duplicates. Field duplicate results were averaged, such that each sampling event had one measured concentration for every PFAS analyte. In the case of a duplicate pair with a non-detect and measured result, the average of one half the MDL for the non-detect and the measured result was used. When a PFAS analyte was not detected in either the parent or duplicate sample, the analyte was marked as a non-detect and assigned the higher MDL for that PFAS (if the MDLs differed). Note that in one case, a parent and duplicate sample pair had MDLs that differed by more than an order of magnitude. In this case, the lower MDL was retained.
- Resampled waterbodies. As described above, two waterbodies (i.e., Falls Pond and Hopedale Pond) were sampled twice (see Appendix 1). Surface water results are available from the first sampling event while both surface water and fish tissue are available from the second. The primary analyses described below are based only on the surface water samples collected during the second sampling event. Differences in PFAS concentrations from surface water samples collected during the two sampling events are discussed separately.
- PFAS sums. In addition to individual PFAS analytes, two PFAS sums were calculated for fish tissue and surface water evaluations. Non-detect observations were not considered when calculating these sums (assumed to be negligible or zero).
  - ΣPFAS40: The sum of all detected PFAS results reported by the laboratory.
  - PFAS6: The sum of detected results for the six PFAS analytes included in the MassDEP drinking water standard (i.e., PFOA, PFOS, PFNA, PFHxS, PFDA, and PFHpA).

Descriptive statistics were calculated for all surface water and fish tissue results, as well as for various stratifications within each media (e.g., by source-impacted waterbodies and reference waterbodies, by fish species). These statistics include the frequency of detection (FOD), range of measured PFAS concentrations, mean, standard deviation (SD), 25th percentile, median, and 75th percentile for each PFAS and for the PFAS sums (i.e., ΣPFAS40 and PFAS6). For all statistical analyses, non-detect observations for individual PFAS analytes were assigned a value equal to one-half of the MDL.

For fish tissue, statistics were weighted by the number of fish in each composite sample. In SAS 9.4, weighted statistics (i.e., mean, SD, median, other percentiles) were calculated using the *PROC MEANS* procedure with the option *VARDEF=WEIGHT* (SAS Institute Inc.). In R, these metrics were calculated using the *weighted.mean()* function from the stats package and the *wtd.quantile()* and *wtd.var()* functions from the Hmisc package (R Core Team, 2022; Harrell 2023). When comparing PFAS concentrations across waterbody types (e.g., lakes and ponds versus rivers), weighted means (with weights equal to the number of fish within each composite) were calculated for each waterbody. Those waterbody-specific weighted means were then used in the analysis. The same weighted mean procedure was followed for comparing PFAS analytes across fish species. All calculations were cross-checked across software as a QC measure.

In addition, regression models were used to investigate differences in ΣPFAS40 concentrations by species, trophic level, and habitat. These models were run in SAS using *PROC SURVEYREG* with a *WEIGHT* statement for number of fish in each composite and a *STRATA* statement to control for the effect of waterbody. For species, we restricted the comparisons to the four most commonly caught fish species. For the trophic level model, we restricted the analysis to trophic levels three and four, and for the habitat model, we restricted the analysis to benthopelagic and benthic species. These restrictions were imposed as the number of fish from other trophic levels was minimal and would not have provided enough information for a reliable model.

Wilcoxon Rank Sum tests were used to test for statistically significant differences in PFAS concentrations by waterbody characteristics (i.e., lakes and ponds versus rivers, reference versus source-impacted waterbodies, and proximity to EJ census blocks [i.e., within versus outside a one-mile radius of a Massachusetts designated EJ census block]). We report p-values from a two-sided test using a continuity correction and average scores for ties. Kruskal Wallis tests were used to explore differences in PFAS results by the four MassDEP regions. These tests were conducted in SAS using the *PROC NPAR1WAY* procedure and in R using the *wilcox.test()* and *kruskal.test()* functions within the stats package. The tests were only run when PFAS were detected in at least 60% of the results being evaluated. The Kruskal Wallis test was followed by a Dunn's Test for pairwise comparison, in cases where the Kruskal Wallis test indicated significant differences between the regions ($p<0.05$).

Correlations between PFAS analytes measured in surface water and fish tissue were assessed with nonparametric Spearman correlation. Correlation coefficients and p-values were calculated for PFAS analytes and PFAS sums measured in both media with an FOD of at least 60%. We also assessed the correlation between PFAS analytes within each medium.

To explore spatial variability, results from the beach samples were compared to the results from the routine surface water samples collected at the same waterbodies. Spearman rank correlation coefficients were used to evaluate the relationship between PFAS measured from samples in the same waterbody. These paired data are available for 11 waterbodies. Re-sampling of two waterbodies resulted in three pairs of water samples (two routine sample pairs and one beach sample pair) collected approximately two months apart. These results were used to characterize temporal variability, though the available data for this analysis are limited.

Finally, BAFs were derived using composite fish sample data and co-located surface water samples (Equation 1). The quality of these estimates was assessed using the evaluation criteria described in a recent review by Burkhard et al. (2021), where 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). 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 location.

$$BAF\ (\frac{L}{Kg}) = C_{fish}/C_{water} \quad \text{X 1000} \qquad \text{[Equation 1]}$$

Where:

C_{fish}= PFAS concentration measured in fish tissue (ng/g)

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

Species-specific BAFs were calculated for each waterbody where results from multiple composite samples of a given species are available. All calculated BAFs are reported in units of log L/kg; the logarithm of the BAF was taken after the BAF was calculated. A logarithmic scale is used because BAFs may vary over several orders of magnitude depending on the fish species, PFAS analyte, and chain length (Pickard et al. 2022). BAFs for the four most commonly caught species are presented graphically. We also calculated BAFs across all species and waterbodies using the geometric mean of individual BAFs within each category; these results are reported for individual analytes detected in at least 25% of waterbodies for both media.

For the BAF calculations, as with the other statistical analyses described above, non-detect observations were first replaced with a value equal to one-half the MDL. In the case of detected observations in fish tissue and non-detect observations for surface water, we report "lower bound" BAF estimates.

4.0 RESULTS AND DISCUSSION

Across this study's complete set of surface water and fish tissue samples, 26 of the 40 PFAS measured by the laboratory were detected above the MDL at least once (Table 5). The remaining 14 PFAS were never detected above the MDL and are not discussed further.

Table 5. PFAS Detected in Surface Water and/or Fish Tissue

PFAS Detected		PFAS Not Detected	
PFDA	7:3FTCA	11Cl-PF3OudS	NEtFOSA
PFDoA	8:2FTS	3:3FTCA	NEtFOSE
PFHpS	PFDoS	4:2FTS	NMeFOSA
PFHxS	PFHpA	5:3FTCA	NMeFOSE
PFNS	PFHxA	9Cl-PF3ONS	PFEESA
PFTeDA	PFPeA	ADONA	PFMBA
PFTrDA	6:2FTS	HFPO-DA	NFDHA
PFUnA	PFBA		
PFOS	PFPeS		
PFDS	PFOSA		
NMeFOSAA	PFOA		
NEtFOSAA	PFBS		
PFMPA	PFNA		

The remainder of this section summarizes results for the 26 detected PFAS. Surface water and fish tissue results are discussed in Sections 4.1 and 4.2, respectively. Trends in PFAS across media are discussed in Section 4.3, and BAFs are shown in Section 4.4. In Section 4.5, measured results are compared to health-based screening values while in Section 4.6 results are compared to EPA draft aquatic life criteria. Limitations of the study are discussed in Section 4.7.

4.1 Surface Water Results

Table 6 presents descriptive statistics for the 16 PFAS detected in at least one surface water sample, as well as ΣPFAS40 and PFAS6. Some important observations are listed below. Results for each waterbody are provided in Appendix B.

- All waterbodies sampled had detectable levels of at least two PFAS analytes.
- PFOA was detected in samples collected from all 52 waterbodies, and PFBS and PFHpA were detected in more than 90% of the waterbodies sampled.
- PFHxS had the highest reported measurement (92.5 ng/L), followed by PFOS (89.0 ng/L).
- PFOA had the highest average concentrations (median=5.70 ng/L, mean=8.04 ng/L).

Table 6. Descriptive Statistics for Surface Water Results (N = 52 samples)

Analyte[a,b]	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	100	1.00	3.15	5.70	9.30	43.0	8.04	8.61
PFBS	92.3	<0.30	0.97	2.20	3.98	15.0	2.83	2.61
PFHpA	92.3	<0.52	1.40	2.58	4.15	24.0	3.67	4.30
PFOS	80.8	<0.50	0.92	2.40	6.00	89.0	7.18	16.4
PFHxA	76.9	<0.50	0.90	3.93	6.75	40.0	6.00	8.15
PFBA	75.0	<2.00	<2.00	3.33	5.05	53.4	4.68	7.42
PFHxS	75.0	<0.57	<0.57	1.25	2.78	92.5	4.17	13.5

Analyte[a,b]	FOD (%)	Min (ng/L)	25th Percentile (ng/L)	Median (ng/L)	75th Percentile (ng/L)	Max (ng/L)	Mean (ng/L)	SD (ng/L)
PFNA	73.1	<0.50	<0.50	0.76	1.20	15.1	1.27	2.20
PFPeA	67.3	<1.00	<1.00	3.15	6.30	48.0	5.55	8.48
PFPeS	34.6	<0.40	<0.40	<0.40	0.48	17.5	0.76	2.40
PFDA	13.5	<0.50	<0.50	<0.50	<0.50	4.30	<MDL	NA
6:2FTS	3.85	<2.50	<2.50	<2.50	<2.50	70.0	3.81	12.8
NEtFOSAA	3.85	<0.70	<0.70	<0.70	<0.70	0.85	<MDL	NA
PFHpS	3.85	<0.40	<0.40	<0.40	<0.40	11.0	0.43	1.50
8:2FTS	1.92	<2.60	<2.60	<2.60	<2.60	22.0	<MDL	NA
PFOSA	1.92	<0.50	<0.50	<0.50	<0.50	1.50	<MDL	NA
PFAS6	NA	1.60	7.75	13.4	22.4	250	24.3	42.3
ΣPFAS40	NA	2.15	12.1	23.7	49.1	467	46.7	82.6

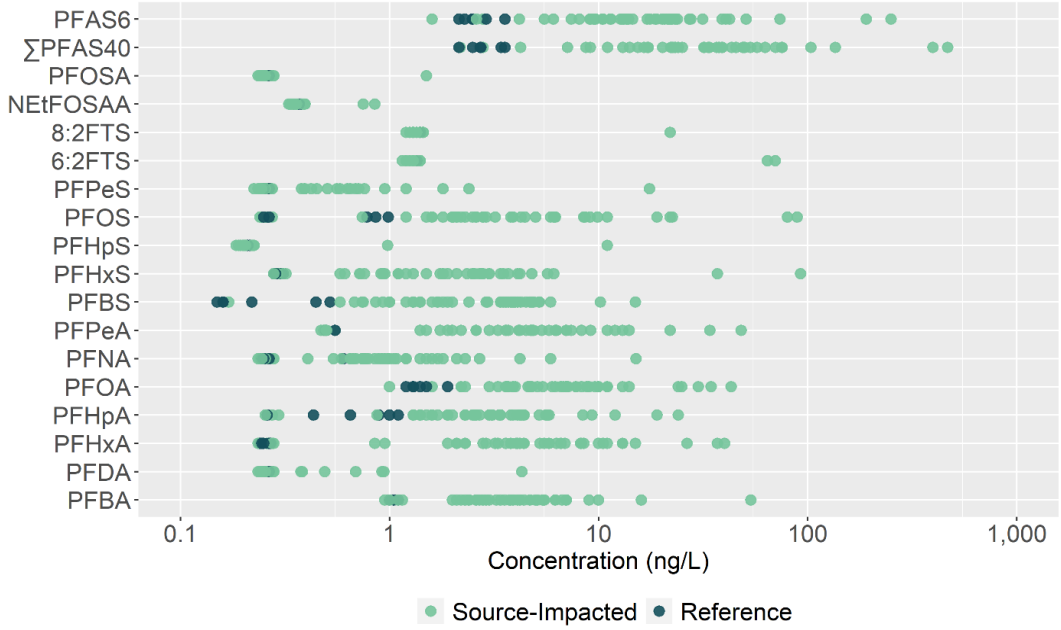
Notes:
ng/L=nanograms per liter, MDL = method detection limit, FOD = frequency of detect, SD=standard deviation, NA=not applicable
Non-detect value are shown as < the laboratory MDL. <MDL indicates that the mean concentration was below the MDL, in which case SD was not calculated (shown as NA).

[a] The following analytes were not detected in any surface water samples and are therefore not included in this table or other tables and figures in this section of the report: 11Cl-PF3OudS, 3:3FTCA, 4:2FTS, 5:3FTCA, 7:3FTCA, 9Cl-PF3ONS, ADONA, HFPO-DA, NEtFOSA, NEtFOSE, NFDHA, NMeFOSA, NMeFOSAA, NMeFOSE, PFDS, PFDoA, PFDoS, PFEESA, PFMBA, PFMPA, PFNS, PFTeDA, PFTrDA, and PFUnA.

[b] Statistics were calculated using the results from routine surface water sampling (n=52). Beach samples were not included in this analysis, as well as in other analyses presented in this section unless specified otherwise.

To further illustrate the distribution of PFAS surface water concentrations, Figure 2 presents a scatter plot of measured concentrations at each waterbody. Visual inspection of the plot suggests that PFAS concentrations in reference waterbodies tend to be lower than those in source-impacted waterbodies—other statistical analyses later in this section confirm this finding.

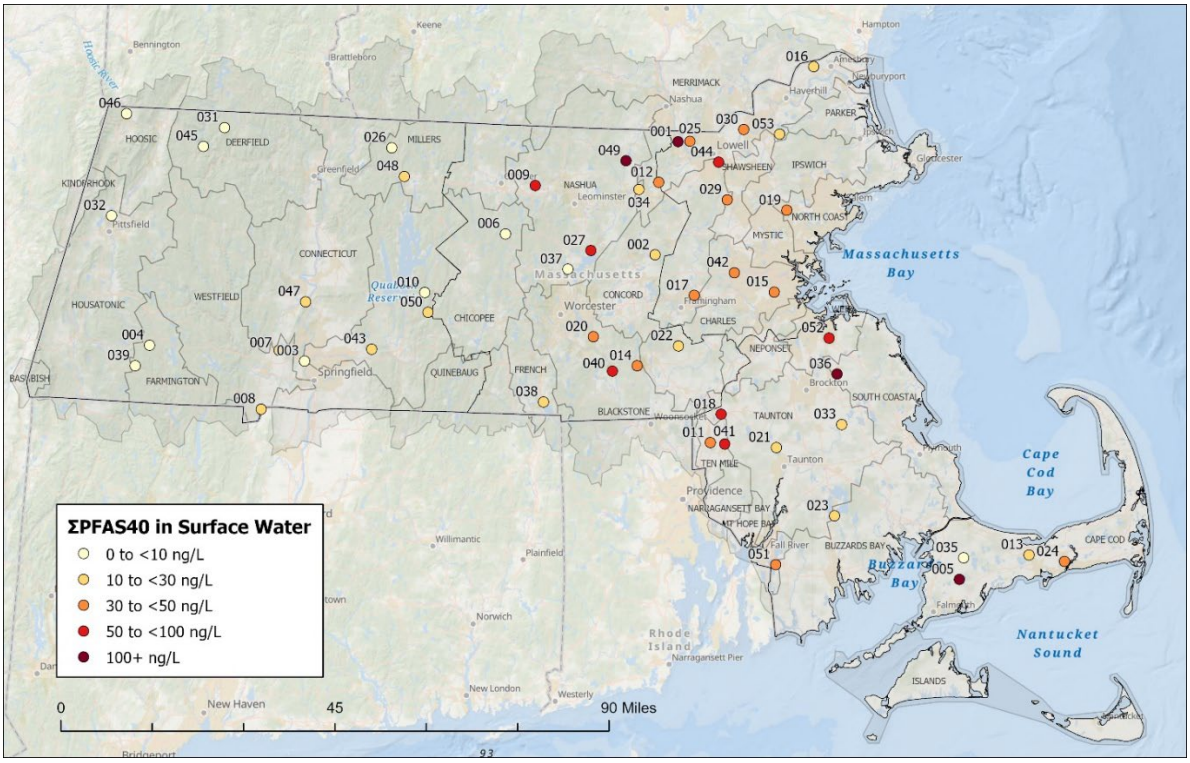
Figure 2. Variability in Surface Water Results



Notes: Each point represents an individual surface water sample result. Points are shaded according to whether corresponding waterbodies are classified as reference (dark blue) or source-impacted (light green) waterbodies. Points may overlap, particularly at lower concentrations. Non-detect values are shown at a concentration equal to ½ the laboratory MDL.

Figure 3 shows ΣPFAS40 surface water results at each waterbody. Twelve waterbodies had ΣPFAS40 concentrations less than 10 ng/L, including all six reference waterbodies, five of which are in the western part of the state. Four waterbodies (i.e., Ashumet Pond, Studley Pond, Nashua River, and Flint Pond) had ΣPFAS40 concentrations exceeding 100 ng/L. These waterbodies are in the eastern part of the state, with two in the Northeast and two in the Southeast. In general, waterbodies in western Massachusetts had lower ΣPFAS40 concentrations; a finding revisited later in this section.

Figure 3. ΣPFAS40 Concentrations in Surface Water

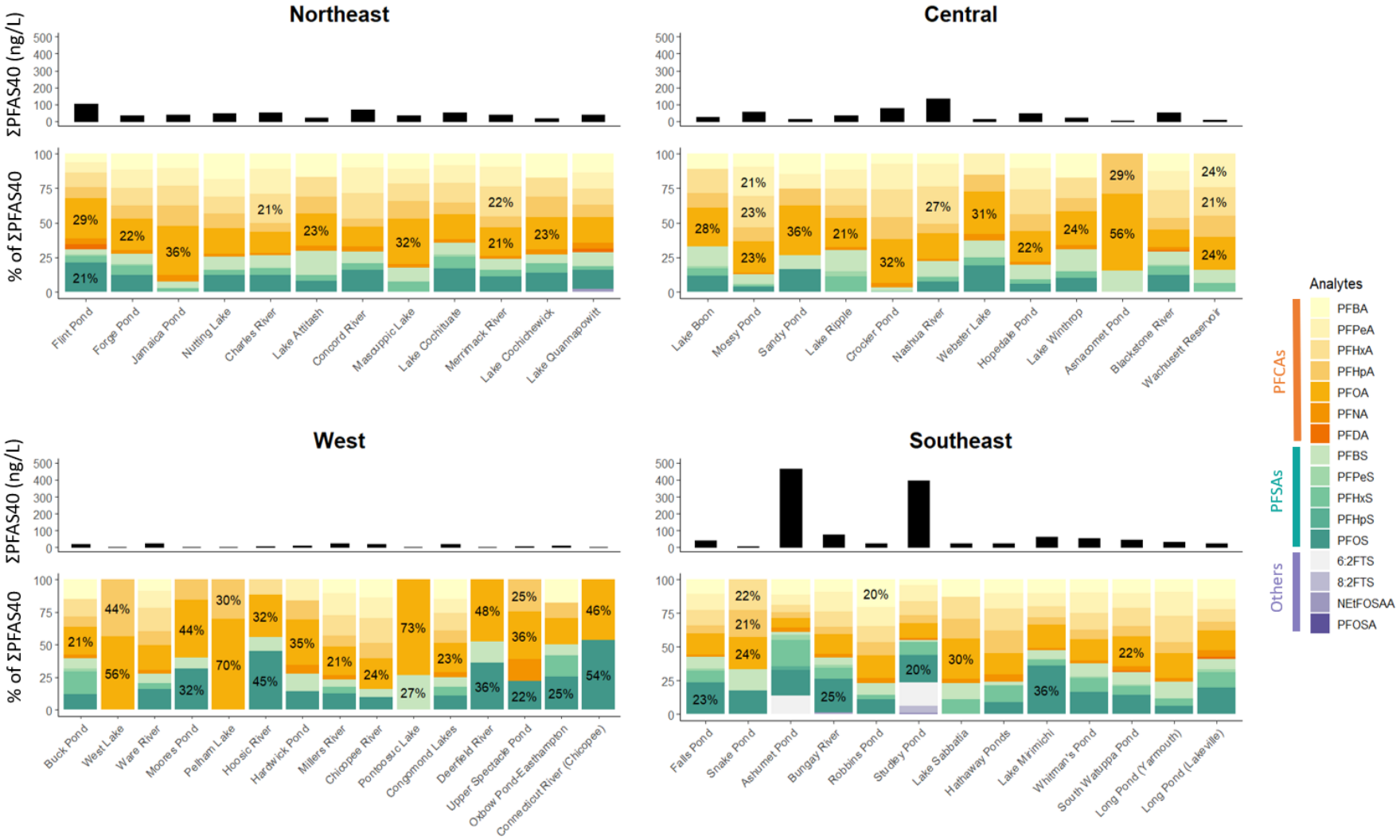


Ashumet and Studley ponds had the highest ΣPFAS40 concentrations in surface water, with measured concentrations exceeding 390 ng/L. Both waterbodies are within one mile of an EJ census block and in the vicinity of current or former DoD sites. Ashumet Pond is located near the Joint Base Cape Cod (JBCC) of Otis National Air Guard Base (1938-present) and Camp Edwards (1911- present). Studley Pond is located near the former South Weymouth Naval Air Station, which was operational from 1942 to 1997. Both bases have been designated as EPA Superfund sites and are sources of various contaminants of concern, including PFAS. Elevated levels of PFAS at Ashumet Pond and Studley Pond likely stem from the use of aqueous film forming foams (AFFF). AFFF use is well documented at both sites and has been the subject of ongoing monitoring and/or remediation efforts by EPA and others. For example, EPA and USGS investigations have found several contaminated groundwater plumes originating from JBCC, one being the "Ashumet Valley" plume that has been associated with elevated PFAS concentrations previously detected in the pond (Weber et al. 2017).

4.1.1 PFAS Profiles in Surface Water

To better understand the distribution of PFAS in surface water, concentrations of detected PFAS analytes in each waterbody were compared to the ΣPFAS40 concentration for that same waterbody. Plotted together, these relative contributions offer insight into the general profile of PFAS in surface water. Figure 4 presents PFAS profiles for each waterbody by region.

Figure 4. PFAS Profiles in Surface Water



Notes: The top chart in each panel compares ΣPFAS40 concentrations across the waterbodies. The bottom panel compares the relative contribution of different PFAS compounds to ΣPFAS40 across waterbodies. Percentages are shown for PFAS (mostly PFOA and PFOS) contributing 20% or more to ΣPFAS40 for a given waterbody.

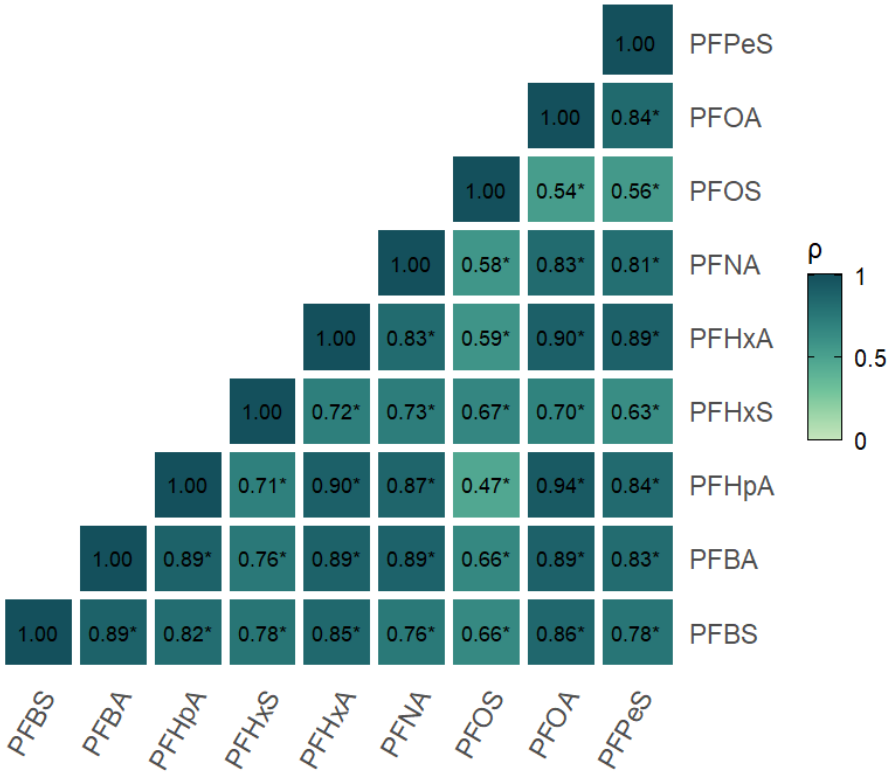
PFOA dominated PFAS profiles in surface water, with PFOA contributing 27% of ΣPFAS40 on average (range: 7.4%-73.4 %). PFOS contributed 15% on average (range: 0.33%, 53.6%). These findings are consistent with other recently published peer-reviewed studies (e.g., Pickard et al., 2022) and state reports (e.g., NHDES, 2021).

In general, perfluorinated carboxylic acids (PFCAs) made up a greater percentage of ΣPFAS40 than perfluorinated sulfonic acids (PFSAs). Across all waterbodies, an average of 70% of ΣPFAS40 came from PFCAs, 29% came from PFSAs, and 1% came from other PFAS analytes. This general trend holds true when looking specifically at source-impacted or reference waterbodies, as well as when looking at waterbodies within a given region or by lakes/ponds versus rivers. This trend was observed for all waterbodies except Ashumet Pond, Studley Pond, Lake Mirimichi, the Hoosic River, the Deerfield River, and the Connecticut River (Chicopee sampling location).

4.1.2 Correlation of PFAS Analytes in Surface Water

To understand PFAS concentration patterns in surface water, we examined correlations among PFAS. Figure 5 presents Spearman correlation coefficients for all PFAS detected in more than half of the surface waters sampled. Note that a Spearman correlation coefficient of one means that the surface water concentration from two PFAS are perfectly correlated – i.e., concentrations for these compounds increase or decrease proportionally. A Spearman correlation coefficient of zero means that the concentrations are completely uncorrelated. We did not examine correlations for analytes detected in less than half of surface waters samples and therefore cannot speak to whether concentrations of these analytes were or were not correlated.

Figure 5. Correlation of PFAS Measured in Surface Water

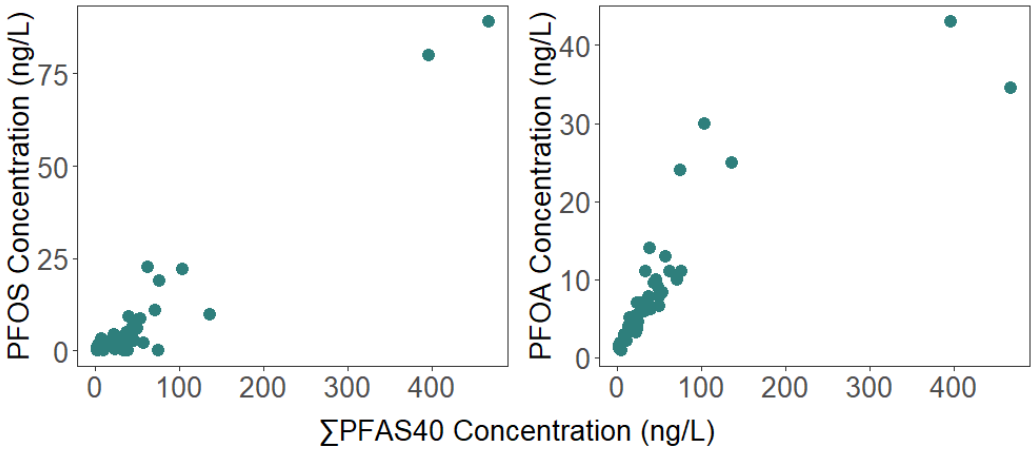


Notes: Correlogram includes analytes detected in at least 50% of samples. Non-detect observations are substituted with a value equal to ½ the laboratory MDL. Values shown represent Spearman's rank correlation coefficients (ρ) between analyte pairs; no negative correlations were identified. An asterisk (*) indicates that the correlation coefficient was significant ($p<0.05$).

For the PFAS analytes that were examined, all correlation coefficients were significant and positive, suggesting that if a sample had a high concentration of one common PFAS analyte, it was likely to have a high concentration of other common analytes. In Figure 5, darker colored squares have a stronger correlation between the pair of PFAS analytes. For example, PFOA and PFHpA are shown to be highly correlated (ρ=0.94) while PFOA and PFOS were only moderately correlated (ρ=0.54). Of note, the correlation coefficient observed in this study between PFOS and PFOA is similar to that reported by Zareitalabad et. al (2013) in a review paper of multiple studies. For these analytes, the researchers reported an overall Kendall's tau rank correlation coefficient of 0.52.

We also examined the relationship of ΣPFAS40 with individual PFAS analyte concentrations. For example, Figure 6 presents the correlation between ΣPFAS40 and PFOA (ρ=0.94, p<0.05), as well as ΣPFAS40 and PFOA (ρ=0.67, p<0.05).

Figure 6. Correlation of ΣPFAS40, PFOS, and PFOA in Surface Water



Notes: Scatterplots show the relationship between ΣPFAS40 and individual PFAS (PFOS and PFOS) concentrations. Points represent individual surface water results from each waterbody. Non-detect observations are shown at ½ the laboratory MDL.

Of all the PFAS analytes examined, PFOS had the weakest correlation with other analytes. This suggests that the factors that affect PFAS levels in surface water may differ most for PFOS. These factors include the original sources of the chemicals and how the individual chemicals degrade differently over time.

4.1.3 Surface Water Results by Waterbody Characteristics

Surface water PFAS concentrations were evaluated by various waterbody characteristics. For each, this section describes the magnitude of PFAS concentration differences and whether concentration differences were statistically significant. These comparisons were only made for PFAS that were detected in at least 50% of samples. Overall, significant differences in PFAS concentrations were found by reference status and region, but not by proximity to EJ communities or type of waterbody.

Reference Versus Source-impacted Waterbodies

Table 7 presents descriptive statistics for PFAS in source-impacted and reference waterbodies. For every PFAS analyte and for ΣPFAS40 and PFAS6, the source-impacted waterbodies had considerably higher concentrations than the reference waterbodies; and for all waterbodies, median concentrations were significantly different (p<0.05). The median ΣPFAS40 concentration in source-impacted waterbodies was 32.0 ng/L, which is more than 10 times higher than that in reference waterbodies (2.72 ng/L). PFOA, the one analyte detected in all waterbodies, had a median concentration of 6.70 ng/L in source-impacted waterbodies and a median concentration of 1.35 ng/L in reference waterbodies. These differences

confirm an expected result: source-impacted waterbodies have higher PFAS surface water concentrations than reference waterbodies. However, it is notable that PFAS were detected in all waterbodies, including reference locations.

Table 7. PFAS in Surface Water by Source-impacted and Reference Waterbodies

PFAS	Source Impacted Waterbodies (n=46)			Reference Waterbodies (n=6)		
	FOD (%)	Max (ng/L)	Median (ng/L)	FOD (%)	Max (ng/L)	Median (ng/L)
PFOA*	100	43.0	6.70	100	1.90	1.35
PFBS*	97.8	15.0	3.18	50.0	0.52	<0.30
PFHpA*	93.5	24.0	3.00	83.3	1.10	0.77
PFHxA*	86.9	40.0	4.20	0.00	NA	NA
PFOS*	84.8	89.0	2.70	50.0	0.99	0.52
PFBA*	84.8	53.4	3.78	0.00	NA	NA
PFHxS*	84.8	92.5	1.78	0.00	NA	NA
PFNA*	80.4	15.1	0.78	16.7	0.60	<0.50
PFPeA*	76.1	48	3.93	0.00	NA	NA
ΣPFAS40*	NA	467	32.0	NA	3.57	2.72
PFAS6*	NA	250	14.2	NA	3.57	2.50

Note: Table shows sums and individual analytes detected across all waterbodies with an FOD > 50%. An asterisk (*) indicates that median concentrations were significantly different for source-impacted and reference waterbodies (p<0.05). Non-detect observations are substituted with a value equal to ½ the laboratory MDL. FOD is used for "frequency of detection."

MassDEP Regions

Table 8 presents PFAS measurements in surface water by MassDEP region. There were significant differences in PFAS concentrations across analytes by region. In general, lower concentrations were measured in waterbodies located in the western region, which is also where five of the six reference waterbodies are located. A post-hoc Dunn's Test was performed after the Kruskal Wallis test was significant (p<0.05) to investigate pairwise differences between regions for the summed PFAS analytes. Concentrations of ΣPFAS40 and PFAS6 in waterbodies from the western region were significantly lower than concentrations of ΣPFAS40 and PFAS6 in waterbodies from the other three regions.

Table 8. PFAS in Surface Water by MassDEP Region

PFAS	Western (n=15)		Central (n=12)		Northeastern (n =12)		Southeastern (n=13)	
	FOD (%)	Median (ng/L)	FOD (%)	Median (ng/L)	FOD (%)	Median (ng/L)	FOD (%)	Median (ng/L)
PFOA*	100	2.20	100	6.80	100	8.30	100	7.00
PFOS*	80.0	1.50	66.7	2.25	83.3	4.63	92.3	6.20
PFBS*	73.3	0.75	100	3.55	100	3.60	100	3.85
PFHpA*	73.3	1.10	100	2.90	100	3.85	100	3.40
PFBA*	40.0	1.10	75.0	3.90	100	4.20	92.3	4.40
PFHxA*	40.0	0.28	75.0	4.25	100	5.65	100	5.25
PFNA*	40.0	0.27	66.7	0.75	100	1.10	92.3	1.08
PFHxS*	33.3	0.31	83.3	0.93	100	2.00	92.3	2.75
PFPeA*	33.3	0.55	75.0	3.35	83.3	5.13	84.6	4.80
ΣPFAS40*	NA	7.10	NA	29.3	NA	38.3	NA	39.1
PFAS6*	NA	5.50	NA	14.2	NA	19.5	NA	21.8

Note: Table shows sums and individual analytes detected across all waterbodies with FOD > 50%. An asterisk (*) indicates that median concentrations were significantly different by region (p<0.05). Non-detect observations are substituted with a value equal to ½ the laboratory MDL. FOD is used for "frequency of detection."

Type of Waterbody

Table 9 presents surface water results for lakes/ponds and rivers. Overall, there were no significant differences in PFAS concentration by waterbody type. PFOS was slightly higher in rivers than lakes and ponds, as well as for PFPeA and PFHxA, though results were significantly different ($p<0.05$).

Table 9. PFAS in Surface Water by Lake/Ponds and Rivers

PFAS	Lakes or Ponds (n= 40)			Rivers (n= 12)		
	FOD (%)	Max (ng/L)	Median (ng/L)	FOD (%)	Max (ng/L)	Median (ng/L)
PFOA	10	43.0	5.70	100	25.0	5.70
PFHpA	97.5	24.0	2.53	75.0	9.30	2.80
PFBS	92.5	10.2	2.20	91.7	15.0	2.33
PFHxS	77.5	92.5	1.25	66.7	6.10	1.45
PFBA	75.0	53.4	3.33	75.0	10.0	2.98
PFHxA	75.0	40.0	3.80	83.3	37.0	6.33
PFNA	75.0	15.1	0.75	66.7	2.70	0.78
PFOS	75.0	89.0	2.10	100	19.0	4.03
PFPeA	65.0	48.0	2.40	75.0	22.0	4.53
ΣPFAS40	NA	467	23.3	NA	136	30.9
PFAS6	NA	250	13.4	NA	50.8	15.2

Note: Table shows sums and individual analytes detected across all waterbodies with FOD > 50%. For all analytes, median concentrations were not significantly different by type of waterbody ($p>0.05$). Non-detect observations are substituted with a value equal to ½ the laboratory MDL. FOD is used for "frequency of detection."

Proximity to EJ Communities

Table 10 compares surface water concentrations of PFAS analytes for waterbodies closer to, and further from, EJ communities. For all but one analyte, median concentrations in waterbodies near EJ census blocks were higher than for waterbodies further from EJ block groups; however, these concentration differences were not statistically significant ($p<0.05$).

Table 10: PFAS in Surface Waterbody by Waterbody Proximity to EJ Community

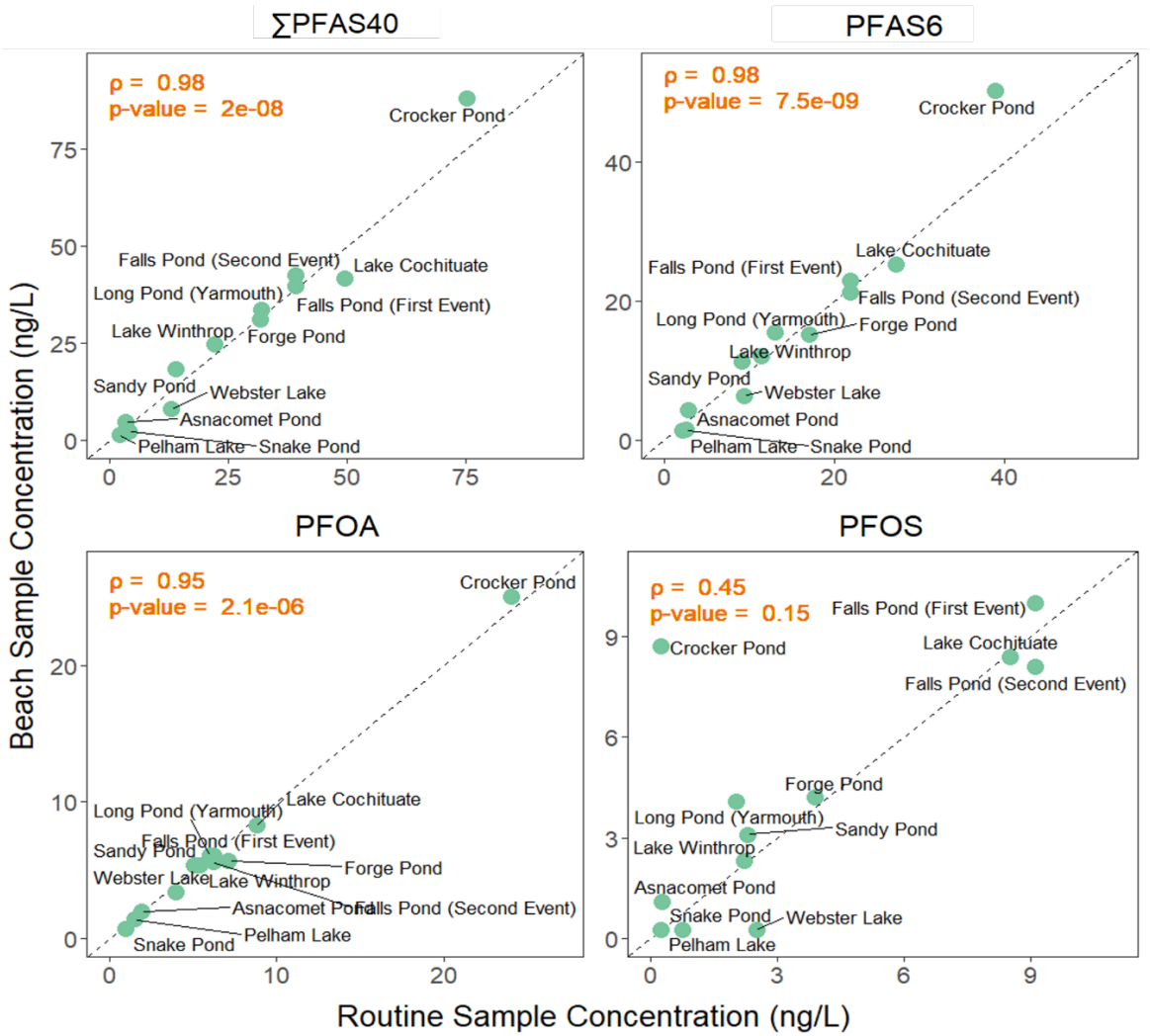
PFAS	Not Within One Mile of an EJ Census Block (n=17)			Within One Mile of an EJ Census Block (n=35)		
	FOD (%)	Max (ng/L)	Median (ng/L)	FOD (%)	Max (ng/L)	Median (ng/L)
PFOA	100	25.0	3.90	100	43.0	7.00
PFHpA	100	9.30	2.30	88.6	24.0	3.00
PFBS	88.2	15.0	2.00	94.3	10.2	2.40
PFOS	88.2	22.5	2.20	77.1	89.0	2.50
PFNA	76.5	2.70	0.76	71.4	15.1	0.75
PFHxA	70.6	37.0	2.90	80.0	40.0	4.20
PFBA	70.6	10.0	3.25	77.1	53.4	3.55
PFHxS	70.6	4.20	1.10	77.1	92.5	1.75
PFPeA	52.9	22.0	1.40	74.3	48.0	4.15
ΣPFAS40	NA	136	22.6	NA	467	32.1
PFAS6	NA	50.8	11.5	NA	250	14.5

Note: Table shows sums and individual analytes detected across all waterbodies with FOD > 50%. For all analytes, median concentrations were not significantly different by proximity to EJ Census blocks ($p>0.05$). Non-detect are observations substituted with a value equal to ½ the laboratory MDL FOD is used for "frequency of detection."

4.1.4 Spatial Variability of PFAS within a Waterbody

Figure 7 shows the correlation between surface water samples collected at beach locations and the corresponding routine water samples, based on 12 sampling events. With one exception, described below, the beach water concentrations for ΣPFAS40, PFAS6, and PFOA were highly correlated (p >0.95) with the corresponding routine surface water concentrations; and these correlations were all statistically significant. These correlations indicate that PFAS water concentrations collected near the surface of lakes and ponds are highly similar across the waterbody, though this analysis is based on only two sampling locations per waterbody.

Figure 7. Correlation of Routine and Beach Sample Results



Notes: The dashed line is a 1:1 line. Results of the corresponding Spearman rank test are shown in the upper left corner in orange text. Non-detect are observations substituted with a value equal to ½ the laboratory method detection limit.

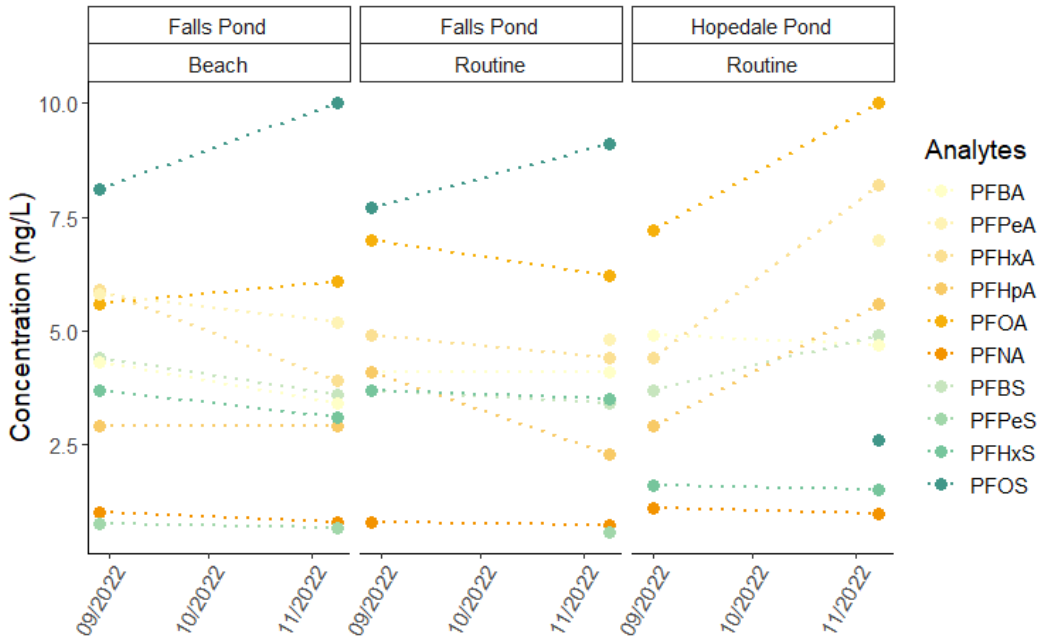
The correlation between PFOS concentrations in beach and routine surface water samples was weaker than other analytes (ρ=0.45, p=0.15). Though most data still fell along the 1:1 line, the sample pair from Crocker Pond noticeably deviated. For this waterbody, the PFOS concentration in the beach surface water sample (8.70 ng/L) was 189% times higher than the corresponding routine water sample (0.25 ng/L). The reasons for this are unclear, but unique characteristics of the waterbody may contribute to the difference (e.g., proximity of the beach sampling location to a tributary with PFAS loading from

upstream sources, the presence of contaminated sediments that were disturbed during the beach sampling event). A sensitivity analysis excluding this point found that the correlation coefficient between PFOS concentrations in beach and routine samples increased to 0.79 (p = 0.004).

4.1.5 Temporal Variability of PFAS within a Waterbody

At two waterbodies (i.e., Falls Pond and Hopedale Pond), two surface water sampling events occurred approximately two months apart (late summer to fall). These events resulted in three pairs of samples: beach samples Falls Pond, routine samples from Falls Pond, and routine samples from Hopedale Pond. Figure 8 depicts how PFAS surface water concentrations differed between sampling events. While there were small differences between the two rounds of samples, there were no clear increasing or decreasing trends among analytes or within waterbodies. However, this study was not designed to characterize temporal variations in PFAS surface water concentrations, and more sampling over longer time frames is needed to fully characterize this issue.

Figure 8. Repeated PFAS Measurements from the Same Waterbody



Note: Only detected surface water concentrations are shown.

4.2 Fish Tissue Results

Table 11 presents descriptive statistics for 21 PFAS detected in at least one fish tissue composite sample, as well as ΣPFAS40 and PFAS6. Some important observations are listed below. Results for each waterbody for the ten most frequently detected PFAS are provided in Appendix C.

- All waterbodies had detectable levels in fish tissue of at least one PFAS.
- PFAS were detected in all but one of the 242 composite samples collected.
- PFOS was the most commonly detected PFAS analyte, detected in 99% of samples and at every waterbody. The other PFAS analytes detected in more than 50% of samples were all PFCAs.
- PFOS had the highest recorded concentration (280 ng/g, Ashumet Pond LMB), as well as the highest average concentrations (median=5.70 ng/g, mean=21.7 ng/g), across all PFAS analytes.
- ΣPFAS40 ranged from 0 ng/g (no detects) to 288 ng/g. PFAS6 ranged from 0 ng/g to 281 ng/g.

Table 11. Descriptive Statistics for Fish Tissue Samples

Analyte[1]	FOD Among Composites (%)	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	99.1	100	<0.12	2.70	5.70	18.5	280	21.66	43.8
PFUnA	94.6	97.9	<0.13	0.43	0.72	1.20	5.00	0.94	0.76
PFTrDA	93.8	97.9	<0.08	0.24	0.37	0.57	2.30	0.45	0.34
PFDoA	90.1	97.9	<0.08	0.22	0.41	0.65	2.60	0.51	0.42
PFDA	81.8	91.5	<0.22	0.27	0.48	0.93	11.0	0.93	1.55
PFTeDA	68.2	89.4	<0.11	<0.11	0.22	0.37	1.40	0.27	0.25
PFNA	27.3	53.2	<0.15	<0.15	<0.15	0.19	1.50	0.16	0.20
PFOSA	24.4	51.1	<0.09	<0.09	<0.09	<0.09	5.70	0.15	0.48
PFDS	19.8	31.9	<0.20	<0.20	<0.20	<0.20	1.20	<0.20	NA
PFHxS	12.0	23.4	<0.08	<0.08	<0.08	<0.08	1.80	0.09	0.21
PFHpS	4.96	4.26	<0.12	<0.12	<0.12	<0.12	0.46	<0.12	NA
PFOA	3.72	12.8	<0.20	<0.20	<0.20	<0.20	0.39	<0.20	NA
PFNS	2.48	2.13	<0.09	<0.09	<0.09	<0.09	0.19	<0.09	NA
7:3FTCA	2.07	2.13	<2.98	<2.98	<2.98	<2.98	21.0	<2.98	NA
8:2FTS	2.07	2.13	<0.68	<0.68	<0.68	<0.68	19.0	<0.68	NA
NMeFOSAA	1.24	4.26	<0.21	<0.21	<0.21	<0.21	1.05	<0.21	NA
PFHpA	0.83	4.26	<0.12	<0.12	<0.12	<0.12	0.21	<0.12	NA
PFMPA	0.83	4.26	<0.12	<0.12	<0.12	<0.12	0.14	<0.12	NA
NEtFOSAA[bc]	0.41	2.13	<1.7[c]	NA	NA	NA	<1.7[c]	NA	NA
PFDoS[b]	0.41	2.13	0.17	NA	NA	NA	0.17	NA	NA
PFHxA[b]	0.41	2.13	1.10	NA	NA	NA	1.10	NA	NA
PFAS6	NA	NA	<MDL	3.14	6.70	19.6	281	22.9	44.4
ΣPFAS40	NA	NA	<MDL	4.61	9.00	23.8	288	25.4	45.6

Notes: Fish tissue data represent results from 242 composite samples. Results shown here are weighted by number of fish within each composite sample.
NA=not applicable and is shown for all statistics when a PFAS analyte was only detected in one sample as well as for SDs when the mean is reported at a concentration <MDL. Non-detect value are shown as < the laboratory MDL. FOD is used for "frequency of detection."

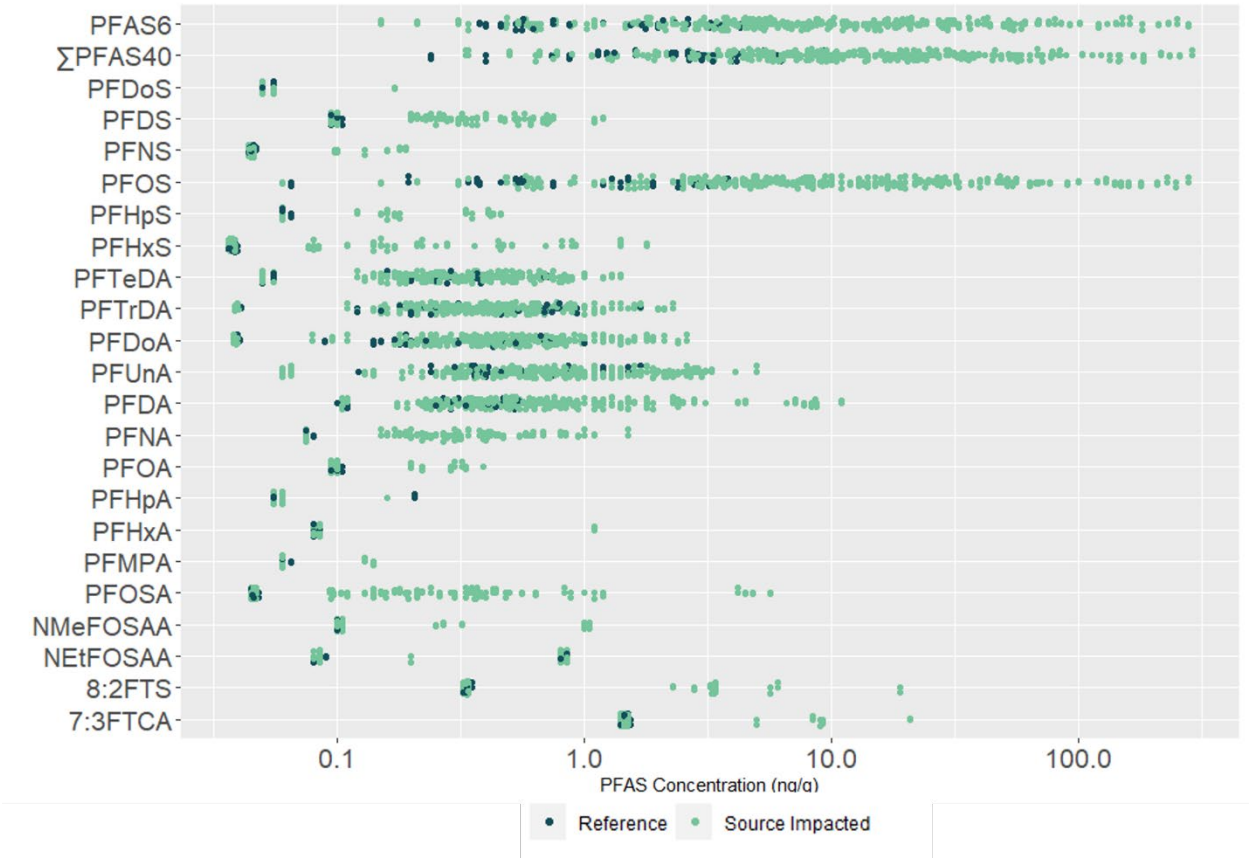
[a] The following analytes were not detected in any fish tissue samples and therefore not included in this table or any of the tables and figures in the rest of this section: PFPeA, 6:2FTS, PFBA, PFPeS, PFBS, 11Cl-PF3OUdS, 3:3FTCA, 4:2FTS, 5:3FTCA, 9Cl-PF3ONS, ADONA, HFPO-DA, NEtFOSA, NEtFOSE, NMeFOSA, NMeFOSE, PFEESA, PFMBA, NFDHA.

[b] This analyte was only detected in one sample. The measured concentration is reported here as the min and max, with NA for all other statistics.

[c] The median laboratory MDL reported for NEtFOSAA was 1.7 ng/g for our data compared to the laboratory target of 0.17 ng/g. Because of the order of magnitude difference, values under 1.7 are reported here as < the median reported MDL.

Figure 9 plots composite sample results for individual PFAS analytes detected in fish tissue, as well as the two PFAS sums. This figure shows the higher concentrations and greater variability of PFOS in fish tissue compared to all other measured PFAS. PFOS also had the highest reported individual measurement. This maximum concentration was observed in a composite sample consisting of five largemouth bass that were caught in Ashumet Pond, the same waterbody where the highest PFAS levels in surface water were found.

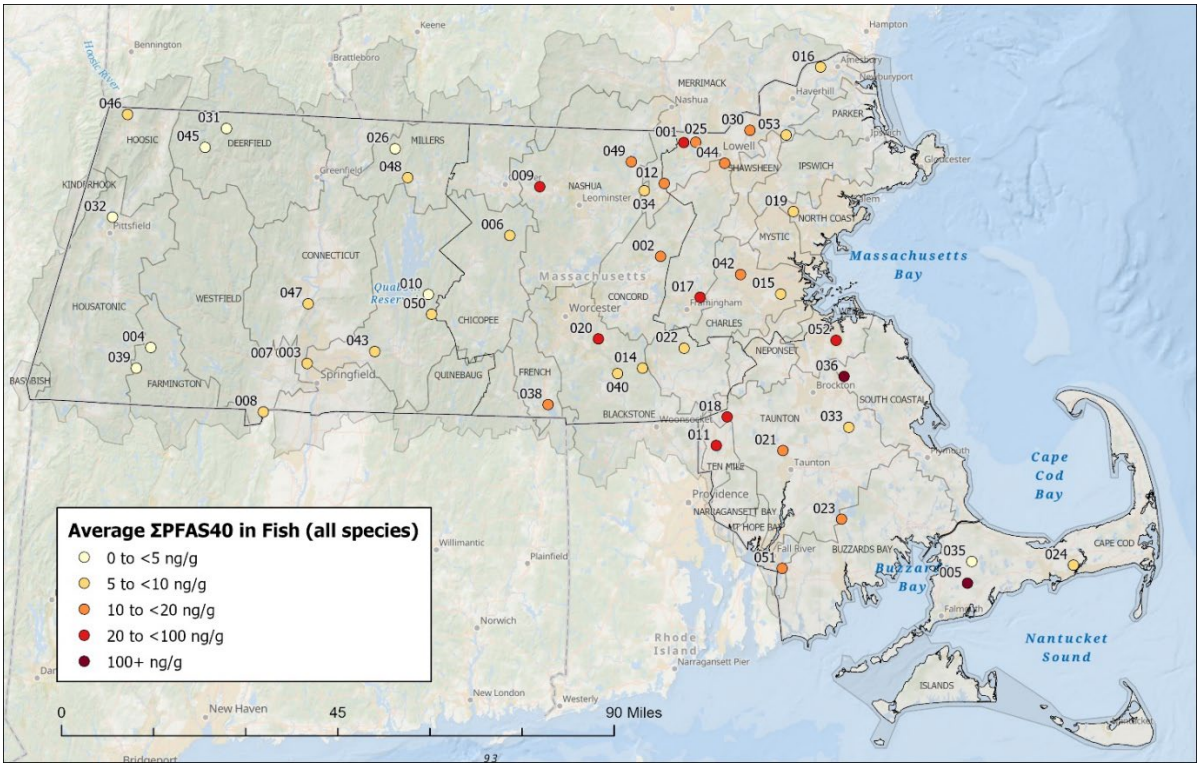
Figure 9. Variability in Fish Tissue Results



Notes: Each point represents a fish tissue composite sample result. Non-detect values are shown at a concentration equal to ½ the laboratory method detection limit. In cases where multiple samples have the same numerical value (e.g., non-detects), they may overlap or appear in this plot as a single point.

Figure 10 presents a map showing the spatial distribution of ΣPFAS40 concentrations measured in fish tissue at the 47 sampled waterbodies. Nine waterbodies had ΣPFAS40 concentrations above 20 ng/L – two of which (i.e., Ashumet Pond and Studley Pond) had concentrations above 100 ng/g. Eleven waterbodies had ΣPFAS40 concentrations between 10 ng/g and 20 ng/g, and 18 waterbodies had concentrations between 5 ng/g and 10 ng/g. Nine waterbodies had average ΣPFAS40 fish tissue concentrations below 5 ng/g, including five of the six waterbodies selected as reference locations for this study (i.e., the Deerfield River [0.40 ng/g], Pelham Lake [1.29 ng/g], West Lake [2.74 ng/g], Upper Spectacle Pond [3.21 ng/g], and Moores Pond [3.92 ng/g]). The remaining reference waterbody, Asnacomet Pond, had an average ΣPFAS40 fish tissue concentration of 6.66 ng/g. In general, and similar to surface water, waterbodies in western Massachusetts had lower ΣPFAS40 concentrations.

Figure 10. ΣPFAS40 Concentrations in Fish Tissue



Notes: Values shown are weighted waterbody means, with weights equal to the number of fish in each composite sample.

Other studies have reported similar median levels of summed PFAS in fish samples across the U.S. For example, Barbo et al., conducted a review including data from 500 composite samples of fish filets collected from U.S. waterbodies between 2013 to 2015. The researchers reported a median "total" PFAS concentration (based on the sum of 13 analytes) of 9.5 ng/g in fish from rivers/streams across the U.S. and 11.8 ng/g in fish sampled from the Great Lakes. Similar to the current study, other researchers have found PFOS to be detected in the largest proportions relative to other PFAS measured in freshwater fish tissue (Barbo et al., 2023; Blazer et al., 2021; Fair et al., 2019; Goodrow et al., 2020). Barbo et al. (2023), for example, found that PFOS made up, on average, 74% of the summed PFAS detected in fish filets. In a study of fish tissue in source-impacted waterbodies in New Jersey. Goodrow et al. (2020) found that across 96 fish samples, PFOS had the greatest average concentration (28.7 ng/g) compared to other PFAS. Similarly, of the five PFAS compounds regulated by Vermont, PFOS was the only compound consistently detected in fish tissue above reporting limits in a recent sampling program (VT DEC 2022). PFUnA, PFDA, PFNA, and PFDoA have also been commonly detected in fish tissue samples from across the country (Stahl et al., 2023; Pickard et al., 2022; MacGillivray 2020; Goodrow et al., 2020; Fair et al., 2019; Blazer et al., 2021; Newsted et al., 2017).

Specific to Massachusetts and as mentioned in Section 2.1, MDPH recently conducted two surveys of PFAS in fish from selected Massachusetts waterbodies. In 2021, MDPH sampled surface water from 16 and fish tissue from five Cape Cod waterbodies located near JBCC (MDPH, 2021). Of note, MDPH collected surface water from Snake Pond and fish tissue and surface water from John's Pond. In the present study, we also sampled surface water and fish tissue from Snake Pond, as well as from Ashumet Pond, which is less than half a mile northwest of John's Pond. The 51 individual fish collected by MDPH for the 2021 Cape Cod study were analyzed for 40 PFAS using SGS AXYS Method MLA-110 (reporting limit=0.1 ng/g). PFTrDA and PFOS were detected in 100% of MDPH's 2021 samples and PFDA, PFUnA,

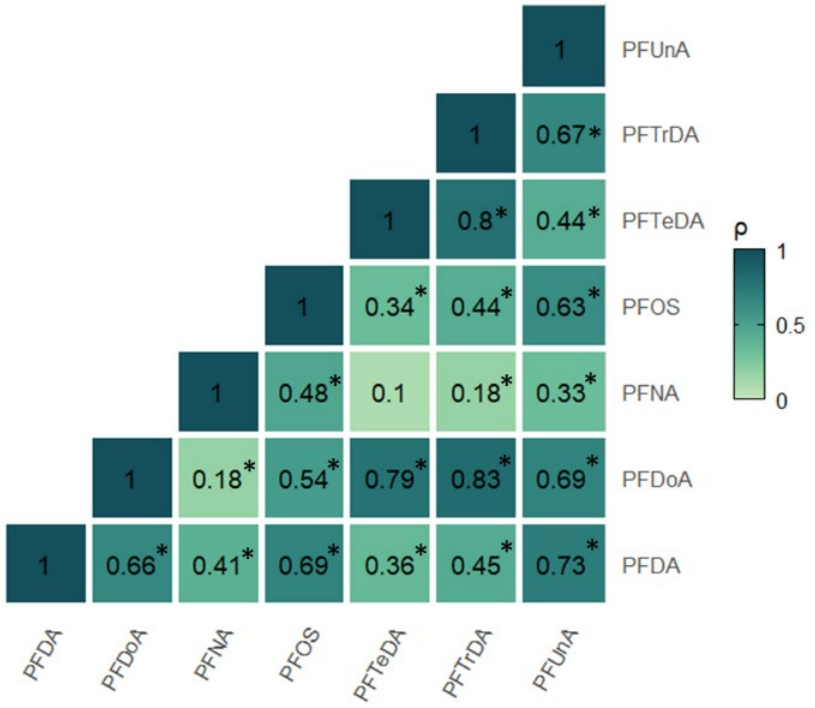
PFDoA, and PFTeDA were detected in 75% or more of the samples. Among these analytes, average concentrations were similar or slightly higher in the present study, with the exception of PFTrDA and PFOS. Six species of fish were collected by MDPH from John's Pond, including largemouth bass, white perch, and yellow perch, which were all also collected in the present study at Ashumet Pond. Average concentrations of PFOS in these species were slightly lower in John's Pond than what was found in the current study from Ashumet Pond; the average PFOS concentration was 73.37 ng/gµg/kg, 140.30 ng/g, and 74.90 ng/g in John's Pond compared to 230.00 µg/kg, 206.67 µg/kg, 126.67 µg/kg in Ashumet Pond for largemouth bass, white perch, and yellow perch, respectively.

MDPH conducted another study in 2022 assessing PFAS in fish at state parks operated by the DCR. This study led to fish consumption advisories at 13 waterbodies, ranging from "do not eat any fish" to limiting fish consumption to "one meal per week" (MDPH, 2023). One of the waterbodies sampled in the MDPH 2022 study overlapped with the current study (i.e., Lake Cochituate). The results of the 2022 MPDH study led to a fish advisory stating not to eat any American eel and to limit consumption of other species to one meal per month at Lake Cochituate. In the present study, PFOS was measured at elevated concentrations in fish tissue from this waterbody, ranging from 16 ng/g to 30 ng/g.

4.2.1 Correlation of PFAS Measured in Fish Tissue

We evaluated Spearman correlations for all analytes detected in 50% or more of the composite samples (Figure 11). All correlation coefficients were positive, though the strength of correlation varied. The strongest correlations were observed for PFDoA and PFTrDA (ρ= 0.83), PFTeDA and PFTrDA (ρ=0.80), and PFTeDA and PFDoA (ρ=0.79), all of which are long-chain PFCAs. Some analytes were not correlated with one another (e.g., PFNA and PFTeDA (ρ=0.1)). Note that we did not examine the correlations involving analytes detected in fewer than half of fish tissue samples.

Figure 11. Correlation of PFAS Measured in Fish Tissue



Notes: Correlogram between PFAS analytes detected in at least 50% of composite samples analyzed. Non-detect observations are substituted with a value equal to ½ the laboratory MDL. Values shown represent Spearman's rank correlation coefficients between analyte pairs; no negative correlations were identified. An asterisk (*) indicates statistical significance ($p<0.05$).

4.2.2 Fish Tissue Results by Species and Species Characteristics

Samples were collected from 16 unique fish species. The species of fish caught varied across waterbodies, with the most frequently caught species being yellow perch (56 composite samples; 28 waterbodies), largemouth bass (45 composite samples, 23 waterbodies), bluegill (40 composite samples, 20 waterbodies), and pumpkinseed (34 composite samples, 18 waterbodies). Several species were only caught at one waterbody, including American eel (2 composite samples from Forge Pond), brown trout (2 composite samples from the Hoosic River), common carp (2 composite samples from Pontoosuc Lake), redbreast (1 fish from Millers River), smallmouth bass (3 composite samples from the Connecticut River), and yellow bullhead (1 fish from Sandy Pond). Species sampled at reference waterbodies included yellow perch, largemouth bass, bluegill, pumpkinseed, black crappie, and rainbow trout.

ΣPFAS40 by Species

Table 12 presents summary statistics for ΣPFAS40 by species. Median ΣPFAS40 concentrations varied from 1.81 ng/g in brown bullhead to 20.3 ng/g in black crappie. The highest concentrations were measured in bluegill, largemouth bass, yellow perch and white perch. Note that white perch were caught at only four waterbodies, one of which was Ashumet Pond. While this table shows variability across species, it is important to note that the waterbody from which the fish were collected likely contributes substantially to variability across species in ΣPFAS40 concentrations and analyte composition. In a liner regression model that included results for the four most commonly caught species (i.e., yellow perch, largemouth bass, pumpkinseed, and bluegill), we found that species was significantly associated with ΣPFAS40, while controlling for waterbody ($p<0.05$). In other words, within each waterbody, certain species had consistently higher or lower ΣPFAS40 than other species. ΣPFAS40 was significantly lower in pumpkinseed compared to yellow perch ($p<0.05$), and there was a trend towards higher ΣPFAS40 in largemouth bass compared to yellow perch ($p=0.08$). There was no significant difference in ΣPFAS40 between bluegill and yellow perch.

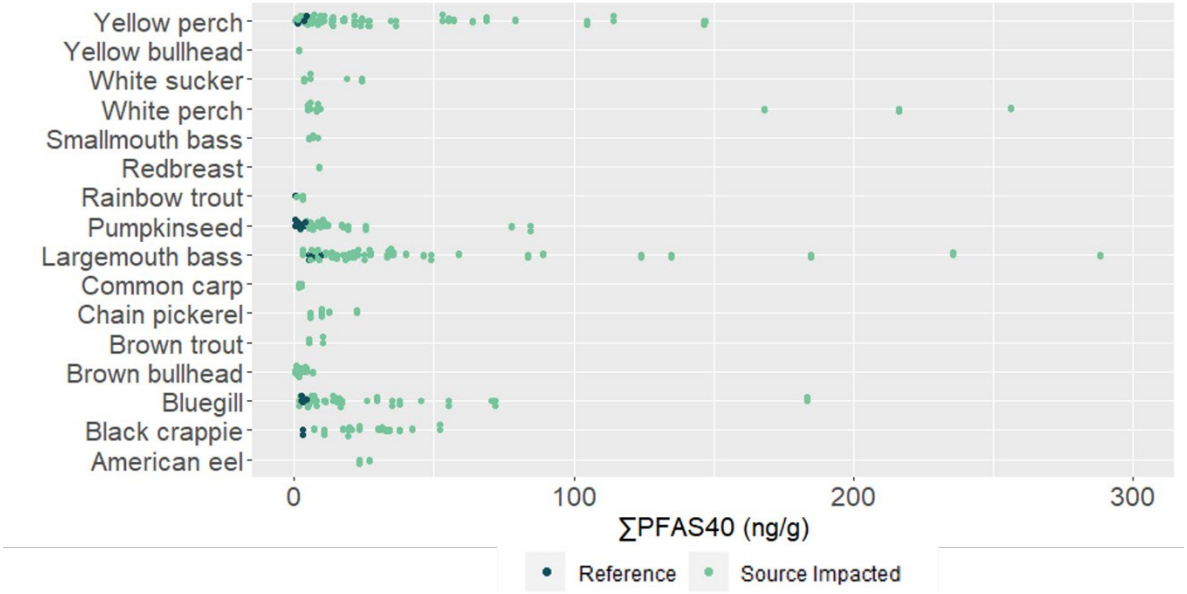
Table 12. ΣPFAS40 in Fish Tissue by Species

Species	Number of Samples	Min (ng/g)	25th Percentile (ng/g)	Median (ng/g)	75th Percentile (ng/g)	Max (ng/g)	Mean (ng/g)	SD (ng/g)
American eel	2	23.1	NA	NA	NA	27.0	NA	NA
Bluegill	40	1.62	4.32	7.21	16.5	183	18.7	28.1
Brown bullhead	15	0.33	1.08	1.81	3.20	6.69	2.37	1.77
Black crappie	17	2.88	10.5	20.3	32.5	52.2	23.6	13.3
Brown trout	2	5.40	NA	NA	NA	10.0	NA	NA
Common carp	2	1.81	NA	NA	NA	2.69	NA	NA
Chain pickerel	6	5.64	5.69	9.74	12.4	22.5	11.1	6.02
Largemouth bass	45	2.77	8.01	20.1	46.1	288	47.8	68.5
Pumpkinseed	34	0.24	3.94	6.41	9.68	84.3	9.58	13.6
Redbreast	1	8.85	NA	NA	NA	8.85	NA	NA
Rainbow trout	4	<MDL	0.89	2.90	2.90	2.90	2.00	1.12
Smallmouth bass	3	5.44	<MDL	6.46	NA	8.47	6.79	1.26
White Perch	10	4.61	5.78	8.18	168	256	77.4	100
White Sucker	4	3.50	3.50	5.81	18.7	24.2	10.9	8.36
Yellow bullhead	1	1.64	NA	NA	NA	1.64	NA	NA
Yellow Perch	56	0.34	4.42	10.3	26.5	147	25.4	35.5

Notes:
<MDL indicates that no PFAS analytes were detected above the individual analyte MDL. NA=not applicable and shown for statistics based on three or fewer samples. All statistics were weighted by the number of fish per composite sample.

Figure 12 shows ΣPFAS40 concentrations measured in each composite sample by species. The composite samples with the highest ΣPFAS40 (>150 ng/g) were largemouth bass and white perch from Ashumet Pond and bluegill from Studley Pond. An additional seven composite samples had ΣPFAS40 concentrations greater than 100 ng/g; these composites consisted of yellow perch and largemouth bass caught at Ashumet Pond, Lake Mirimichi, and Studley Pond. With the exception of white perch, species with the greatest ranges of ΣPFAS40 were those caught across the largest number of waterbodies.

Figure 12. ΣPFAS40 Concentrations by Species



ΣPFAS40 by Trophic Level and Habitat

Several studies have found that species from lower trophic levels tend to have higher PFAS concentrations than those from higher trophic levels (Goodrow et al., 2017; VT DEC 2022). Other studies, such as that conducted by Newstead et al. (2017) on the Mississippi River, suggest that migratory patterns and habitat may play a role in PFAS concentrations.

Figure 13 plots composite results by trophic level from this study. This figure shows results for species from trophic levels three and four; only three composite samples contained fish from tropic level two and no fish were caught from trophic level one. Using a linear regression model, while adjusting for waterbody, we found that fish from trophic level three had lower ΣPFAS40 concentration than fish from trophic level four (p= 0.07). Brief descriptions of the trophic levels, which describe a species' position within a food chain or food web, are as follows:

- Trophic level two: Grazers that consume algae, phytoplankton, or detritus
- Trophic level three: Carnivores that consume herbivorous fish and zooplankton
- Trophic level four: Carnivores that consume other carnivorous fish

Figure 13: ΣPFAS40 in Fish Tissue Composite Samples by Trophic Level

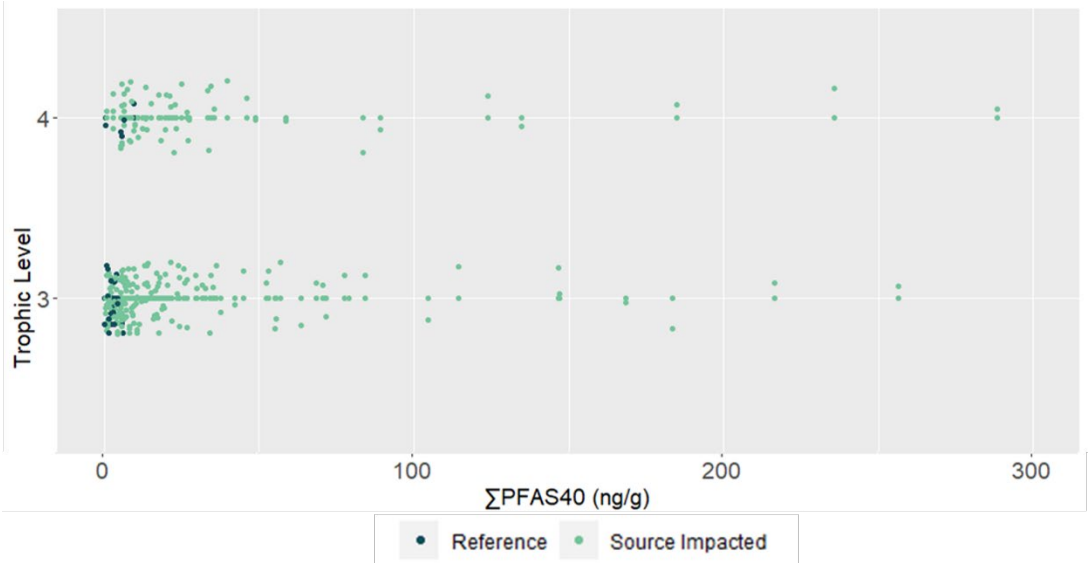


Figure 14 plots composite results by habitat. This figure shows results for species from benthopelagic and benthic habitats; only four composites for species from pelagic-neritic habitats were collected . A linear regression model, adjusting for waterbody, found that benthic species had significantly lower ΣPFAS40 concentrations than benthopelagic species ($p<0.05$). Brief descriptions of the habitats are:

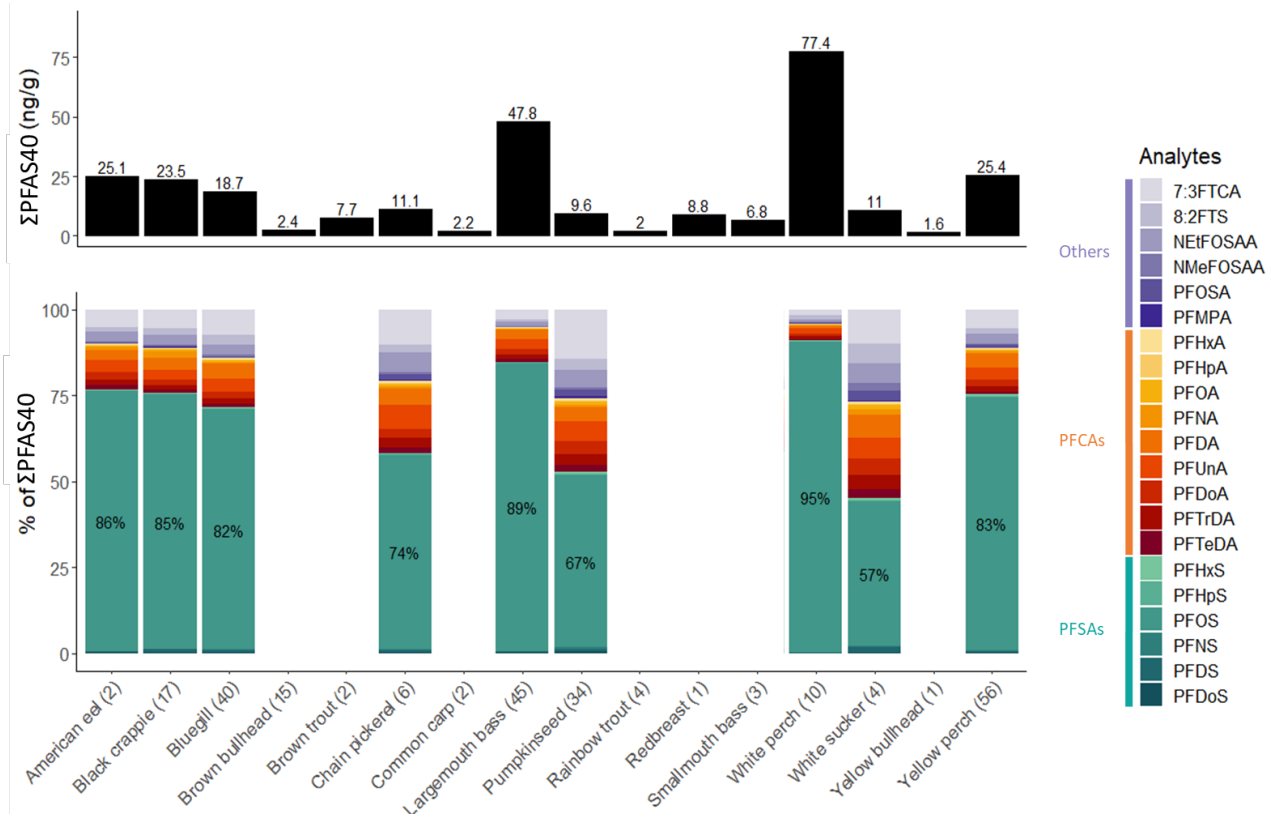
- Pelagic-neritic species: Live in midwaters and near the surface, as well as in nearshore ocean ecosystems (0-200 meter depth). Consume plankton and other free-living organisms like small fish and crustaceans.
- Benthopelagic species: Live and feed near the bottom, in midwaters, and near the surface. Opportunistically forage both free benthic and free-living organisms.
- Benthic species: Live on or near the bottom and feed on benthic organisms like detritus, plankton, and small invertebrate

Figure 14. ΣPFAS40 in Fish Tissue Composite Samples by Habitat

PFAS Composition by Species

To better understand the distribution of PFAS in fish tissue, concentrations of individual PFAS analytes measured in fish tissue were compared to the ΣPFAS40 concentration in fish tissue from the same waterbody. Plotted together, these relative contributions offer insight into the general profile of PFAS in fish tissue. Figure 15 presents these comparisons for nine species with average PFAS concentrations greater than 10 ng/g. Across all species, PFOS contributed the greatest amount to ΣPFAS40 concentrations, particularly for those species with higher average ΣPFAS40 concentrations.

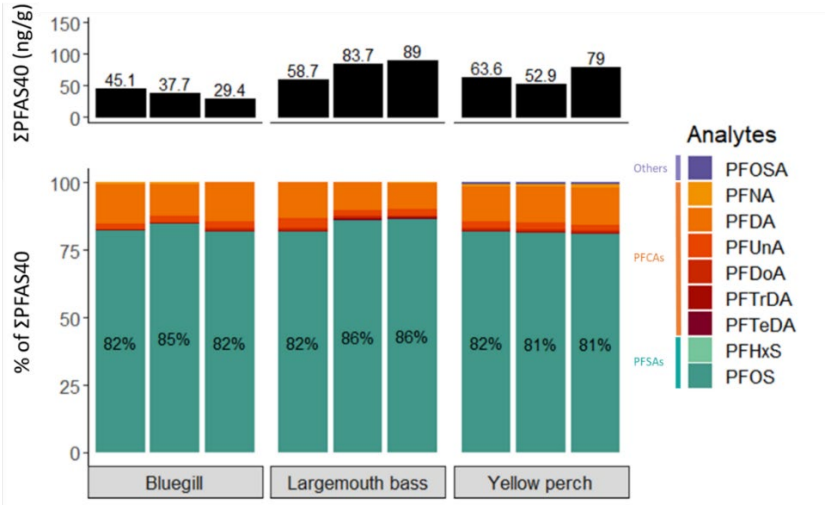
Figure 15. Average ΣPFAS40 and Composition of Average PFAS Analyte Concentrations by Species



Notes: Each bar represents average results for the species. The top (black) bars represent the average ΣPFAS40 for each species. Bottom bars (colored) represent the contribution of each PFAS analyte to the summed PFAS concentration (ΣPFAS40). Each color represents a different PFAS analyte. Results below the MDL were not included in ΣPFAS40, while results for individual analytes that were below the MDL were included in the calculation of the average analyte concentrations for a given species at ½ of the laboratory MDL. Because of this, the analyte proportion bars are censored for species with an average ΣPFAS40 below 10 ng/g.

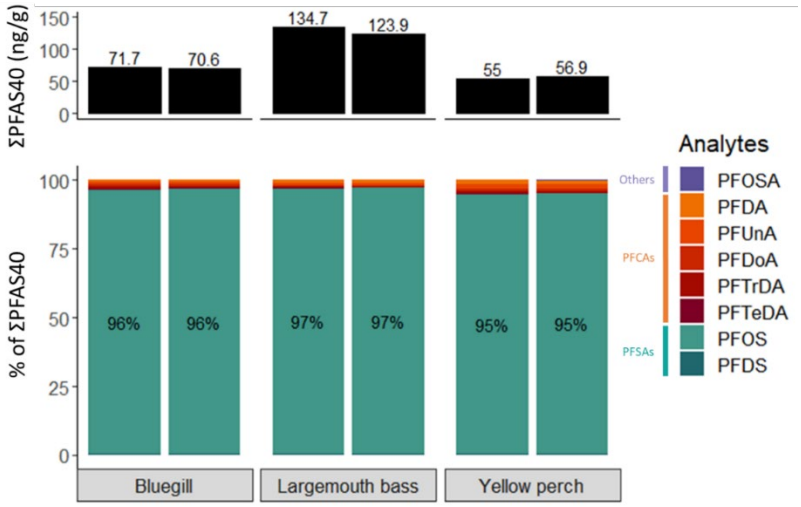
Within a waterbody, species tend to have similar PFAS profiles, even though they vary in ΣPFAS40. To illustrate this point, Figure 16 shows ΣPFAS40 concentrations and the PFAS composition of each composite sample, by species, for Flint Pond. Here, the PFAS profile is similar across species, though largemouth bass have higher ΣPFAS40 than bluegill or yellow perch. Figure 17 illustrates this point for Lake Mirimichi, where the same species were caught. Similarly, we found comparable PFAS profiles across samples, even with higher ΣPFAS concentrations in largemouth bass. This phenomenon was common for most waterbodies sampled.

Figure 16: Composite Fish Tissue Results from Flint Pond



Notes: Each bar represents one composite sample. The top panel represents the ΣPFAS40 detected in each sample. The lower panel (colored bars) represent the analytes contributing to ΣPFAS40.

Figure 17: Composite Fish Tissue Results from Lake Mirimichi

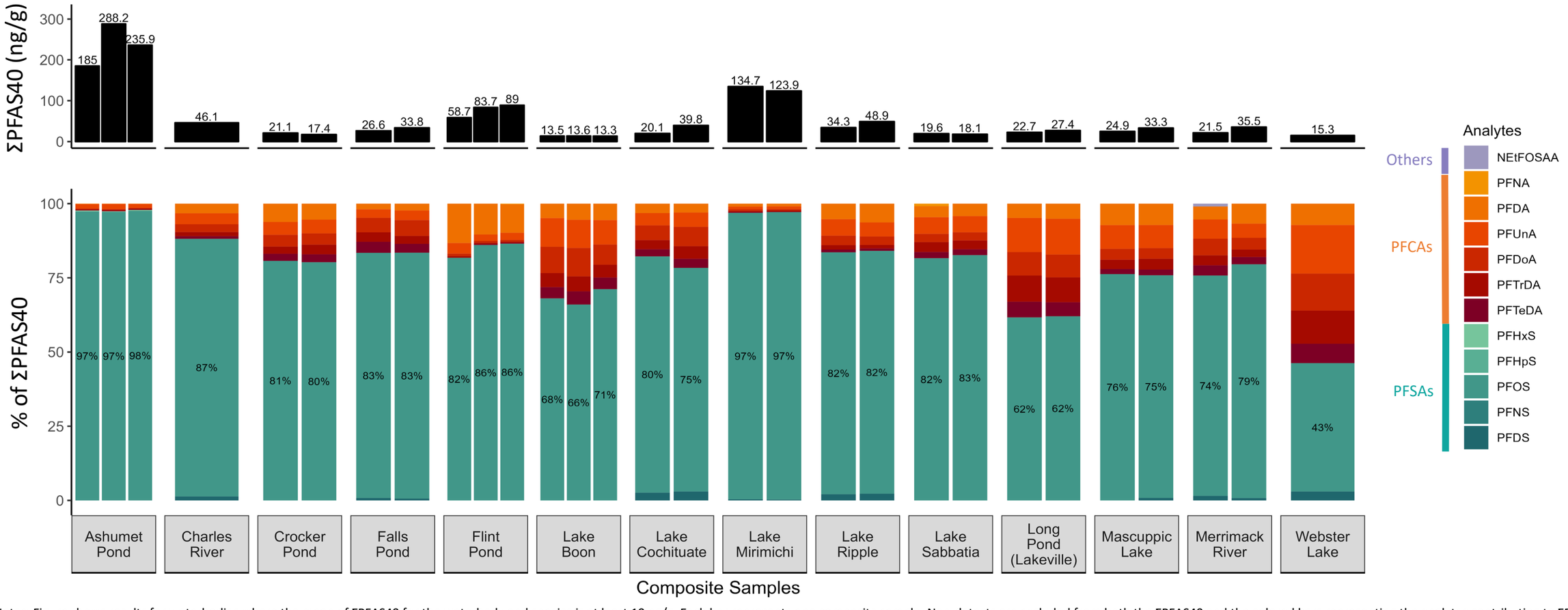


Notes: Each bar represents one composite sample. The top panel represents the ΣPFAS40 detected in each sample. The lower panel (colored bars) represent the analytes contributing to ΣPFAS40.

Note that due to variations in the PFAS burden across waterbodies, it would be inappropriate to ignore the waterbody from which fish were caught when comparing results across species. Figure 18 and Figure 19 display ΣPFAS40 and the proportions of each component PFAS analyte per composite for largemouth bass and yellow perch, respectively. These figures show that within a species and waterbody, composites have similar proportions of each measured PFAS analyte, even with variation in ΣPFAS40.

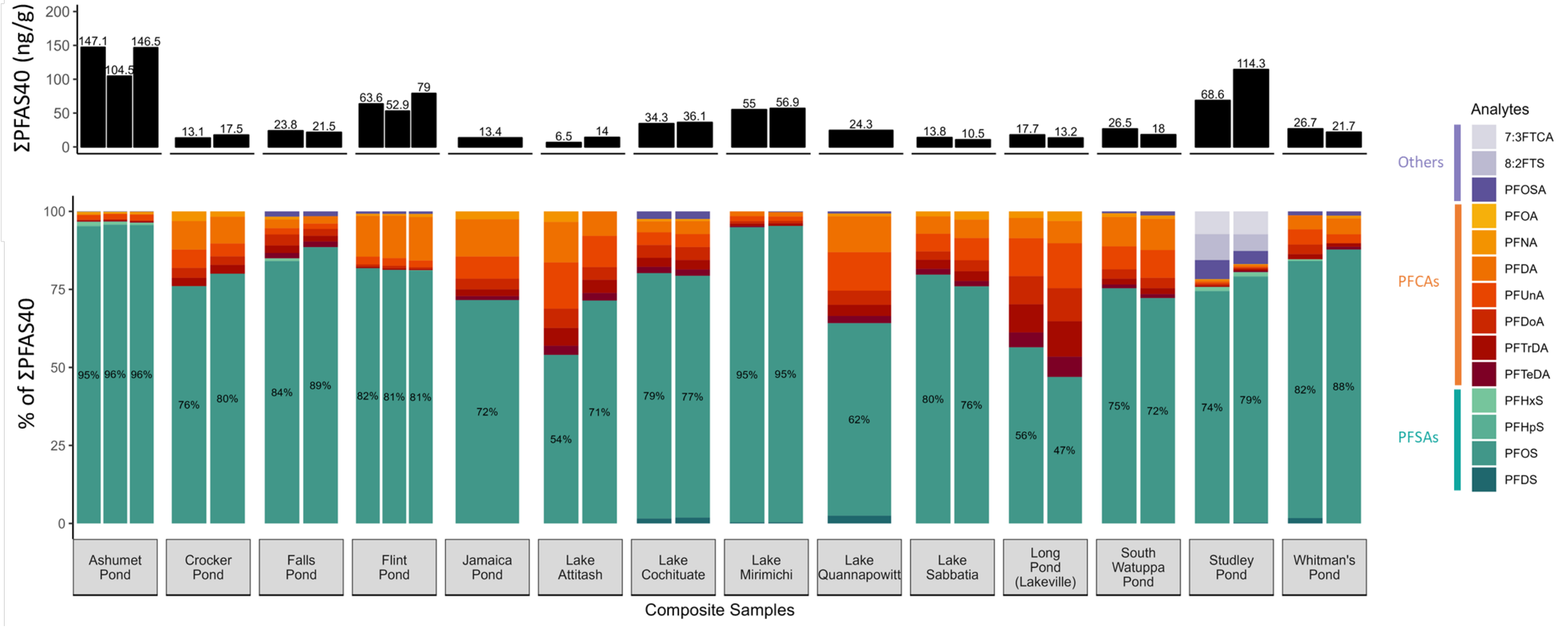
Interestingly, PFOSA was detected in several of the yellow perch samples and none of the largemouth bass samples, even when both species were collected from the same waterbody. Yellow perch collected in Studley Pond also had higher proportions of 7:3FTCA, 8:2FTS, and PFOSA compared to yellow perch collected from other ponds.

Figure 18. PFAS in Largemouth Bass



Notes: Figure shows results for waterbodies where the mean of ΣPFAS40 for the waterbody and species is at least 10 ng/g. Each bar represents one composite sample. Non-detects are excluded from both the ΣPFAS40 and the colored bars representing the analytes contributing to ΣPFAS40.

Figure 19. PFAS in Yellow Perch



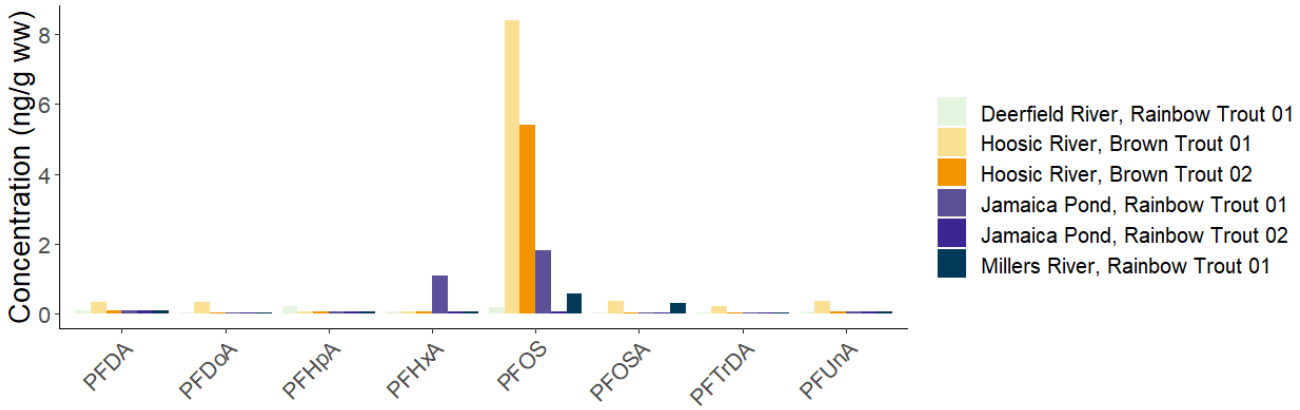
Notes: Figure shows results for waterbodies where the mean of ΣPFAS40 for the waterbody and species is at least 10 ng/g. Each bar represents one composite sample. Non-detects are excluded from both the ΣPFAS40 and the colored bars representing the analytes contributing to ΣPFAS40.

Trout

Albeit with limited data, two different species of trout (i.e., brown trout and rainbow trout) were analyzed in this study. Seven rainbow trout were collected from three waterbodies – the Deerfield River, Millers River, and Jamaica Pond – and six brown trout were collected from the Hoosic River. Results for the most commonly detected PFAS in trout are displayed in Figure 20. Interestingly and despite high surface water concentrations in Jamaica Pond (ΣPFAS40=38.95 ng/L), the first composite of rainbow trout from this waterbody had low ΣPFAS40concentrations (2.9 ng/g) and the second had no detected PFAS (ΣPFAS40 = 0 ng/g). In contrast, brown trout caught from Hoosic River (surface water ΣPFAS40 = 7.10 ng/L) had the highest PFOS and ΣPFAS40, as well as the greatest number of PFAS detected among the sampled trout. The Hoosic brown trout were smaller than the trout caught in other waterbodies.

MassWildlife stocks the Hoosic River in the spring and stocks the Deerfield River, Millers River, and Jamaica Pond in the spring and fall. The majority of stocked fish in Massachusetts are brown and rainbow trout. Although the small number of trout samples collected in this study limit the ability to draw any definitive conclusions regarding whether the trout collected in this study were stocked or not, it is likely that a majority of the trout captured in this study were of hatchery origin. As stocked fish spend time in ambient waters, they accumulate PFAS if present in the water, biota and/or sediments. A recent Maine study showed that stocked fish may accumulate PFAS as quickly as 1 week after being stocked. Prior to stocking, Danielson (2022) found that hatchery-born fingerling (<1 year old) brown trout had PFOS and other PFAS concentrations below MDLs. Within one week of stocking in a pond with surface water concentration of PFOS >500 ng/L, skinless filets from these fingerlings exceeded Maine's PFOS fish tissue action level of 3.5 ng/g by tenfold (Danielson 2022). Further study is needed to understand differences in PFAS concentrations among hatchery and native-born trout.

Figure 20: PFAS in Trout



Note: Bars represent composite samples. Non-detects are substituted with ½ the MDL.

4.2.3 Fish Tissue Results by Waterbody Characteristics

Fish tissue concentrations of PFAS were compared by waterbody characteristics including designation as a reference or source-impacted waterbody, region, proximity to an EJ census block, and type of waterbody. These comparisons were made for ΣPFAS40, PFAS6, and individual PFAS analytes that were detected in 50% or more of waterbodies, using waterbody means. Overall, significant differences in mean PFAS concentrations were observed for reference status and region. There were no significant differences in mean PFAS concentrations by proximity to EJ communities or type of waterbody.

Reference versus Source-Impacted Waterbodies

Table 13 presents descriptive statistics of PFAS in fish tissue separately for source-impacted and reference waterbodies. ΣPFAS40, PFAS6, PFDA, PFNA, PFOS, and PFOSA were significantly different between groups, with reference waterbodies having lower concentrations than source-impacted waterbodies. In both groups, PFOS was the dominant PFAS analyte.

Table 13: PFAS in Fish Tissue by Source-impacted and Reference Waterbodies

PFAS	Source Impacted (n=41)			Reference (n=6)		
	FOD (%)	Max (ng/g)	Median (ng/g)	FOD (%)	Max (ng/g)	Median (ng/g)
ΣPFAS40*	100	194	9.25	100	6.66	2.97
PFAS6*	100	189	7.08	100	0.43	1.34
PFDA*	95.1	7.37	0.57	66.7	0.41	0.20
PFDoA	100	1.44	0.42	83.3	0.62	0.26
PFOS*	100	188	6.78	100	3.35	1.18
PFTeDA	92.7	0.87	0.21	66.7	0.41	0.15
PFTrDA	100	1.53	0.35	83.3	0.89	0.40
PFUnA	100	3.03	0.76	83.3	1.07	0.54

Note: An asterisk (*) indicates that median concentrations were significantly different between source-impacted and reference waterbodies ($p<0.05$). MDL = method detection limit. Non-detect observations substituted with ½ the laboratory MDL. FOD is used for "frequency of detection."

MassDEP Region

Table 14 presents PFAS results by MassDEP regions. There were significant differences in means for ΣPFAS40, PFAS6, and all analytes detected at 50% or more of waterbodies, with the exception of PFOSA and PFTeDA. In a sensitivity analysis excluding reference waterbodies, significant differences remained by region, with the western region generally having lower PFAS concentrations. Dunn's Test was performed after the Kruskal Wallis test was significant at $\alpha=0.05$ to investigate pairwise differences between regions for the summed PFAS analytes. The western region was significantly different from the central, northeastern, and southeastern regions for ΣPFAS40 and PFAS6. There were no significant pairwise differences between results in the central, northeastern, and southeastern regions.

Table 14: PFAS in Fish Tissue by MassDEP Region

PFAS	Western (n=15)		Central (n=10)		Northeastern (n=11)		Southeastern (n=11)	
	FOD (%)	Median (ng/g)	FOD (%)	Median (ng/g)	FOD (%)	Median (ng/g)	FOD (%)	Median (ng/g)
ΣPFAS40*	100	4.12	100	9.63	100	14.95	100	19.15
PFAS6*	100	3.27	100	6.26	100	12.02	100	14.52
PFDA*	80.0	0.22	100	0.65	100	0.82	90.9	0.70
PFDoA*	93.3	0.29	100	0.57	100	0.40	100	0.50
PFOS*	100	2.32	100	5.65	100	11.07	100	13.47
PFTeDA	66.7	0.11	100	0.34	100	0.20	100	0.23
PFTrDA*	93.3	0.29	100	0.48	100	0.34	100	0.50
PFUnA*	93.3	0.38	100	1.00	100	0.89	100	0.85

Note: An asterisk (*) indicates that median concentrations were significantly different by region ($p<0.05$). MDL = method detection limit. Non-detect observations substituted with ½ the laboratory MDL. FOD is used for "frequency of detection."

Waterbody Type

Table 15 presents PFAS results by waterbody type (i.e., lakes/ponds versus rivers). There were no significant differences in PFAS means by waterbody type, with the exception of PFUnA which was detected at lower concentrations in rivers than lakes and ponds.

Table 15: PFAS in Fish Tissue by Waterbody Type

PFAS	Lake or Pond (n=36)			River (n=11)		
	FOD (%)	Max (ng/g)	Median (ng/g)	FOD (%)	Max (ng/g)	Median (ng/g)
ΣPFAS40	100	194	7.33	100	18.7	7.53
PFAS6	100	189.	4.87	100	16.4	5.89
PFDA	94.4	7.37	0.56	81.8	0.88	0.34
PFDoA	100	1.44	0.40	90.9	0.94	0.42
PFOS	100	188	4.27	100	15.5	5.57
PFTeDA	91.7	0.87	0.21	81.8	0.75	0.24
PFTrDA	100	1.53	0.40	90.9	0.65	0.34
PFUnA*	100	3.03	0.85	90.9	1.40	0.53

Note: An asterisk (*) indicates that median concentrations were significantly different by waterbody type ($p<0.05$). MDL = method detection limit. Non-detect observations substituted with ½ the laboratory MDL. FOD is used for "frequency of detection."

Proximity to EJ Populations

Table 16 reports PFAS results by proximity to EJ census blocks. A Wilcoxon Rank Sum test did not find any significant differences in PFAS mean concentrations between waterbodies located within one mile of an EJ census block than those located further from an EJ census block.

Table 16: PFAS in Fish Tissue by Waterbody Proximity to EJ Community

PFAS	Within One Mile of an EJ Census Block (n=31)			Not Within One Mile of an EJ Census Block (n=46)		
	FOD (%)	Max (ng/g)	Median (ng/g)	FOD (%)	Max (ng/g)	Median (ng/g)
ΣPFAS40	100	194	7.72	100	83.3	6.93
PFAS6	100	189	5.89	100	80.8	4.59
PFDA	87.1	7.37	0.53	100	1.1	0.51
PFDoA	96.8	1.33	0.40	100	1.44	0.41
PFOS	100	188	5.57	100	80.0	4.19
PFTeDA	87.1	0.79	0.21	93.8	0.87	0.21
PFTrDA	96.8	1.26	0.34	100	1.53	0.37
PFUnA	96.8	3.03	0.59	100	2.16	0.85

Note: None of the analytes had significant differences in PFAS concentration by EJ proximity at $p<0.05$. MDL = method detection limit. Non-detect observations substituted with ½ the laboratory MDL. FOD is the acronym used for "frequency of detection."

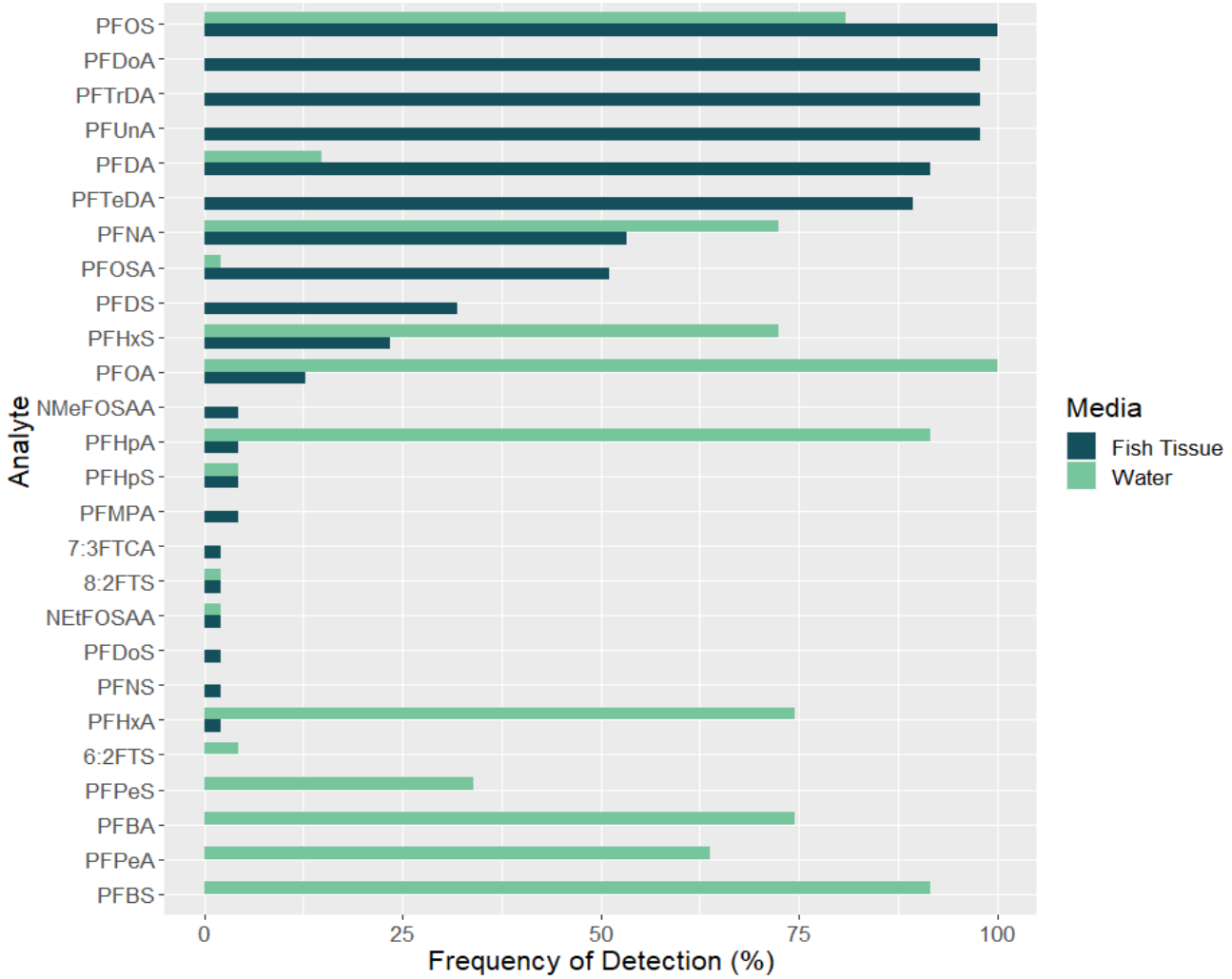
4.3 Relationships Across Surface Water and Fish Tissue

Fish tissue and water samples were collected concurrently from 47 waterbodies. Figure 21 displays the FOD of PFAS for each media. Eleven PFAS analytes were detected in both surface water and fish tissue; five were detected in surface water only, and 10 were detected in fish tissue only. Some analytes detected at a high frequency in surface water did not have high FODs in fish tissue, and some analytes detected at a high FODs in fish tissue were not detected frequently in surface water. There are many

possible reasons for these differences, including differences in MDLs across media, exposure pathways for fish other than surface water, and patterns of bioaccumulation or fate and transport.

Several analytes, including PFDoA, PFTrDA, and PFUnA, were detected in fish tissue from nearly all waterbodies but were not detected in surface water. One analyte, PFOS, was detected in all waterbodies for fish tissue but was not detected in all waterbodies for surface water samples. Similarly, the one analyte detected in all waterbodies for surface water, PFOA, was detected in fish tissue from relatively few waterbodies.

Figure 21. PFAS Detects in Surface Water Versus Fish Tissue

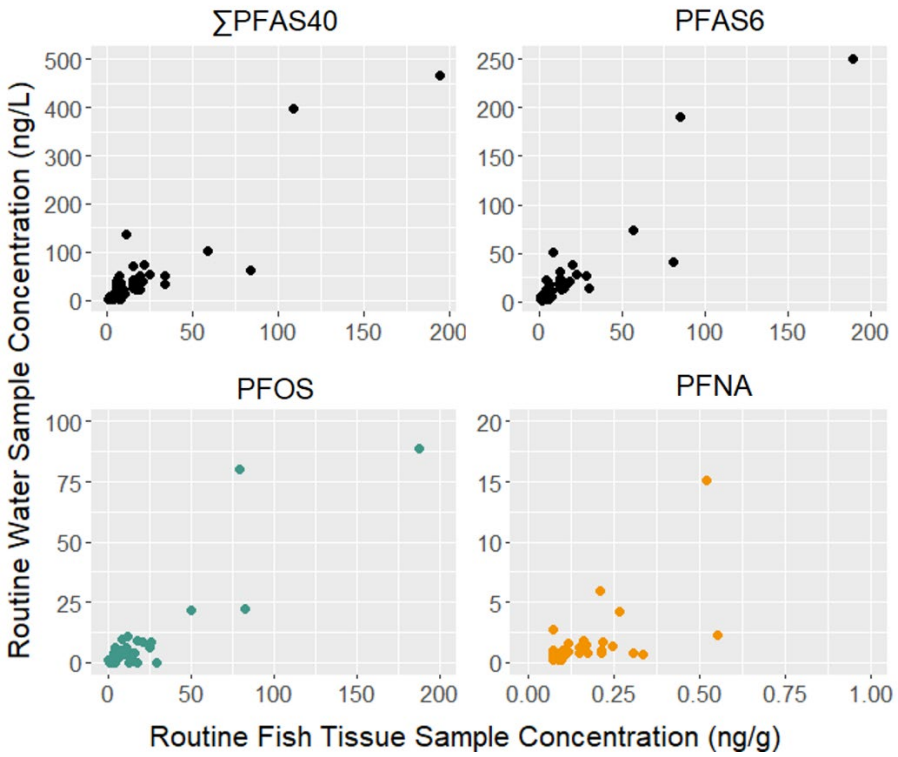


Notes: Figure shows frequency of detect for PFAS analytes by media at the waterbody level. An analyte was considered detected in fish tissue in a waterbody if at least one composite sample from the waterbody had concentrations above the MDL.

To further explore the relationship between PFAS measured in surface water and fish tissue, Spearman correlations were evaluated for ΣPFAS40 and PFAS6 and the two PFAS analytes (PFOS and PFNA) that were detected in 50% or more of waterbodies in both media. Figure 22 displays scatterplots comparing fish tissue to surface water sample results for these analytes. All correlations were positive and significant ($p<0.05$), suggesting that where these specific PFAS and PFAS sums are high in surface water, they will also tend to be high in fish tissue. Correlations were estimated at 0.84 for PFAS6, 0.77 for ΣPFAS40, 0.62 for PFNA, and 0.59 for PFOS.

Goodrow et al. (2020) similarly reported strong and significant correlations among ΣPFAS concentrations from surface water, fish tissue, and sediment media. While they reported the strongest correlation between PFAS in sediment and fish (Pearson correlation coefficient=0.872, $p<0.05$), they also observed significant correlations between PFAS in fish and water (correlation coefficient>0.7 and $p<0.05$).

Figure 22. PFAS in Fish Compared to PFAS in Surface Water



Notes: Fish tissue concentrations are plotted against water concentrations for the same PFAS analytes for analytes detected in ≥50% of waterbodies. MDL = method detection limit. Values <MDL were plotted at ½*MDL.

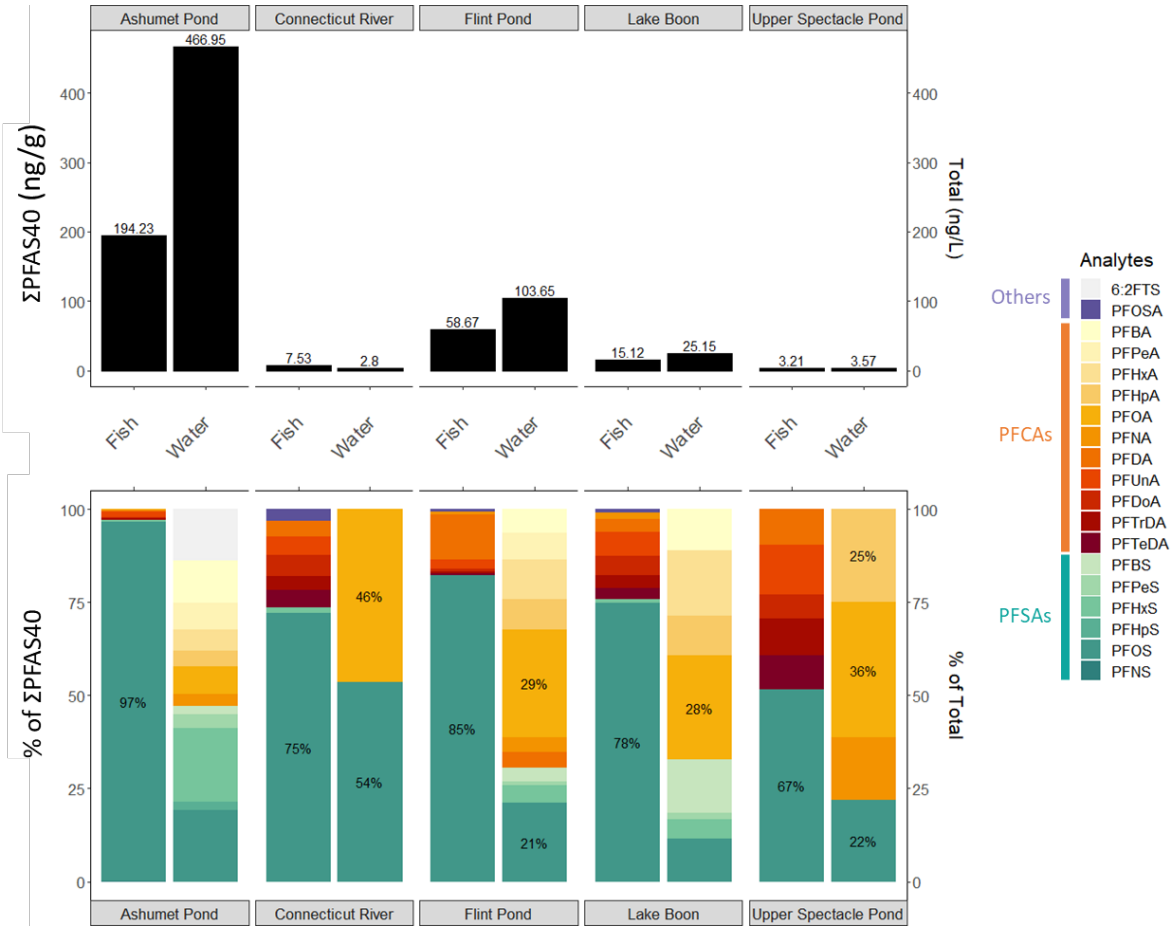
We also compared PFAS profiles across media. Figure 23 displays PFAS profiles for surface water and fish tissue from five waterbodies with a range of PFAS concentrations. Differences in the PFAS analytes detected in fish tissue and surface water are apparent for all five waterbodies displayed. These example cross-media comparisons show a range of different profiles. While the profiles at each waterbody may be unique, differences between media are typical across all waterbodies in this dataset.

Across waterbodies, there are PFAS analytes detected in fish tissue that were not detected in surface water (e.g., PFOSA, PFTeDA, PFTrDA), and PFAS detected in both media represent different proportions of the summed PFAS. As an example, while Ashumet Pond had the highest ΣPFAS40 for fish tissue and surface water, the PFAS analyte driving ΣPFAS40 concentrations differed. For fish tissue, 97% of ΣPFAS40 was contributed by PFOS. For surface water, PFOS constituted only 17% of ΣPFAS40. A range of additional analytes were detected in surface water in Ashumet Pond which were not detected in fish tissue. Some possible reasons may be variability in laboratory sensitivity to detect PFAS across media, fish being exposed to PFAS through other exposure pathways, or that certain types of PFAS bioaccumulate in fish but do not remain in surface water at detectable levels.

The results also indicate that compositional profiles of PFAS in surface water are not a reliable predictor for the compositional profiles of PFAS in fish. These findings align with that of other studies that have reported PFOS and other PFSAs contributing more to the summed measured PFAS concentrations in

fish, and PFOA and other PFCAs contributing more to summed PFAS concentrations in surface water (Pickard et al. 2022; NHDES, 2021).

Figure 23. PFAS Profiles in Fish Compared to PFAS Profiles in Surface Water



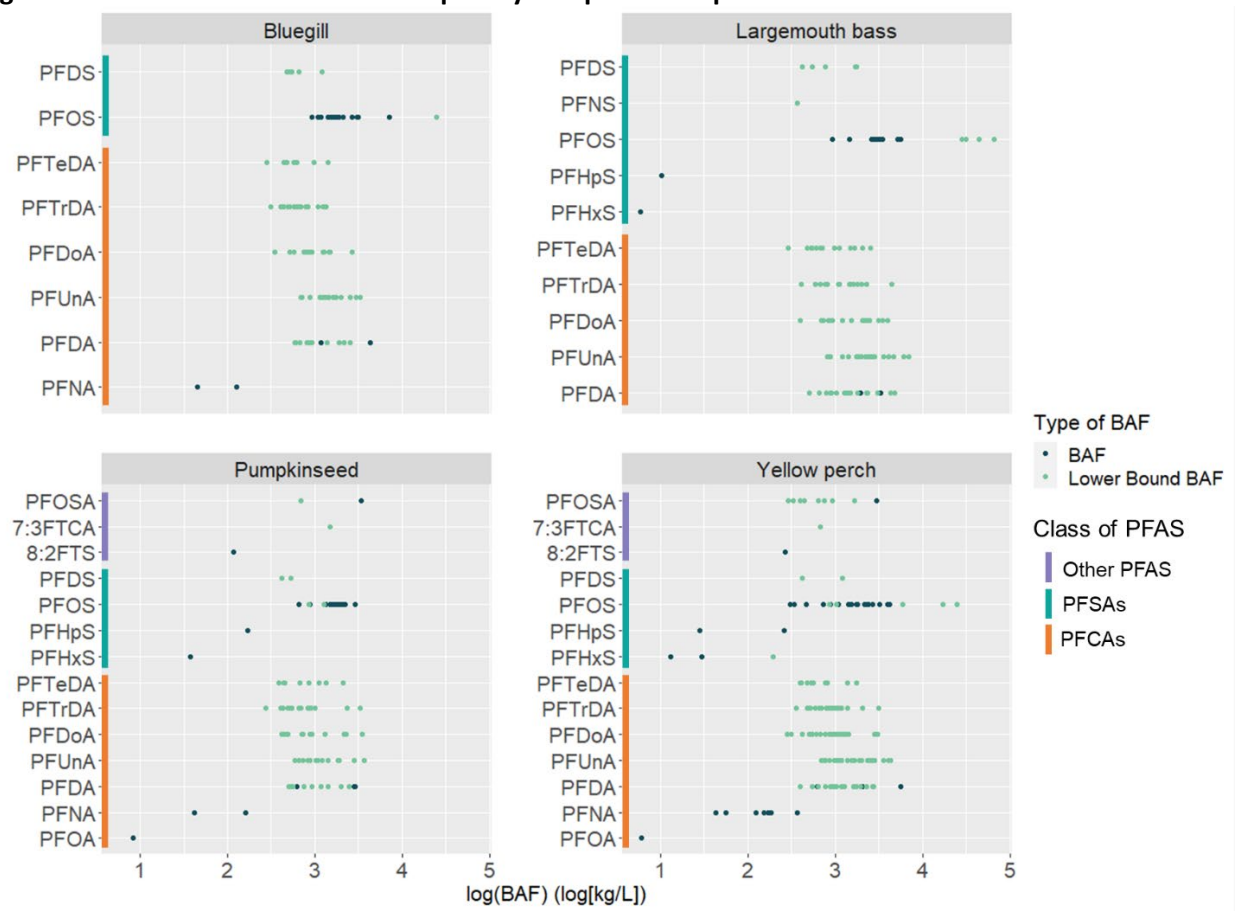
Notes: Each bar represents the waterbody average for the labeled media. The top panel shows ΣPFAS40 concentrations while the lower panel shows the analytes contributing to ΣPFAS40.

4.4 Bioaccumulation factors

BAFs for fish tissue were calculated using Equation 1 and detected concentrations of PFAS in co-located surface water and fish tissue samples (see Section 3.5). Using the method reported by Pickard et al. (2022), "lower bound" BAFs were calculated in cases where analytes were detected in fish tissue but not in the corresponding surface water sample. To calculate the "lower bound" BAF in these situations, the fish tissue concentration was divided by the surface water MDL for the analyte.

Here, we use BAFs to quantify the extent to which PFAS bioaccumulate in fish muscle from the surface water to which they are exposed. Fish are relatively high on the aquatic food chain, so they have a greater potential to accumulate chemicals from surface water and from the organisms that they eat. Figure 24 presents waterbody specific BAFs and lower bound BAFs for the four most frequently sampled species, organized by PFAS class and chain length. Within each species-analyte combination, BAFs and lower bound BAFs frequently span one or more orders of magnitude. (Note that the figure presents data on a logarithmic scale.) In general, BAFs for the PFCAs tended to increase with decreasing chain length (between chain lengths of 11 and 14), which is consistent with recent literature (Pickard et al, 2022).

Figure 24: BAFs for the Four Most Frequently Sampled Fish Species



Notes: Points shown represent waterbody specific BAFs. PFAS analytes are organized by PFAS class and decreasing chain length.

Table 17 presents minimum, maximum, geometric mean, and median BAFs for analytes detected in at least 25% of waterbodies for both fish tissue and surface water for the same four species. Only two analytes, PFOS and PFNA, met these criteria. The geometric mean BAFs shown in the table all meet Burkhard et al. (2021) criteria to be designated as "high quality" estimates – i.e., geometric mean BAFs are based on at least two water samples and at least four fish samples, water and fish samples were collected concurrently and at the same location, and no mixed species tissue samples were included. Geometric mean BAFs for PFOS were at least one order of magnitude higher than those for PFNA.

The average BAFs estimated in this study for PFNA are similar to those reported by Pickard et al. (2022), who reported average BAFs for bluegill, pumpkinseed, and yellow perch at 1.67 log(L/kg), 1.71 log(L/kg), and 2.08 log(L/kg), respectively. Pickard et al. (2022) also reported similar BAFs for PFOS, ranging from 3.17 log(L/kg) for yellow perch to 3.39 log(L/kg) for largemouth bass. Additionally, in a recent review of PFAS BAFs and bioconcentration factors, Burkhard et al. (2021) reported a similar median BAF of 2.16 log(L/kg) for PFNA based on 79 BAFs calculated across species and published in the peer-reviewed literature and a similar median BAF for PFOS of 3.18 log(L/kg) based on 155 BAFs across multiple species.

Table 17: BAFs Across Waterbodies

Species	Analyte	Number of Waterbodies[a]	Minimum BAF log (L/kg)	Geometric Mean BAF log (L/kg)	Median BAF log (L/kg)	Maximum BAF log (L/kg)	Quality[b]
Bluegill	PFNA	2	1.65	1.88	1.65	2.10	High
Pumpkinseed	PFNA	2	1.62	1.91	1.62	2.21	High
Yellow perch	PFNA	8	1.63	2.16	2.19	2.56	High
Bluegill	PFOS	16	2.96	3.26	3.21	3.85	High
Largemouth	PFOS	15	2.97	3.45	3.47	3.74	High
Pumpkinseed	PFOS	13	2.82	3.18	3.21	3.46	High
Yellow perch	PFOS	20	2.48	3.16	3.19	3.63	High

Notes:
This table only includes calculated BAFs for analytes that were detected in both fish tissue and surface water in at least 25% of waterbodies. PFNA was not detected in largemouth bass fish tissue samples.
[a] Number of waterbodies with detections in both surface water and fish tissue for that species-analyte combination.
[b] Quality was assessed based on Burkhard et al. (2021). Quality designations are "high," "medium," or "low."

4.5 Comparison of PFAS Results to Health-Based Guidelines and Standards

To provide additional context for the PFAS concentrations measured in surface water and fish tissue, results were compared to draft health-based screening criteria developed by MDPH. This comparison is only an initial screening of the sampling results and may be used by MDPH in public health risk assessment and evaluation.

Surface Water

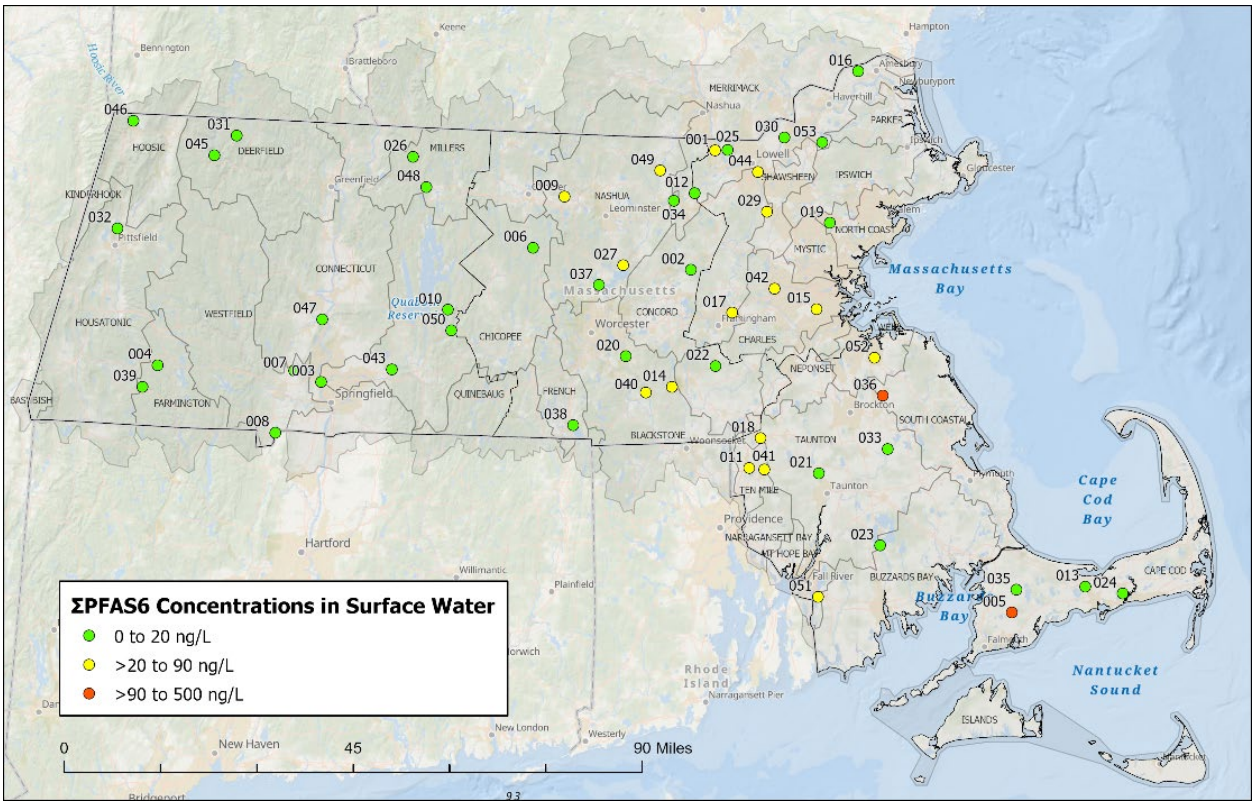
For surface water, MDPH has developed draft health-based screening values for PFAS6 concentrations (i.e., the sum of PFHxS, PFHpA, PFOA, PFOS, PNFA, and PFDA) based on recreational exposure scenarios (e.g., incidental ingestion during wading and swimming at public beaches) (MDPH, interagency communication, February 2023). The draft guidelines are:

- PFAS6 ≤20 ng/L: no restrictions
- PFAS6 >20 ng/L to 90 ng/L: notifications required (e.g., posting signage)
- PFAS6 >90 ng/L to 500 ng/L: site specific evaluation required
- PFAS6 >500 ng/L: no swimming

For comparison purposes only, Figure 25 shows how measured routine surface water concentrations compare to MDPH's draft guidelines for permitted bathing beaches (Note: MDPH's Operational Beach Guidance only applies to PFAS6 data collected at permitted bathing beaches.) 18 of the 52 waterbodies had PFAS6 concentrations above 20 ng/L, at which the Massachusetts Department of Public Health (MDPH) recommends public notification of the presence of PFAS confirmed by at least two rounds of sampling at permitted bathing beaches per the agency's draft Bathing Beach Operational PFAS Guidance (MDPH, interagency communication, September 2023). However, of these 18 waterbodies, only three included the collection of samples at permitted bathing beaches (in addition to open water locations). Beach samples (taken at locations representative of the point of exposure when bathing) collected at Crocker Pond (Westminster), Lake Cochituate (Natick), and Falls Pond (North Attleborough) had PFAS6 concentrations of 50 ng/l, 25 ng/l and 22 ng/l, respectively. One other waterbody with a permitted bathing beach, Nutting Lake (Billerica), also had PFAS6 concentrations above 20 ng/L. However, samples were not collected at the permitted bathing beach. While two waterbodies (Studley Pond in Rockland and Ashumet Pond in Mashpee) had concentrations of PFAS6 exceeding the Public Beach Action Level of

90 ng/L, these waterbodies do not warrant site-specific evaluation since Studley Pond does not have a permitted bathing beach and the PFAS samples at Ashumet Pond were not collected at the permitted bathing beach. Per the MDPH Guidance, confirmatory sampling by MDPH at all aforementioned waterbodies except for Studley Pond is warranted to support future decision making for these permitted bathing beaches.

Figure 25. PFAS6 in Surface Water Compared to Draft MDPH Health-based Guidance*



* Current MDPH draft Operational Beach Guidance only applies to PFAS6 data collected at bathing beaches (figure shows data for mostly open-water locations)

Several waterbodies included in this study are the sites of or are located nearby and upstream of primary or emergency drinking water intakes. These include Whitman's Pond in Weymouth, Lake Cochichewick in North Andover, Lake Attitash in Amesbury, the Wachusett Reservoir in Clinton, South Watuppa Pond in Westport, the Merrimack River in Methuen, and the Concord River in Billerica. The Massachusetts maximum contaminant level (MMCL) for PFAS6 in drinking water is 20 ng/L. EPA has proposed 4.0 ng/L as the maximum contaminant level (MCL) for both PFOS and PFOA in drinking water. EPA has also proposed MCLs for PFNA, PFBS, PFHxS, and HFPO-DA using a combined hazard index approach. (A hazard index is calculated by dividing the concentration of each analyte by an analyte-specific health-based value and then summing the resulting analyte-specific hazard quotients).

Five of the seven waterbodies identified as sources of drinking water or upstream of drinking water intakes had measured PFAS concentrations above one or more of these thresholds. Lake Attitash exceeded EPA's proposed MCL for PFOA. The Merrimack River exceeded EPA's MCL for PFOA and PFOS. South Watuppa Pond, Whitman's Pond, and the Concord River exceeded the EPA's MCL for PFOA and PFOS as well as Massachusetts' MMCL for PFAS6. (While not directly relevant or comparable, out of the 52 waterbodies included in this study, a total of 18 waterbodies exceeded the MMCL, 17 waterbodies

exceeded the proposed 4.0 ng/L limit for PFOS, 31 exceeded the proposed 4.0 ng/L limit for PFOA, and two waterbodies exceeded the combined hazard index threshold of 1.0).

Fish Tissue

For fish tissue, individual measurements of seven PFAS (i.e., PFBS, PFHxS, PFOA, PFOS, PFNA, GenX, and PFBA) were compared to MDPH's draft cFAL of 0.22 ng/g (MDPH, interagency communication, February 2023). These seven PFAS were compared to the cFAL since each have established toxicity criteria. Table 18 shows the data comparisons. In all but one waterbody (i.e., Deerfield River), PFOS was detected in fish tissue at levels above the cFAL. This occurred less frequently for PFNA (45% of waterbodies sampled), PFOA (8.5%), and PFHxS (6.4%).

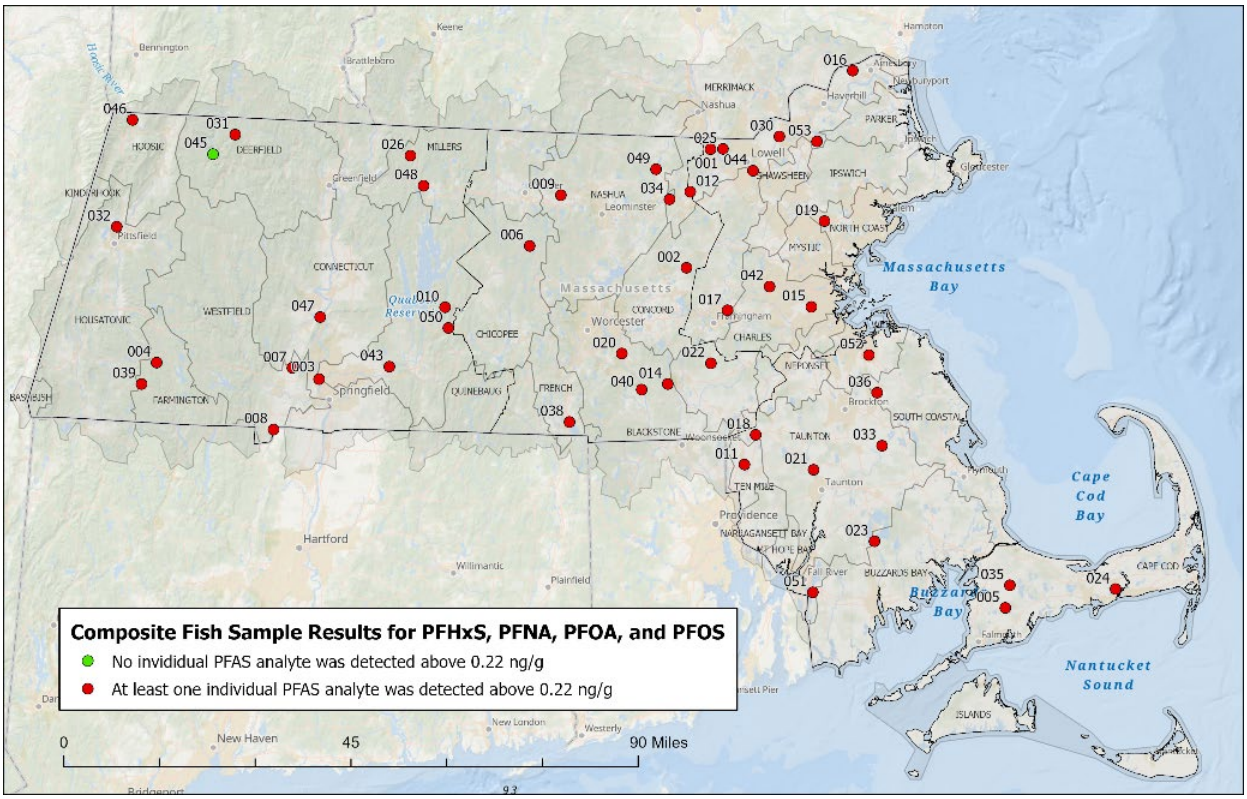
Table 18. Fish Tissue Results Compared to Draft MDPH Health-based Guidance

PFAS	Number (%) of waterbodies with detected concentrations	Number (%) of waterbodies with detected concentrations above 0.22 ng/g
PFOA	6 (13%)	4 (8.5%)
PFOS	47 (100%)	46 (98%)
PFNA	25 (53%)	21 (45%)
PFHxS	11 (23%)	3 (6.4%)
PFBS	0	NA
PFBA	0	NA
HFPO-DA	0	NA

Figure 26 compares PFAS measurements from each waterbody to MDPH's draft cFAL. The Deerfield River was the only waterbody sampled where fish tissue composite sample results did not exceed MDPH's draft cFAL. However, at this waterbody, field crews were only able to catch one fish (i.e., a single rainbow trout) that had PFOS and PFHpA concentrations of 0.20 ng/g and 0.17 ng/g, respectively. The Deerfield River is stocked with trout each year, and the river was stocked prior to sample collection in late October. However, there is no way of knowing if the one fish that was caught was stocked or not.

Notably, many of these waterbodies shown in Figure 26 have evidence of fishing pressure. For example, at the waterbody (Ashumet Pond) with the highest observed fish tissue concentrations (280 ng/g), MassWildlife maintains a paved boat ramp and parking area and the waterbody is stocked with trout (MassWildlife, 2018). At Studley Pond, the waterbody with the next highest fish tissue concentration, fishing is reportedly common (NSRWA, 2023).

Figure 26. PFAS in Fish Tissue Compared to Draft MDPH Health-based Guidance



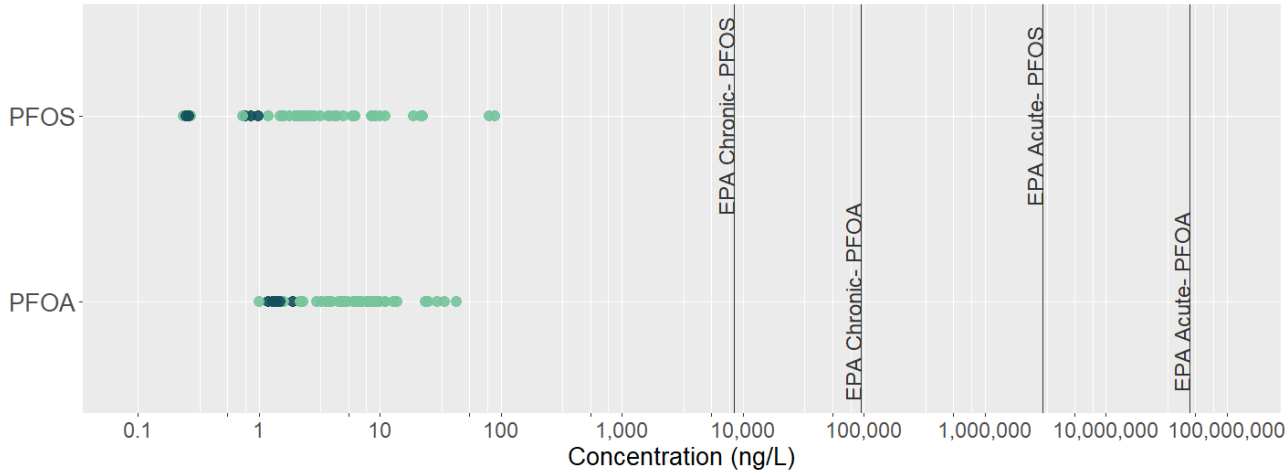
4.6 Comparison of PFAS Results to EPA Draft Aquatic Life Criteria

The U.S. EPA recently issued draft Aquatic Life Ambient Water Quality criteria for PFOA and PFOS (expected to be finalized in late 2023). These criteria are a set of concentrations for PFOA and PFOS in acute water columns (CMC), chronic water columns (CCC), invertebrates, and fish which protect aquatic systems from acute and chronic toxic effects (EPA, 2022c). Although the surface water samples collected as part of this project were collected only at one point in time, we compared surface water results to both the CMC and CCC.

In surface water, maximum PFOA and PFOS concentrations were orders of magnitude below EPA's draft aquatic life ambient water quality criteria for chronic exposures: PFOA (94,000 ng/L) and PFOS (8,400 ng/L) (Figure 27). Maximum detected surface water concentrations were also orders of magnitude below the criteria for acute exposures: PFOA (49,000,000 ng/L) and PFOS (3,000,000 ng/L) (EPA, 2022a).

The fish tissue composite results were similarly well below EPA's draft recommended aquatic life instantaneous water quality criteria for fish muscle for PFOA and PFOS (EPA, 2022a). The recommended draft criteria for PFOS in fish muscle is 2,910 ng/g and the maximum PFOS concentration detected in any composite sample was 280 ng/g. The recommended criteria for PFOA in fish muscle is 125 ng/g and the maximum PFOA concentration detected in any composite sample was 0.39 ng/g.

Figure 27. Surface Water Compared to EPA's Draft Aquatic Life Ambient Water Quality Criteria



4.7 Uncertainty and Limitations

This study is the most extensive PFAS fish tissue sampling in Massachusetts to date. However, because it did not consider a statistically based sample of water bodies (by design), the descriptive statistics shown in this report are not necessarily representative of statewide conditions. The findings from this study only apply to certain freshwater environments; the findings may not necessarily represent conditions in smaller streams, shallow pond and wetland systems, salt ponds, or marine waters.

Additionally, and by the very nature of fish sample collection, different numbers of fish and species were collected across waterbodies. Some species were only caught at a handful of waterbodies. In some cases, this limits interpretation of cross-species and cross-waterbody comparisons.

Another limitation is the lack of comprehensive, source-specific data on the magnitude of PFAS releases to the environment and ultimately to surface waters sampled. This study evaluated general indicators of PFAS releases (i.e., source-impacted, reference). A more robust statistical analysis would consider actual PFAS loadings to different watersheds, but these data are not available. Relatedly, this study evaluated PFAS concentrations by proximity to EJ census blocks (i.e., within one mile). This assumes that EJ populations only access waterbodies in their immediate proximity. A better analysis of EJ populations and susceptibility would have to consider surveying community members for fishing preferences.

Finally, in any scientific study involving laboratory analyses, one must be concerned about uncertainties associated with analytical measurements. Although a draft analytical method (EPA 1633) was utilized for all analyses, this method is the current state-of-the-art method for PFAS in multiple media that is recommended for use by EPA. The on-going review and multi-lab validation of this method is described in Appendix A, and finalization of the method by EPA is estimated for late 2023. Appendix A also provides a summary of project data validation based on laboratory and field QC results, which confirm the validity of the data for decision making.

5.0 CONCLUSIONS

PFAS concentrations in surface water and fish tissue in many states and countries continue to be a major concern for human health and the environment. Although limited to freshwater, the results of this study add to the growing body of evidence that PFAS are ubiquitous in the environment. This study characterized the environmental burden and human exposure to PFAS in Massachusetts at targeted waterbodies selected based on the presence or absence of known or suspected contamination, with priority given to waterbodies with high fishing pressure and proximity to EJ communities. The following list highlights key findings.

- PFAS were detected in surface water and fish tissue from all sampled waterbodies across the state, including those in rural areas far from any known or suspected sources of PFAS contamination. The range of PFAS contamination varied widely in fish tissue and surface water though concentrations in both media were significantly higher in areas near known or suspected PFAS sources.

- With respect to health-based screening values using MDPH draft guidance (2023), open water PFAS concentrations from at least one waterbody (Ashumet Pond) were high enough to potentially trigger confirmatory sampling and/or site-specific evaluation by DPH pursuant to recreational use of the permitted bathing beach. Also, several waterbodies had PFAS concentrations at bathing beach locations high enough to warrant confirmatory sampling by MDPH. For fish, all but one waterbody had at least one sample with a concentration above MDPH's draft cFAL of 0.22 ng/g for at least one of the seven PFAS for which MDPH issues fish consumption advisories.

- All surface water concentrations of PFOS and PFOA were well below EPA's draft acute and chronic water column Aquatic Life Ambient Water Quality Criteria values. All fish tissue concentrations of PFOS and PFOA were also well below EPA's draft Aquatic Life Ambient Water Quality Criteria values (for fish muscle). MassDEP will compare results of this study, and other studies in Massachusetts, to EPA's final aquatic life criteria, as well as future human health criteria, when available. These comparisons will help determine the appropriateness of nationally recommended criteria in Massachusetts and whether specific considerations suggest the need to develop additional protective criteria in this state.

- The PFAS analytes driving the ∑PFAS40 differed across media, with PFOA having the highest relative concentrations in surface water and PFOS having the highest relative concentrations in fish tissue. PFOA was detected in surface water from all waterbodies. PFOS was detected in 99% of composite fish tissue samples and in at least one sample from each waterbody.

- There were significant differences in PFAS concentrations measured in surface water and fish tissue between source impacted and reference waterbodies and by region, but not between rivers/streams and lakes/ponds. While there were no significant differences observed in PFAS concentrations between waterbodies located within one mile of an EJ census tract and those located more than one mile away from an EJ census tract, median and mean PFAS concentrations were consistently higher in waterbodies near EJ census tracts.

- In analyzing the four most frequently caught species, there were significant differences in ∑PFAS40 between species within the same waterbody, with pumpkinseed having the lowest concentrations and largemouth bass having the highest concentrations of ∑PFAS40.

- Species-specific geometric mean bioaccumulation factors calculated for PFNA and PFOS using data from this study are consistent with those reported from other studies in the peer-reviewed literature. The BAFs indicate the degree to which each analyte may accumulate over time in fish from surface water.

The results and descriptive statistics presented in the project report pertain to PFAS contamination levels in the waterbodies sampled. These statistics do not necessarily represent average or typical conditions in Massachusetts, since the study design did not involve randomized site selection of a statistical sampling population.

It is also important to note that while the analytical method used (draft EPA 1633) tested for 40 PFAS analytes (including many of the more commonly used and observed PFAS), there are thousands of additional PFAS compounds in existence --- many of which may be present in environmental media but are not included in current analytical methods. As a result, the ∑PFAS40 data likely underestimate the true total PFAS concentrations reported for surface water and fish tissue. This study used the uppercase sigma notation (∑40=sum of 40 analytes) to denote the inherent limitations on any estimates of "total" PFAS.

5.1 Considerations for Additional PFAS Data Collection

While this study answered many questions and generated a robust dataset on PFAS in freshwater fish and waterbodies across the state, it highlights the need for additional data collection and analysis. Possible areas of future WPP investigations under the auspices of the Clean Water Act are listed below.

- A similar study conducted in coastal brackish and saltwater locations for recreational fishing in Massachusetts would provide useful data. Only two such U.S. based studies were identified in the peer-reviewed literature, one in Charleston Harbor and the other in both tidal and nontidal sections of the Delaware River (e.g., Fair et al., 2019; Macgillivray 2020). These coastal recreational fish data would also allow comparison to PFAS being found in open ocean seafood.
- Monitoring that includes repeated site visits and sampling over a longer period (e.g., covering multiple seasons) would offer additional insight into temporal variability of PFAS in waterbodies and present an improved dataset for comparison to chronic water quality criteria. This could be planned, for example, for a subset of the waterbodies targeted in this study by WPP or as part of the ongoing mercury sampling program by MassDEP ORS.
- The data generated for PFAS in trout in the current study did not allow for conclusions to be drawn regarding PFAS concentrations in stocked versus native trout, although trout were stocked by DFW in all waterbodies where trout were caught. Further investigation into PFAS levels measured in hatchery trout compared to native born trout and the rate of PFAS bioaccumulation following stocking is needed. A study by the state of Maine showed rapid PFAS bioaccumulation in trout following stocking into ambient waters (Danielson, 2022).
- Data on PFAS in whole body freshwater fish and invertebrates would be useful for comparison with EPA's draft/final recommended Aquatic Life Water Quality Criteria for PFOA and PFOS. While the fish muscle (tissue) and surface water data from the current study are directly comparable and the values observed are well below applicable draft criteria, potential exceedances based on whole body burden for fish and invertebrates in source-impacted and reference areas could be explored to confirm non-exceedances for all components of the draft criteria.

- This study relied on draft EPA Method 1633. Though this method is becoming widely accepted in the scientific community, it is still being assessed through a multi-laboratory validation study. Incorporating an interlaboratory study, where results from samples collected from a subset of waterbodies are split and sent to two different laboratories, into future PFAS monitoring work by MassDEP will provide valuable quality assurance information on inter-laboratory precision. Such an inter-laboratory comparison could include both a private laboratory and the MassDEP Wall Experiment Station laboratory.
- Future water quality studies for PFAS could consider including analysis for Total Oxidizable Precursors (TOP) and/or Total Organic Fluorine (TOF). TOP methods convert oxidizable PFAS precursors into PFAAs, which can be measured using a validated PFAS analytical method. TOF provides a single result which can be used as a surrogate for the total PFAS in a sample. Similar to TOP, TOF takes into account PFAS that are not measured by other validated laboratory methods. Both methods would provide a better estimate of "total" PFAS contamination and provide more information on the presence of PFAS precursors than methods that test for a limited set of PFAS analytes. These tests may also be useful if screening criteria are developed for PFAS as a class of contaminants.

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APPENDIX A

Summary of Data Validation Results for Water and Fish Tissue PFAS Data Collected in 2022 at Selected MA Rivers and Lakes

April 6, 2023

The following summary provides an overview of the data validation approach, methods[1] and results for the MassDEP 2022 PFAS (per- and polyfluoroalkyl substances) monitoring project investigating PFAS levels in fish tissue and water in MA lakes and rivers. The data validation decision-making process used by the MassDEP's Watershed Planning Program (WPP), in consultation with the contract project manager (Eastern Research Group (ERG), resulted in a final, quality-assured dataset (dated March, 2023) suitable for data analysis and decision-making.

The final project report is being prepared by ERG and will be available in June, 2023. The final report will provide a more comprehensive presentation and analysis of the final data. No changes to the final March, 2023 dataset are anticipated in the final report.

[1] *The data validation guidance for the MassDEP 2022 PFAS monitoring project investigating PFAS levels in fish tissue and water in MA lakes and rivers was adapted from Appendix H - Data Review Guidelines for Analysis of PFAS in Non-Potable Water 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).*

Planning for Quality Assurance

Prior to sample collection, a Quality Assurance Project Plan (QAPP) was prepared and approved by MassDEP-WPP (June, 2022). 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 relative to ensuring data quality for both field and laboratory data generated by the Normandeau field team and the Eurofins-Lancaster environmental testing lab. This included Eurofins' laboratory SOPs for draft EPA method 1633 for non-potable water and fish tissue.

Field and Lab Qualifications

The project team consisted of MassDEP, Eastern Research Group (ERG), PG Environmental (PG), Normandeau Associates and the Eurofins-Lancaster 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. PG's field ecologists are experienced in water quality monitoring, conducting fish population surveys, and collecting fish tissue samples. PG assisted with the sampling design and helped address potential PFAS cross-contamination during fish and water collections. Normandeau is experienced in sampling fish from lakes and rivers across Massachusetts and the eastern United States, including long-term monitoring of mercury levels in selected lakes and ponds throughout Massachusetts. Normandeau conducted all the field sampling and sample preparation. The Eurofins group operates across a network of hundreds of laboratories in over 60 countries and offer a portfolio of over 200,000 analytical methods. Operating 42 environmental testing laboratories, the Eurofins Environment Testing (ET) network in the US performs analysis of waters, soils and solids, air, and tissue using state-of-the-art

analytical methods. Following Eurofins' participation in EPA's multi-lab validation of the draft EPA 1633 method, the Eurofins ET laboratories in Lancaster, PA received accreditation for Draft EPA Method 1633 for the US Department of Defense under QSM 5.4 Table B-24 for all 40 PFAS compounds for water, solids and tissue matrices (May 2022). The Eurofins-Lancaster laboratory is also certified in the state of Massachusetts for potable water PFAS analyses using EPA method 537.1 (MA certification for draft EPA method 1633 is currently unavailable).

Use of EPA Draft Analytical Method 1633

Per MassDEP's request, the Eurofins-Lancaster laboratory utilized the draft EPA Method 1633 (pfas by 1633). Draft Method 1633 is an EPA-developed test method suitable for quantitating up to 40 unique PFAS compounds in non-potable water and other matrices, such as solids and tissue. In September 2021, the EPA, in collaboration with the US Department of Defense (DoD), published the first draft of the first EPA-validated laboratory analytical method using the data from the single laboratory validation. This method employs isotope dilution to achieve lower reporting limits and reduce matrix-influenced bias. The method has since undergone a multi-lab validation study process. In June 2022, a second draft of Method 1633 was published, which included clarification on several issues identified by the laboratories participating in the multi-laboratory validation study. The second draft is the basis for the Eurofins Lab Standard Operating Procedure (SOP) used for the 2022 MassDEP fish tissue project. A final version of the method for all eight environmental matrices (wastewater, surface water, groundwater, soil, biosolids, sediment, landfill leachate, and fish tissue) is anticipated later in 2023. In the interim, EPA has been recommending use of the draft Method 1633 for analyzing PFAS in environmental samples.

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 solids (i.e., tissue) PFAS data, and therefore were applied to the review of both water sample and fish tissue sample analytical PFAS results from the Eurofins-Lancaster laboratory (based on the draft EPA Method 1633).

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

- Eurofins lab SOP for draft EPA1633
- Eurofins lab reports (Level 2 and Level 4) and completed COCs
- Eurofins 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

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 Eurofins 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.

Table 1. Translation table for data qualifiers

ISSUE	Eurofins Lab qualifier	Lab Definition	WPP (final) data qualifier	WPP Definition
Lab QC outside acceptance limits (potential high bias)	*+	LCS and/or LCSD is outside acceptance limits, high biased.	a	accuracy as estimated at WES 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.
Same as above.	*5+	Isotope dilution analyte is outside acceptance limits, high biased.	a	Same as above.
Outside calibration range	E	Result exceeded calibration range.	a	Same as above.
Lab QC outside acceptance limits (potential low bias)	*5-	Isotope dilution analyte is outside acceptance limits, low biased.	a	Same as above.
Holding time violation	H	Sample was prepped or analyzed beyond the specified holding time	h	holding time violation (usually indicating possible bias low)

ISSUE	Eurofins Lab qualifier	Lab Definition	WPP (final) data qualifier	WPP Definition
Between MDL and RL	J	Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.	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).
Estimated value	I	Value is EMPC (estimated maximum possible concentration).	j	Same as above.
Blank contamination	B	Compound was found in the blank and sample.	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	Not_Detected	---	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	cn	Refer to Case Narrative for further detail	---	Apply appropriate WPP qualifier dependent on case narrative description

5. The following additional, non-analytical WPP data qualifiers are also used if/when applicable.

Table 2. Additional 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.
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 fieldsheet metadata for water and fish tissue 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, fish or water sample taken from an isolated pool, weather-related effects on water sample contents, possible PFAS-contamination of sample, etc.). Apply "r" or "m" 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 fish 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 6ºC 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

Blanks

In addition to lab method blanks run by Eurofins, ambient field blank water samples (in the field during water sampling) and equipment rinsate blanks (during fish tissue sample prep in the field lab) were collected by field crews at 25 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 lab method blanks, 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

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. 25 percent of the sampled water bodies. During fish processing, duplicate fish tissue samples were collected at approx. 10-20 percent of the sampled water bodies by filleting both sides of the same fish during compositing (parent=all

right side filets; duplicate=all left side filets). 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 Eurofins SOP, the signal to noise 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 Eurofins SOP for EPA 1633, the minimum of six calibration standards are required when using an average or linear curve fit. A minimum of seven calibration standards are required for a second-order (quadratic) curve fit. The relative standard deviation (RSD) for all analytes should 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 Eurofins SOP for EPA 1633, continuing calibration verification (CCV) checks should be analyzed at a frequency of one per ten field samples. The calculated amount for each compound (native and extraction standard) 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. 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 40% - 150% (Eurofins 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 40% - 150% (Eurofins 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 20% - 150% (Eurofins SOP acceptance limits). Per Eurofins 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 Eurofins SOP, data reported as estimated maximum possible concentrations (EMPC) are qualified with "I". 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 " I "	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 Eurofins 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" for non-detects and detects

Performance Evaluation Samples

Performance evaluation of Eurofins 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 lab. Reagent water blanks were also submitted to the lab. 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%).

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).

Final Results of 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 fish tissue. 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 fish tissue are considered valid and usable for decision-making. Lab qualifications were carried forward, but none were considered significant enough to censor the associated results. Similarly, quality control information contained in the case narratives in the lab reports was reviewed but did not result in any censoring over and above the lab qualifications. By WPP convention, any qualified data are considered usable for decision-making, albeit with general caveat to the data user. Only one result (for water) was censored (due to poor field precision) in the final dataset and was removed from further data analysis.

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 were 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 fish tissue samples) were collected at an approx. frequency of 25% 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

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

Two corrective actions were issued by the Eurofins lab due to two separate incidents that occurred at the laboratory and affected MassDEP project samples. The first incident involved the premature discarding of 15 fish tissue samples prior to analysis. This necessitated resampling of three waterbodies by the field crews to replace the samples with new ones. The lab determined the root cause to be lack of organization, inadequate training, and inadequate communication on the part of the sample support technician and the PFAS analyst. Corrective action was taken at the lab to prevent this same problem from happening again (and a monetary credit was issued to MassDEP for this error). The second incident involved a holding time exceedance for fish tissue samples from one job. The root causes were determined to be an erroneous assumption that MassDEP requested the samples be placed on hold, not sending appropriate notifications and a sample scheduling error. Corrective action was taken at the lab to prevent this problem from reoccurring. The affected samples were qualified (the holding time exceedance was not considered significant enough to censor the results).

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 occasional poor percent recoveries for NEtFOSA, NEtFOSE (and precision), NMeFOSA and NMeFOSE (and precision) at lower dilution levels (1/10 and 1/5); poor accuracy (and precision) for 5:3FTCA and 7:3FTCA for one of 1/10 dilution samples; and poor accuracy (and precision) for 3:3FTCA for one of the 1/20 dilution samples. None of the results for the performance evaluation samples were considered severe enough to require qualification or censoring of any of the project data.

Sample Representativeness

To evaluate any anomalies that may have affected sample representativeness, sample metadata including fieldsheets, Chain-of-Custody (COC) records and related documentation were reviewed and corrections made as needed. No sample results were qualified or censored based on this review.

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 97 ng/l (PFHxS, Ashumet Pond; within range of other surface water results observed in rivers). The maximum fish tissue result was 280 ng/g (PFOS, Ashumet Pond) with 6 other PFOS results ranging from 150-250 ng/g (mostly in Ashumet Pond). 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), as shown in the censored (##) example below (Table3). 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.

Table 3. Example from final database spreadsheet showing project qualification.

Result	LabQual	ResComm	Units	MDL	RDL	UQL	Matrix	Analytical Method	AnalDate	CollectDate	ProjectQual
##	U	added "d" and censored "<MDL" result (dup sample was 3.8)	ng/L	0.49	2.0		Water	EPA 1633	12/05/2022	10/18/2022	d

APPENDIX B: Surface Water Sample Results by Waterbody

Table 1: Concentrations (ng/L) measured in Routine Surface Water Samples

Waterbody	6:2FTS	8:2FTS	NEtFOSAA	PFBA	PFBS	PFDA	PFHpA	PFHpS	PFHxA	PFHxS	PFNA	PFOA	PFOS	PFOSA	PFPeA	PFPeS	PFAS6	∑PFAS40
Ashumet Pond	64.25	<2.7	<0.72	53.4	10.2	<0.52	19	11	26.5	92.5	15.1	34.5	89	<0.52	34	17.5	250.1	466.9
Asnacomet Pond	<2.6	<2.7	<0.73	<2.1	0.52	<0.52	1.0	<0.42	<0.48	<0.59	<0.52	1.9	<0.52	<0.52	<1.0	<0.52	2.90	3.42
Blackstone River	<2.4	<2.5	<0.67	6.2	4.8	0.49	4.2	<0.39	10	3	0.95	6.6	6.2	<0.48	7.0	0.63	21.4	50.1
Buck Pond	<2.4	<2.5	<0.68	2.6	1.4	<0.49	1.4	<0.39	2.3	3	0.41	3.7	2.0	<0.49	<0.97	0.39	10.5	17.2
Bungay River	<2.5	<2.6	0.75	7.0	4.1	<0.49	4.1	<0.39	8.5	6.1	2.1	11	19	<0.49	11	1.8	42.3	75.5
Charles River	<2.5	<2.6	<0.69	5.45	4.25	<0.49	3.0	<0.39	10.5	2.35	0.89	7.8	6.1	<0.49	9.2	0.38	20.1	49.9
Chicopee River	<2.5	<2.7	<0.71	2.3	1.0	<0.51	1.9	<0.41	3.2	<0.58	<0.51	3.9	1.6	<0.51	2.6	<0.51	7.40	16.5
Concord River	<2.8	<2.9	<0.77	7.0	5.9	<0.55	4.3	<0.44	13	3.4	2.7	10	11	<0.55	13	<0.55	31.4	70.3
Congomond Lakes	<2.6	<2.7	<0.73	2.6	1.3	<0.52	1.6	<0.42	2.3	1.2	0.65	3.9	1.8	<0.52	1.9	<0.52	9.15	17.3
Ct River (Chicopee)	<2.8	<2.9	<0.79	<2.3	<0.34	<0.56	<0.59	<0.45	<0.56	<0.64	<0.56	1.3	1.5	<0.56	<1.1	<0.45	2.80	2.80
Crocker Pond	<2.5	<2.6	<0.69	5.4	1.8	<0.49	12	<0.40	15	0.61	2.3	24	<0.49	<0.49	14.0	<0.49	38.9	75.1
Deerfield River	<2.5	<2.6	<0.70	<2.0	0.45	<0.5	<0.52	<0.40	<0.50	<0.57	<0.50	1.3	0.99	<0.50	<1.0	<0.50	2.29	2.73
Falls Pond	<2.5	<2.6	<0.69	4.1	3.4	<0.49	2.3	<0.39	4.4	3.5	0.74	6.2	9.1	<0.49	4.8	0.58	21.8	39.1
Flint Pond	<2.8	<2.9	<0.79	6.7	3.9	4.3	8.4	<0.45	11	4.8	4.2	30	22	<0.56	7.4	0.95	73.7	103.7
Forge Pond	<2.4	<2.5	<0.68	3.8	2.4	<0.49	3.1	<0.39	4.1	2.1	0.85	7.2	3.9	<0.49	4.15	0.40	17.1	31.8
Hardwick Pond	<2.7	<2.8	<0.77	<2.2	1.2	<0.55	1.3	<0.44	<0.55	<0.62	0.59	3.0	1.2	<0.55	1.4	<0.55	6.09	8.69
Hathaway Ponds	<2.6	<2.7	<0.72	2.4	0.74	<0.51	3.9	<0.41	3.8	2.8	1.2	3.7	2.1	<0.51	2.6	<0.51	13.7	23.2
Hoosic River	<2.5	<2.6	<0.69	<2.0	0.75	<0.49	<0.51	<0.40	0.85	<0.56	<0.49	2.3	3.2	<0.49	<0.99	<0.49	5.50	7.10
Hopedale Pond	<2.5	<2.6	<0.69	4.7	4.9	<0.49	5.6	<0.39	8.2	1.5	0.98	10	2.6	<0.49	7.0	<0.49	20.7	45.5
Jamaica Pond	<2.4	<2.5	<0.68	4.2	1.9	<0.49	5.7	<0.39	5.5	0.95	1.8	14	<0.49	<0.49	4.9	<0.49	22.5	39.0
Lake Attitash	<2.5	<2.6	<0.69	3.4	3.5	<0.5	2.5	<0.40	2.9	0.91	0.76	4.7	1.6	<0.50	<0.99	<0.50	10.5	20.3
Lake Boon	<2.8	<2.9	<0.79	2.8	3.6	<0.56	2.7	<0.45	4.4	1.3	<0.56	7.0	2.9	<0.56	<1.1	0.45	13.9	25.2
Lake Cochichewick	<2.5	<2.6	<0.71	2.7	1.0	<0.5	2.3	<0.40	2.1	1.1	0.54	3.6	2.1	<0.5	<1.0	<0.50	9.64	15.4
Lake Cochituate	<2.6	<2.7	<0.72	4.2	4.1	<0.51	4.4	<0.41	6.9	4.1	1.4	8.8	8.5	<0.51	6.3	0.76	27.2	49.5
Lake Mirimichi	<2.6	<2.7	<0.72	6.2	3.9	<0.51	3.4	<0.41	5.3	2.8	1.1	11	22.5	<0.51	6.2	0.43	40.7	62.6
Lake Quannapowitt	<2.5	<2.6	0.85	5.1	3.7	0.94	3.4	<0.40	4.2	0.93	1.6	6.8	5.0	<0.49	4.2	<0.49	18.7	36.7
Lake Ripple	<2.5	<2.6	<0.71	3.9	5.2	<0.51	3.1	<0.41	4.1	3.7	0.74	7.0	<0.51	<0.51	4.5	1.2	14.5	33.4

Waterbody	6:2FTS	8:2FTS	NEtFOSAA	PFBA	PFBS	PFDA	PFHpA	PFHpS	PFHxA	PFHxS	PFNA	PFOA	PFOS	PFOSA	PFPeA	PFPeS	PFAS6	∑PFAS40
Lake Sabbatia	<2.7	<2.8	<0.77	3.0	2.9	<0.55	3.4	<0.44	3.8	2.5	0.69	7.0	<0.55	<0.55	<1.1	<0.55	13.6	23.3
Lake Winthrop	<2.5	<2.6	<0.69	3.9	3.5	<0.49	2.0	<0.39	3.3	1.1	0.76	5.4	2.2	<0.49	<0.99	<0.49	11.5	22.2
Long Pond (Lakeville)	<2.4	<2.5	<0.68	3.3	1.7	0.38	1.5	<0.39	2.1	2.55	1.1	3.3	4.5	<0.49	1.75	0.51	13.3	22.5
Long Pond (Yarmouth)	<2.4	<2.5	<0.68	2.9	4.0	<0.49	2.6	<0.39	6.3	1.75	0.75	6.0	2.0	<0.49	5.8	<0.49	13.1	32.1
Mascuppic Lake	<2.5	<2.6	<0.69	3.8	3.4	<0.49	4.4	<0.39	4.2	2.5	1.0	11.0	<0.49	<0.49	3.6	<0.49	18.9	33.9
Merrimack River	<2.7	<2.8	<0.77	3.6	3.0	<0.55	3.0	<0.44	8.3	1.8	0.79	7.8	4.25	<0.55	5.35	<0.55	17.6	37.7
Millers River	<2.4	<2.5	<0.68	2.4	1.3	<0.49	1.9	<0.39	3.6	1.1	0.77	4.8	2.8	<0.49	3.7	<0.49	11.4	22.4
Moores Pond	<2.5	<2.6	<0.69	<2.0	0.22	<0.49	0.43	<0.40	<0.49	<0.56	<0.49	1.2	0.86	<0.49	<0.99	<0.49	2.49	2.71
South Meadow Pond	<2.6	<2.8	<0.74	5.5	3.8	<0.53	5.8	<0.42	13.0	0.76	0.76	13.0	2.0	<0.53	12.0	0.69	22.3	57.3
Nashua River	<2.6	<2.7	<0.73	10.0	15.0	0.69	9.3	<0.42	37.0	4.2	1.7	25.0	9.9	<0.52	22	0.71	50.8	135.5
Nutting Lake	<2.5	<2.6	<0.71	9.0	4.5	<0.51	5.2	<0.40	5.8	1.9	1.2	9.0	5.9	<0.51	6.3	<0.51	23.2	48.8
Oxbow Pond	<2.3	<2.4	<0.66	2.0	0.93	<0.47	1.3	<0.37	<0.47	1.8	<0.47	2.2	2.8	<0.47	<0.94	<0.47	8.10	11.0
Pelham Lake	<2.5	<2.6	<0.69	<2.0	<0.30	<0.49	0.65	<0.40	<0.49	<0.56	<0.49	1.5	<0.49	<0.49	<0.99	<0.49	2.15	2.2
Pontoosuc Lake	<2.6	<2.7	<0.74	<2.1	0.58	<0.53	<0.55	<0.42	<0.53	<0.60	<0.53	1.6	<0.53	<0.53	<1.1	<0.53	1.60	2.2
Robbins Pond	<2.5	<2.6	<0.70	4.7	2.0	<0.5	2.3	<0.40	2.8	0.72	0.92	3.9	2.6	<0.50	3.3	<0.50	10.4	23.2
Sandy Pond	<2.5	<2.6	<0.70	2.1	1.4	<0.5	1.7	<0.40	<0.5	<0.57	<0.50	5.1	2.3	<0.50	1.5	<0.50	9.10	14.1
Snake Pond	<2.6	<2.7	<0.72	<2	0.68	<0.51	0.87	<0.41	0.95	<0.58	<0.51	1.0	0.74	<0.51	<1.0	<0.51	2.61	4.2
South Watuppa Pond	<2.5	<2.6	<0.70	4.4	3.95	0.38	3.4	<0.40	5.8	2.7	1.5	9.6	6.2	<0.5	4.75	0.65	23.8	43.3
Studley Pond	70.0	22.0	<0.72	16.0	4.70	0.92	24.0	0.98	40.0	37	5.9	43	80.0	1.5	48.0	2.4	190.8	396.4
Upper Spectacle Pond	<2.7	<2.8	<0.76	<2.2	<0.32	<0.54	0.89	<0.43	<0.54	<0.62	0.6	1.3	0.78	<0.54	<1.1	<0.54	3.57	3.6
Wachusett Reservoir	<2.4	<2.5	<0.67	<1.9	0.86	<0.48	1.4	<0.38	1.9	0.58	<0.48	2.2	<0.48	<0.48	2.2	<0.48	4.18	9.1
Ware River	<2.6	<2.7	<0.73	2.2	1.7	<0.52	2.6	<0.42	4.4	1.1	0.67	4.6	3.8	<0.52	3.0	<0.52	12.8	24.1
Webster Lake	<2.6	<2.7	<0.73	<2.1	1.6	<0.52	1.6	<0.42	<0.52	0.72	0.65	4.0	2.5	<0.52	2.0	<0.52	9.47	13.1
West Lake	<2.7	<2.8	<0.74	<2.1	<0.32	<0.53	1.1	<0.42	<0.53	<0.61	<0.53	1.4	<0.53	<0.53	<1.1	<0.53	2.50	2.5
Whitman's Pond	<2.5	<2.6	<0.71	5.0	5.2	<0.50	3.8	<0.40	6.6	5.7	1.2	8.3	8.6	<0.50	8.3	0.56	27.6	53.3

Notes:
This table includes PFAS analytes detected in in at least one surface water analyte, as well as the sum of all detected PFAS (∑PFAS40) and the sum of PFAS regulated by Mass DEP in drinking water (PFAS6). Results are shown in units of ng/L and non-detects observations are represented by <[MDL].

Table 2: Concentrations (ng/L) Measured in Beach Surface Water Samples

Waterbody	6:2FTS	8:2FTS	NEtFOSAA	PFBA	PFBS	PFDA	PFHpA	PFHpS	PFHxA	PFHxS	PFNA	PFOA	PFOS	PFOSA	PFPeA	PFPeS	PFAS6	∑PFAS40
Asnacomet Pond	<2.4	<2.5	<0.68	<2.0	0.5	<0.49	1.2	<0.39	<0.48	<0.56	<0.49	2.0	1.1	<0.49	<0.98	<0.49	4.3	4.8
Crocker Pond	<2.5	<2.6	<0.69	5.8	2.0	<0.49	13.0	<0.40	17.0	0.60	2.9	25.0	8.7	<0.49	13.0	<0.49	50.2	88.0
Falls Pond	<2.5	<2.6	<0.71	3.4	3.6	<0.50	2.9	<0.40	3.9	3.1	0.79	6.1	10.0	<0.50	5.2	0.68	22.9	39.7
Falls Pond	<2.4	<2.5	<0.69	4.3	4.4	<0.49	2.9	<0.39	5.9	3.7	1.0	5.6	8.1	<0.49	5.8	0.75	21.3	42.5
Forge Pond	<2.5	<2.6	<0.70	3.8	2.9	<0.50	2.6	<0.40	4.8	1.8	0.86	5.7	4.2	<0.50	4.5	<0.50	15.2	31.2
Lake Cochituate	<2.6	<2.7	<0.74	5.0	3.9	<0.53	3.8	<0.42	6.8	3.8	1.0	8.3	8.4	<0.53	<1.1	0.73	25.3	41.7
Lake Winthrop	<2.4	<2.5	<0.68	4.0	3.3	<0.49	2.4	<0.39	2.6	1.1	0.83	5.4	2.3	<0.49	2.7	<0.49	12.0	24.6
Long Pond (Yarmouth)	<2.4	<2.5	<0.68	3.1	3.6	<0.49	2.6	<0.39	6.0	1.9	0.72	6.1	4.1	<0.49	5.6	<0.49	15.4	33.7
Pelham Lake	<2.6	<2.7	<0.72	<2.1	<0.31	<0.51	<0.53	<0.41	<0.51	<0.58	<0.51	1.4	<0.51	<0.51	<1.0	<0.51	1.4	1.4
Sandy Pond	<2.7	<2.8	<0.75	2.3	1.0	<0.53	2.1	<0.43	1.9	0.70	<0.53	5.4	3.1	<0.53	1.9	<0.53	11.3	18.4
Snake Pond	<2.6	<2.7	<0.74	<2.1	0.82	<0.53	0.8	<0.42	<0.53	<0.60	<0.53	0.71	<0.53	<0.53	<1.1	<0.53	1.5	2.3
Webster Lake	<2.6	<2.7	<0.72	<2	1.8	<0.51	1.7	<0.41	<0.51	0.75	0.51	3.4	<0.51	<0.51	<1.0	<0.51	6.4	8.2

Notes:
This table includes PFAS analytes detected in at least one surface water analyte as well as the sum of all detected PFAS (∑PFAS40) and the sum of PFAS regulated by Mass DEP in drinking water (PFAS6). Results are shown in units of ng/L and non-detects observations are represented by <[MDL].

APPENDIX C: Fish Tissue Sample Results by Waterbody

Waterbody	Species	Mean Fish Length	Mean Fish Weight	Number of Fish	Number of Composite Samples	Mean PFDA	Mean PFDS	Mean PFDoA	Mean PFHxS	Mean PFNA	Mean PFOA	Mean PFOS	Mean PFOSA	Mean PFTeDA	Mean PFTrDA	Mean PFUnA	Mean PFAS6	Mean ∑PFAS40
Ashumet Pond	LMB	423.00	1217.67	15	3	0.34	NA	0.43	0.54	NA	NA	230.00	NA	0.31	0.84	3.63	230.89	236.35
Ashumet Pond	WP	205.87	118.67	15	3	0.33	NA	0.51	0.36	0.64	NA	206.67	0.12	0.31	0.88	3.23	208.01	213.62
Ashumet Pond	YP	219.67	123.53	15	3	0.21	NA	0.26	1.20	0.85	0.21	126.67	0.17	0.21	0.47	2.23	129.07	132.72
Asnacomet Pond	B	173.00	107.33	3	1	0.38	NA	0.43	NA	NA	NA	3.20	NA	0.26	0.62	0.86	3.58	5.75
Asnacomet Pond	LMB	300.00	353.00	1	1	0.50	NA	1.00	NA	NA	NA	3.80	NA	0.69	1.70	1.70	4.30	9.39
Blackstone River	WP	214.25	151.75	4	2	0.15	0.52	0.46	NA	NA	NA	4.35	0.46	0.55	0.31	0.21	4.45	6.92
Blackstone River	YP	193.00	77.00	1	1	0.60	0.61	0.67	NA	NA	NA	4.50	NA	0.83	0.52	0.55	5.10	8.28
Buck Pond	B	191.43	135.43	7	2	NA	NA	NA	NA	NA	NA	2.30	NA	NA	NA	0.35	2.30	2.65
Buck Pond	LMB	412.83	1135.67	6	2	0.44	NA	0.22	NA	NA	NA	6.10	NA	NA	0.39	0.99	6.54	8.11
Buck Pond	YP	272.75	245.50	4	2	NA	NA	NA	NA	NA	NA	0.61	NA	NA	NA	0.13	0.61	0.71
Charles River	B	161.00	78.80	10	2	0.69	0.26	0.65	NA	NA	NA	10.90	NA	0.24	0.30	0.63	11.59	13.67
Charles River	BC	222.00	151.00	1	1	1.50	0.54	0.82	0.17	0.39	NA	37.00	NA	0.28	0.38	1.10	39.06	42.18
Charles River	LMB	356.00	668.00	1	1	1.50	0.62	1.20	NA	NA	NA	40.00	NA	0.41	0.66	1.70	41.50	46.09
Chicopee River	B	177.40	106.70	10	2	0.31	NA	0.29	NA	NA	NA	3.00	NA	0.23	0.35	0.59	3.31	4.75
Chicopee River	LMB	352.33	744.00	6	2	0.41	NA	0.37	NA	NA	NA	5.20	NA	0.27	0.41	0.73	5.61	7.38
Concord River	B	168.50	101.10	10	2	0.51	0.36	0.42	NA	NA	NA	12.00	NA	0.14	0.24	1.40	12.51	15.04
Congomond Lakes	B	151.90	63.20	10	2	1.13	NA	1.39	NA	NA	NA	2.95	NA	0.74	0.70	1.70	4.08	8.60
Congomond Lakes	BB	256.17	234.83	6	2	0.31	NA	0.55	NA	NA	NA	0.59	NA	0.23	0.31	0.35	0.90	2.28
Congomond Lakes	P	142.50	60.00	6	2	1.30	NA	1.20	NA	NA	NA	3.00	NA	0.58	0.53	1.45	4.30	8.12
Connecticut River (Chicopee)	SMB	327.92	471.58	12	3	0.23	NA	0.37	NA	NA	NA	5.25	0.18	0.27	0.21	0.33	5.44	6.79
Connecticut River (Chicopee)	YP	238.89	197.22	9	3	0.36	NA	0.51	0.12	NA	NA	6.00	0.25	0.45	0.39	0.44	6.48	8.52
Crocker Pond	BC	263.30	266.20	10	2	1.65	NA	0.48	NA	1.23	0.33	25.50	NA	0.41	0.47	0.69	28.70	30.75
Crocker Pond	LMB	389.00	947.10	10	2	1.12	NA	0.75	NA	NA	NA	15.50	NA	0.48	0.55	0.86	16.62	19.25
Crocker Pond	YP	210.30	120.80	10	2	1.35	NA	0.45	NA	0.36	NA	12.00	NA	NA	0.42	0.75	13.71	15.32
Deerfield River	RT	375.00	540.00	1	1	NA	NA	NA	NA	NA	NA	0.20	NA	NA	NA	NA	0.40	0.40
Falls Pond	LMB	410.80	1130.40	10	2	0.64	0.21	1.55	NA	NA	NA	25.00	NA	1.00	0.88	0.94	25.64	30.21

Waterbody	Species	Mean Fish Length	Mean Fish Weight	Number of Fish	Number of Composite Samples	Mean PFDA	Mean PFDS	Mean PFDoA	Mean PFHxS	Mean PFNA	Mean PFOA	Mean PFOS	Mean PFOSA	Mean PFTeDA	Mean PFTrDA	Mean PFUnA	Mean PFAS6	Mean ∑PFAS40
Falls Pond	P	163.50	94.80	10	2	0.37	NA	0.45	0.06	NA	NA	7.95	0.20	0.22	0.21	0.41	8.36	9.82
Falls Pond	YP	205.60	117.40	10	2	0.58	NA	0.66	0.12	0.15	NA	19.50	0.37	0.40	0.48	0.43	20.30	22.63
Flint Pond	B	175.20	125.53	15	3	5.10	NA	0.10	NA	0.19	NA	31.00	NA	NA	0.18	0.89	36.26	37.41
Flint Pond	LMB	369.67	701.42	12	3	8.37	NA	0.52	NA	0.11	NA	65.67	NA	0.16	0.38	2.00	74.09	77.13
Flint Pond	YP	226.73	165.33	15	3	8.83	NA	0.44	0.05	0.51	NA	53.00	0.52	NA	0.29	1.53	62.37	65.15
Forge Pond	AE	602.00	536.67	6	2	0.82	NA	0.59	NA	0.33	NA	21.50	NA	0.34	0.52	0.97	22.64	25.06
Forge Pond	BC	220.50	171.00	10	2	0.47	NA	0.21	0.06	0.48	NA	17.50	NA	0.13	0.21	0.40	18.49	19.42
Forge Pond	P	172.40	114.10	10	2	0.47	NA	0.36	0.06	0.13	NA	7.93	0.07	0.20	0.28	0.53	8.52	9.94
Hardwick Pond	B	186.10	132.40	10	2	NA	NA	0.11	NA	NA	NA	1.10	NA	NA	0.23	0.38	1.10	1.80
Hardwick Pond	LMB	366.33	904.17	6	2	0.28	NA	0.11	NA	NA	NA	1.75	NA	NA	0.23	0.45	2.03	2.80
Hardwick Pond	YP	232.70	147.20	10	2	NA	NA	NA	NA	NA	NA	0.41	NA	NA	NA	0.17	0.41	0.55
Hoosic River	BRT	271.50	173.33	6	2	0.23	NA	0.19	NA	NA	NA	6.90	0.20	NA	0.13	0.21	7.08	7.72
Hopedale Pond	B	168.83	90.17	6	2	0.17	NA	0.14	NA	NA	NA	3.05	NA	0.12	0.24	0.44	3.17	4.05
Hopedale Pond	BC	226.17	156.83	6	2	0.45	NA	0.35	NA	0.15	NA	6.70	NA	0.16	0.33	0.64	7.26	8.70
Hopedale Pond	YP	221.67	132.00	6	2	0.44	NA	0.30	NA	NA	NA	3.80	0.07	0.16	0.29	0.52	4.24	5.51
Jamaica Pond	RT	326.80	466.80	5	2	NA	NA	NA	NA	NA	NA	1.10	NA	NA	NA	NA	1.80	2.90
Jamaica Pond	YP	162.00	40.00	1	1	1.60	NA	0.46	NA	0.34	NA	9.60	NA	0.17	0.29	0.95	11.54	13.41
Lake Attitash	BB	272.17	299.33	6	2	0.20	NA	0.16	NA	NA	NA	1.31	0.08	0.11	0.19	0.25	1.45	2.15
Lake Attitash	P	157.40	90.20	10	2	0.59	NA	0.45	NA	0.23	NA	2.50	0.07	0.23	0.42	0.93	3.29	5.35
Lake Attitash	YP	222.60	119.60	10	2	0.97	NA	0.49	NA	0.15	NA	6.75	NA	0.27	0.48	1.18	7.83	10.24
Lake Boon	B	168.53	95.00	15	3	0.34	NA	0.48	0.07	0.15	NA	20.73	NA	0.35	0.39	0.97	21.22	23.42
Lake Boon	LMB	330.00	484.87	15	3	0.71	NA	1.14	NA	NA	NA	9.23	NA	0.55	0.63	1.23	9.95	13.50
Lake Boon	WP	230.53	157.60	15	3	0.47	NA	0.81	NA	NA	NA	5.20	0.14	0.38	0.62	0.82	5.67	8.43
Lake Cochichewick	LMB	381.50	925.50	6	2	0.74	NA	0.46	NA	NA	NA	6.55	NA	0.28	0.39	1.15	7.29	9.56
Lake Cochichewick	P	180.67	133.50	6	2	0.60	NA	0.24	NA	NA	NA	3.15	0.11	0.11	0.21	0.72	3.75	5.07
Lake Cochichewick	YP	228.67	139.17	6	2	0.39	NA	0.16	NA	NA	NA	2.30	NA	0.10	0.11	0.36	2.69	3.37
Lake Cochituate	BC	229.40	187.70	10	2	0.82	0.74	0.88	0.14	0.41	NA	28.00	0.11	0.58	0.67	0.70	29.36	33.27
Lake Cochituate	LMB	355.83	679.83	6	2	0.92	0.87	1.80	NA	NA	NA	23.00	NA	0.84	1.16	1.37	23.92	29.95

Waterbody	Species	Mean Fish Length	Mean Fish Weight	Number of Fish	Number of Composite Samples	Mean PFDA	Mean PFDS	Mean PFDoA	Mean PFHxS	Mean PFNA	Mean PFOA	Mean PFOS	Mean PFOSA	Mean PFTeDA	Mean PFTrDA	Mean PFUnA	Mean PFAS6	Mean ∑PFAS40
Lake Cochituate	YP	246.70	179.40	10	2	1.35	0.61	1.45	NA	0.26	NA	27.50	0.86	0.71	1.05	1.45	29.11	35.24
Lake Mirimichi	B	192.00	135.90	10	2	0.43	0.25	0.47	NA	NA	NA	68.50	NA	0.30	0.56	0.66	68.93	71.15
Lake Mirimichi	LMB	335.13	498.25	8	2	1.20	0.40	0.62	NA	NA	NA	125.00	NA	0.25	0.57	1.25	126.20	129.28
Lake Mirimichi	YP	239.11	169.00	9	2	0.82	0.21	0.43	NA	NA	NA	52.89	0.08	0.15	0.44	0.85	53.71	55.83
Lake Quannapowitt	WP	159.20	53.40	10	2	0.43	NA	0.21	NA	NA	NA	2.80	0.37	0.10	0.24	0.47	3.23	4.64
Lake Quannapowitt	YP	212.50	96.50	2	1	2.80	0.61	1.10	NA	0.21	NA	15.00	0.17	0.56	0.87	3.00	18.01	24.32
Lake Ripple	B	160.00	75.80	10	2	0.97	0.62	0.76	NA	NA	NA	12.50	NA	0.22	0.43	1.30	13.47	16.77
Lake Ripple	BC	215.13	151.75	8	2	2.30	0.49	0.46	NA	0.49	NA	40.00	NA	NA	0.23	0.91	42.79	44.88
Lake Ripple	LMB	374.30	820.30	10	2	2.45	0.91	1.25	NA	NA	NA	34.00	NA	0.34	0.56	2.10	36.45	41.60
Lake Sabbatia	BC	207.75	116.50	4	2	0.81	NA	0.50	NA	0.64	NA	18.00	NA	0.41	0.62	0.91	19.45	21.89
Lake Sabbatia	LMB	355.75	652.50	4	2	0.75	NA	0.52	NA	0.12	NA	15.50	NA	0.39	0.60	1.05	16.33	18.88
Lake Sabbatia	YP	178.00	68.71	7	2	0.71	NA	0.37	NA	0.25	NA	9.71	NA	0.23	0.37	0.77	10.67	12.40
Lake Winthrop	BC	228.63	166.25	8	2	0.85	NA	0.25	NA	0.31	NA	11.15	NA	NA	0.17	1.20	12.31	13.92
Lake Winthrop	CP	457.50	567.25	4	2	0.71	NA	0.33	NA	NA	NA	7.00	NA	0.09	0.24	1.40	7.71	9.74
Lake Winthrop	YP	212.38	122.75	8	2	0.51	NA	0.21	NA	0.14	NA	2.30	NA	NA	0.24	0.98	2.91	4.33
Long Pond (Lakeville)	LMB	413.33	1084.67	6	2	1.25	NA	1.95	NA	NA	NA	15.50	NA	1.25	2.15	2.95	16.75	25.05
Long Pond (Lakeville)	P	151.30	86.80	10	2	1.06	NA	1.07	NA	0.18	NA	12.80	NA	0.66	1.15	1.80	14.03	18.70
Long Pond (Lakeville)	YP	199.67	98.22	9	2	1.06	NA	1.51	NA	0.39	NA	8.31	NA	0.85	1.56	2.04	9.76	15.72
Long Pond (Yarmouth)	LMB	379.70	504.80	10	2	0.16	NA	0.20	NA	NA	NA	5.28	NA	NA	0.30	0.44	5.38	6.31
Long Pond (Yarmouth)	P	173.50	72.20	10	2	0.25	NA	0.23	NA	NA	NA	2.75	NA	0.10	0.33	0.44	3.00	4.07
Mascuppic Lake	BB	251.63	246.50	8	2	NA	NA	0.18	NA	NA	NA	1.35	NA	0.16	0.20	0.16	1.35	2.02
Mascuppic Lake	CP	484.00	768.83	6	2	1.07	NA	0.62	NA	NA	NA	13.10	0.44	0.42	0.64	1.15	14.17	17.44
Mascuppic Lake	LMB	425.50	1221.67	6	2	2.10	0.19	1.06	NA	NA	NA	22.00	NA	0.54	0.99	2.30	24.10	29.13
Merrimack River	BB	202.20	112.60	5	2	0.21	NA	0.65	NA	NA	NA	1.42	0.15	0.70	0.52	0.42	1.63	4.07
Merrimack River	LMB	363.50	802.50	4	2	1.68	0.30	1.30	NA	NA	NA	22.00	NA	0.82	0.81	1.55	23.68	28.55
Millers River	P	170.00	102.67	3	1	NA	NA	0.20	NA	NA	NA	5.70	NA	NA	0.20	0.31	5.70	6.41
Millers River	RB	177.00	105.00	1	1	NA	0.33	0.33	NA	NA	NA	7.30	NA	0.22	0.30	0.37	7.30	8.85
Millers River	RT	362.00	438.00	1	1	NA	NA	NA	NA	NA	NA	0.59	0.30	NA	NA	NA	0.59	0.89

Waterbody	Species	Mean Fish Length	Mean Fish Weight	Number of Fish	Number of Composite Samples	Mean PFDA	Mean PFDS	Mean PFDoA	Mean PFHxS	Mean PFNA	Mean PFOA	Mean PFOS	Mean PFOSA	Mean PFTeDA	Mean PFTrDA	Mean PFUnA	Mean PFAS6	Mean ∑PFAS40
Moores Pond	B	186.90	129.70	10	2	0.18	NA	0.71	NA	NA	NA	1.80	NA	0.48	0.62	0.61	1.92	4.33
Moores Pond	LMB	315.00	390.00	1	1	0.47	NA	0.73	NA	NA	NA	2.70	NA	0.37	0.74	1.20	3.17	6.21
Moores Pond	P	167.00	103.00	2	1	NA	NA	0.09	NA	NA	NA	0.38	NA	NA	0.15	0.12	0.38	0.74
Nashua River	BB	241.90	228.60	10	2	0.31	NA	0.33	NA	NA	NA	3.20	0.29	0.28	0.32	0.22	3.51	4.94
Nashua River	WS	461.67	1165.00	6	2	1.85	0.40	1.35	0.24	0.36	0.15	13.00	1.15	0.75	1.05	1.05	15.55	21.45
Oxbow Pond-Easthampton	BB	322.90	494.30	10	2	NA	NA	0.11	NA	NA	NA	0.57	NA	0.23	0.21	0.10	0.57	1.17
Oxbow Pond-Easthampton	P	166.40	109.10	10	2	0.27	NA	0.23	NA	NA	NA	6.30	0.07	0.14	0.24	0.31	6.57	7.50
Oxbow Pond-Easthampton	YP	222.30	133.80	10	2	0.37	NA	0.58	NA	NA	NA	4.90	0.14	0.37	0.55	0.54	5.27	7.43
Pelham Lake	P	182.67	141.17	6	2	NA	NA	0.21	NA	NA	NA	0.64	NA	NA	0.25	0.37	0.64	1.47
Pelham Lake	YP	172.60	55.60	10	2	NA	NA	0.14	NA	NA	NA	0.52	NA	NA	0.18	0.35	0.52	1.19
Pontoosuc Lake	BB	223.38	139.13	8	2	NA	NA	0.07	NA	NA	NA	0.26	NA	NA	0.12	0.10	0.26	0.49
Pontoosuc Lake	C	609.50	3225.00	6	2	NA	NA	0.25	NA	NA	NA	1.21	NA	0.14	0.23	0.35	1.29	2.25
Pontoosuc Lake	YP	205.10	98.10	10	2	0.34	NA	0.48	NA	NA	NA	3.15	NA	0.30	0.35	0.63	3.49	5.25
Robbins Pond	B	175.50	65.30	10	2	0.41	NA	0.26	NA	NA	NA	3.90	NA	0.14	0.32	0.67	4.31	5.70
Robbins Pond	CP	449.00	510.33	6	2	0.39	NA	0.22	NA	NA	NA	4.10	0.09	0.10	0.25	0.57	4.49	5.67
Robbins Pond	WS	385.80	581.30	10	2	0.49	NA	0.33	NA	0.21	0.15	2.25	NA	0.12	0.35	0.84	3.05	4.66
Sandy Pond	B	191.50	133.90	10	2	0.43	NA	0.41	NA	NA	NA	3.85	NA	0.15	0.42	0.72	4.28	5.94
Sandy Pond	YB	250.00	230.00	1	1	NA	NA	0.22	NA	NA	NA	0.67	NA	0.15	0.28	0.32	0.67	1.64
Sandy Pond	YP	243.10	133.20	10	2	0.87	NA	0.53	NA	0.11	NA	3.55	NA	0.24	0.57	1.31	4.50	7.14
Snake Pond	B	233.00	262.00	1	1	NA	NA	0.27	NA	NA	NA	0.62	NA	0.20	0.44	0.39	0.62	1.92
Snake Pond	P	224.00	276.00	2	1	NA	NA	0.28	NA	NA	NA	0.61	NA	0.32	0.63	0.31	0.61	2.15
Snake Pond	YP	257.00	256.11	9	2	NA	NA	0.28	NA	NA	NA	0.37	NA	0.13	0.52	0.38	0.37	1.66
South Watuppa Pond	B	161.60	85.90	10	2	1.65	NA	0.62	NA	0.19	NA	9.75	NA	0.29	0.40	1.50	11.59	14.40
South Watuppa Pond	P	164.60	100.60	10	2	1.10	NA	0.37	NA	NA	NA	5.30	NA	0.10	NA	0.95	6.40	7.79
South Watuppa Pond	YP	208.30	115.20	10	2	2.15	NA	0.70	NA	0.25	NA	16.50	0.20	0.28	0.42	1.78	18.90	22.27
Studley Pond	B	179.00	112.00	3	1	1.10	0.26	0.45	0.51	NA	NA	150.00	1.00	0.67	0.59	0.51	151.61	183.39
Studley Pond	P	151.25	75.25	4	2	0.57	0.28	0.68	1.40	0.25	0.36	53.00	5.10	0.46	0.47	0.57	55.58	80.92
Studley Pond	YP	185.40	68.60	5	2	0.55	0.17	0.43	1.05	0.24	NA	66.60	4.44	0.23	0.39	0.38	68.44	86.85

Waterbody	Species	Mean Fish Length	Mean Fish Weight	Number of Fish	Number of Composite Samples	Mean PFDA	Mean PFDS	Mean PFDoA	Mean PFHxS	Mean PFNA	Mean PFOA	Mean PFOS	Mean PFOSA	Mean PFTeDA	Mean PFTrDA	Mean PFUnA	Mean PFAS6	Mean ∑PFAS40
Upper Spectacle Pond	B	194.07	169.80	15	3	0.36	NA	0.19	NA	NA	NA	2.07	NA	NA	0.28	0.47	2.43	3.36
Upper Spectacle Pond	LMB	380.67	755.33	6	2	0.49	NA	0.46	NA	NA	NA	2.30	NA	0.38	0.82	1.04	2.79	5.48
Upper Spectacle Pond	P	191.00	188.20	15	3	0.28	NA	0.08	NA	NA	NA	1.42	NA	NA	0.15	0.32	2.46	2.15
Ware River	LMB	373.70	948.00	10	2	0.54	NA	0.36	NA	NA	NA	3.55	NA	0.18	0.36	0.64	4.09	5.59
Ware River	YP	198.60	92.70	10	2	0.50	NA	0.23	NA	0.15	NA	2.80	NA	NA	0.36	0.51	3.41	4.49
Webster Lake	BB	307.25	392.50	4	1	NA	NA	0.22	NA	NA	NA	0.88	NA	0.14	0.27	0.30	0.88	1.81
Webster Lake	LMB	389.67	1037.67	3	1	1.10	0.46	1.90	NA	NA	NA	6.60	NA	1.00	1.70	2.50	7.70	15.26
Webster Lake	P	162.86	89.29	7	2	0.98	0.22	1.71	NA	0.13	0.18	4.71	0.07	1.06	1.64	1.83	5.91	12.43
West Lake	BC	210.86	130.86	7	2	0.27	NA	0.17	NA	0.14	NA	1.41	NA	0.18	0.27	0.53	1.80	2.94
West Lake	P	164.70	89.10	10	2	NA	NA	0.17	NA	NA	NA	0.45	NA	0.13	0.36	0.54	0.45	1.61
West Lake	YP	224.50	135.60	10	2	0.29	NA	0.60	NA	NA	NA	0.46	NA	0.29	0.74	1.35	0.75	3.72
Whitman's Pond	B	183.17	123.67	6	2	1.28	0.28	0.64	NA	0.19	NA	27.00	NA	NA	0.29	1.00	28.43	30.62
Whitman's Pond	P	168.67	111.17	6	2	0.70	0.21	0.47	NA	0.14	NA	15.00	0.35	0.34	0.35	0.60	15.80	18.11
Whitman's Pond	YP	217.17	119.00	6	2	1.15	0.28	0.43	0.09	0.13	NA	20.50	0.32	0.12	0.35	0.96	21.82	24.18

Notes:
This table includes PFAS analytes detected in 10% or more of waterbodies as well as the sum of all detected PFAS (∑PFAS40) and the sum of PFAS regulated by Mass DEP in drinking water (PFAS6).
NA indicates that the PFAS analyte was not detected in any of the composite samples.
Results are shown in units of ng/g
Means weighted by the number of fish in the contributing composites were calculated for any PFAS analyte – waterbody – species combination where an analyte was detected in at least one sample; if some samples did not have the analyte detected, the concentration for that sample was set to ½*MDL for the purposes of calculating a mean. Note that some of the resulting means may be less than the laboratory reported MDL. Interpret these values with caution. Refer to the laboratory SOP for MDLs.
Species codes: LMB- Largemouth bass; P- Pumpkinseed; YP- Yellow perch; WP- White perch; B- Bluegill; SMB- Smallmouth bass; WS- White sucker; BB- Brown bullhead; BC- Black crappie; AE- American eel; CP- Chain pickerel; C- Common carp; RT- Rainbow trout; RB- Redbreast; YB- Yellow bullhead; BRT- Brown trout.

APPENDIX D: Quality Assurance Project Plan

Available at: https://www.mass.gov/info-details/pfas-in-surface-water-and-fish-tissue.

APPENDIX E: Sampling and Analysis Plan

Available at: https://www.mass.gov/info-details/pfas-in-surface-water-and-fish-tissue.