Investigation of Levels of Perfluorinated Compounds in New Jersey Fish, Surface Water, and Sediment

New Jersey Department of Environmental Protection
Division of Science, Research, and Environmental Health

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Executive Summary

Per- and polyfluorinated substances (PFAS) are used in the manufacture of useful products that impart stain resistance, water resistance, heat resistance and other desirable properties. PFAS are also used in various Aqueous Film Forming Foams (AFFF) that are used in fire-fighting. These substances are in wide use today, found at industrial sites that use or manufacture them and at military bases, airports and other areas known for fire-fighting activities. A subset of PFAS, perfluorinated compounds (PFCs), have fully fluorinated carbon chains as their backbone, and their extremely strong carbon-fluorine bonds makes them very resistant to degradation. When released to the environment, PFCs persist indefinitely and can travel distances from their source in surface water, groundwater, or in the atmosphere. PFAS are considered “emerging contaminants” because additional information on their presence and toxicity to ecosystems and humans continues to become available.

The Division of Science, Research and Environmental Health (DSREH) performed an initial assessment of 13 PFAS, all of which are perfluorinated compounds (PFCs), at 11 waterways across the state. Fourteen surface water and sediment samples and 94 fish tissue samples were collected at sites along these waterways. The sites were selected based on their proximity to potential sources of PFAS and their likelihood of being used for recreational and fishing purposes. The sampling sites are located within Passaic, Middlesex, Ocean, Burlington, Gloucester, and Salem Counties.

All surface water samples contained detectable levels of at least four PFAS. The lowest total PFAS in surface water was in the Cohansey River, with Horicon Lake and Echo Lake having the second and third lowest total PFAS, respectively. The highest total level of PFAS was found in Little Pine Lake, near the Joint Base McGuire-Dix-Lakehurst, with Mirror Lake and Pine Lake ranking the second and third highest, respectively. Consistent with the known characteristics of preferential partitioning of longer chain PFCs to sediment and shorter chain PFCs to the water column, the PFAS detected in surface water were those with a carbon chain length of nine carbons or less.

Ten of the 14 sites where sediment samples were collected had detectable levels of at least one, and up to eight, PFAS. Pine Lake had the highest total PFAS concentration (30.93 ng/g) in the sediment, with the majority being perfluorooctane sulfonate (PFOS), the eight-carbon chain sulfonate. Echo Lake (West Milford in Passaic County), often used as a New Jersey “background” site, had no detectable levels of PFAS in the sediment. All detectable PFAS in the sediment were compounds with six or more carbons (i.e. PFHxS and longer carbon chain length).

One to three individual fish from two to four species (three each of three species at most sites) were collected and analyzed at each site. The average detectable concentrations (non-detects were not included in the averaging of the tissue concentrations) of the individual PFAS showed that all species at all sites were impacted by one or more PFAS compounds. These contaminants are “proteinophilic” (e.g. bind to muscle tissue in the fillets) and do not bioaccumulate in the fatty tissue like other persistent organic pollutants frequently found in fish (e.g. PCBs, dioxins). In general, the sites with identified sources and detectable levels of PFAS in surface water and sediment had higher levels of PFAS in the fish tissue, with the samples from Pine Lake and Little Pine Lake having the highest detected concentrations.

This report includes preliminary fish consumption advisories for three PFAS – PFNA, PFOA and PFOS - based on current New Jersey Reference Doses established for each of these compounds. While these preliminary advisories provide the reader with an early indication of potential outcomes, it is emphasized that the advisories have not been finalized as of this writing and should only be viewed as potential benchmarks for evaluating the data. Based on the preliminary advisories, all of the 11 sites would have some level of fish consumption guidance ranging from "one meal per week" to "do not eat".

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Introduction

The Division of Science, Research and Environmental Health (DSREH) performed an initial assessment of 13 perfluorinated compounds, in surface water, sediment, and fish tissue at 11 waterbodies across the state. Water and sediments were collected at two different locations along three of the waterbodies. The sites were selected due to their proximity to potential sources of perfluorinated compounds and likelihood of being used for recreational and sustenance fishing. The sampling sites include areas within Passaic, Middlesex, Ocean, Burlington, Gloucester, and Salem Counties.

Per- and polyfluoroalkyl substances (PFAS) are a group of compounds that have been manufactured and used in multiple industrial processes since the 1950's (Prevedouros et al., 2006; Lindstrom et al., 2011). The structure of the compounds is based on a characteristic carbon chain that is surrounded by fluorine atoms. The *poly*-fluorinated compounds are not fully fluorinated and include another atom or atoms attached to at least one other carbon (e.g. hydrogen or oxygen atom(s)), whereas the *per*-fluorinated compounds have a carbon backbone that is fully fluorinated. The carbon-fluorine bond is extremely strong and is therefore highly resistant to degradation in the environment.

PFAS have surfactant properties and are widely used to coat solid materials such as paper, packaging (including food wrappers), textiles, and carpets (Renner et al., 2001). These coatings provide water-, grease-, and heat-proofing, and impart stain-resistance. PFAS compounds are also used to produce various materials, including fluoropolymers such as polytetrafluoroethylene used in non-stick cookware. In addition, PFAS are used in fire-fighting foams at military sites (as required by military specifications), firefighter training facilities, and in fighting petroleum fires (Moody and Field, 1999). Subsequently, these aqueous film-forming foams (AFFF) have led to groundwater contamination, particularly at multiple military installations (Backe et al., 2013 and Arias et al., 2015).

While the general population is exposed to low levels of PFAS from sources such as the food supply and consumer products, elevated exposures near contaminated sites may occur through ingestion of drinking water and consumption of fish from contaminated sites (Post et al., 2012; Fujii et al., 2015). Several studies by the Department have identified elevated levels of perfluorinated compounds in source water and finished drinking water throughout the state (Post et al., 2009; Post, et al., 2013).

Three media - sediment, surface water, and fish tissue - were analyzed for a total of 13 perfluorinated compounds of various chain lengths. Three of these compounds were sulfonates (containing the functional group $R\text{-}SO_3^-$), nine compounds were carboxylates (containing the function group $R\text{-}COO^-$), and the thirteenth compound was perfluorooctane sulfonamide (PFOSA; $R\text{-}SO_2NH_2$), a perfluorinated compound that degrades to PFOS (C8-S) in the environment. The length of the carbon chain and the type of attached functional group influences the compound's chemical properties and behavior in the environment (Labadie et al., 2011) These characteristics, along with the magnitude of concentration in the environment, will affect the compound's impact on the ecosystem and human health receptors.

PFAS in surface water may originate from a groundwater source, stormwater runoff, or a direct discharge to the waterbody, such as industrial release or wastewater treatment plant effluent. The PFAS could also be delivered via wet or dry atmospheric deposition from long range transport or a localized source (Barber et al., 2007; Taniyasu et al., 2013).

Concentrations of PFAS in sediments are determined by the compounds that have been present in the system and extent of each compound's preferential partitioning to the organic compounds found in sediments. Typically, the longer chain perfluorinated compounds preferentially partition to sediments, while the shorter chain compounds remain largely in the dissolved state. However, even though the longer chain compounds may generally partition to the sediments, sediments can also serve as a source of these compounds to the adjacent surface water

Unlike typical bioaccumulative organic compounds such as PCBs, PFAS do not primarily partition to the fatty tissues of the fish because of their chemical structure. These compounds are not "lipophilic" or "hydrophilic", but can be better described as "proteinophilic". This means that the compounds preferentially partition to the blood, liver, and other high protein tissues such as muscle. In this study, only the fillet was analyzed for the 13 PFAS, since it is the part of the fish normally used for human consumption.

Human exposure to PFAS in surface waters occurs primarily through the use of the waterbody as a drinking water source and/or for recreational fishing. Certain PFAS, especially PFOS and longer perfluorinated carboxylates such as PFUnA, are found in surface waters and can bioaccumulate over time in the tissue of fish (Ahrens et al., 2010 and Labadie et al., 2011). Very low or even non-detectable levels of these PFAS in water may bioaccumulate to a level of concern in fish.

Objectives

The results of this investigation will provide the Department with a preliminary assessment of the occurrence, magnitude, and potential for bioaccumulation/biomagnification at sites that are suspected to be impacted by PFAS in New Jersey. The determination of levels of PFAS in fish tissue will provide the Department with preliminary species-specific data that can be used to evaluate the necessity of developing fish consumption advisories.

In addition, the results of this study will provide the Department with:

1. A PFAS fish tissue contaminant database;
2. An understanding of potential human exposure to PFAS from recreational fishing;
3. A basis for understanding PFAS partitioning in sediment and surface water, and bioaccumulation/biomagnification potential in consumable fish tissue;
4. The data necessary to determine if further investigations of PFAS in other waterbodies of the state is warranted; and
5. The data necessary for development of preliminary fish consumption advisory for PFAS

Site Selection

Eleven waterbodies across the state were selected based on proximity to potential sources of PFAS in areas of likely recreational and/or sustenance fishing. Additional samples were collected and analyzed at three of the waterbodies where conditions were assumed to be spatially independent. The eleven sites, plus the additional samples, are shown in Table 1. The location of these sites is shown in Figures 1, 2, and 3.

Table 1: Study Sites

Id	Site Name	Waterway	Sample Site Description	County	X coord	Y coord
					(State Feet)	
1	Echo Lake Reservoir	Echo Lake Channel	Pristine, wooded area	Passaic	516528.3	807686.8
2	Passaic River 1	Passaic River	Industrialized area, upstream, below Route 4	Bergen/Passaic	593434.5	757303.9
2a	Passaic Riv 2	Passaic River	Industrialized area, above Dundee Dam	Bergen/Passaic	595219.8	747080.7
3	Raritan River	Raritan River	Industrialized area, near Kin-Buclandfill	Middlesex	522954.0	602318.8
4	Metedeconk 2	Metedeconk River	Residential and light industry, by wastewater treatment plant discharge	Ocean	591702.4	452007.5
4a	Metedeconk 1	Forge Pond	Impoundment near residential, light industry, source identified. Drinking water intake located here.	Ocean	594375.9	449967.6
5	Pine Lake	Union Branch/Ridgeway Branch, northern portion	Impoundment east of Joint Base McGuire-Dix-Lakehurst; receiving drainage from norther portion of base	Ocean	561393.5	428026.8
6	Horicon Lake	Blacks Branch	Impoundment south of eastern edge of Joint Base McGuire-Dix-Lakehurst; recieves trib from Pine Lake and groundwater from base	Ocean	541862.2	428131.9
7	Little Pine Lake	Jacks Run	Impoundment receiving drainage from western edge of JB MDL	Burlington	472633.7	421150.1
8	Mirror Lake	North Branch Rancocas	Impoundment receiving drainage from central are of JB MDL	Burlington	472515.2	414430.7
9	Woodbury Creek	Delaware River	Tributary to Delaware River; near identified source	Gloucester	300571.7	373608.9
10	Fenwick Creek	Fenwick Creek Tributary	Downstream from rug manufacturer	Salem	221581.7	273032.6
11	Cohansey River	Cohansey River	Mouth of Rocaps Creek tributary to Cohansey; agriculture, residential, and light manufacturing	Cumberland	285609.4	208155.2
11a	Cohansey River 2	Cohansey	Upstream mainstem Cohansey; ag, residential, and light manufacturing	Cumberland	285001.3	213424.8

From north to south, the sites chosen are as follows:

Three sampling locations in Northern New Jersey (Figure 1):

1. Echo Lake Reservoir (potential background site, West Milford in Passaic County)
2. Passaic River 1 and 2a (bordering of Passaic and Bergen Counties, upstream of the Dundee Dam)
3. Raritan River (Middlesex County, near Route 1)

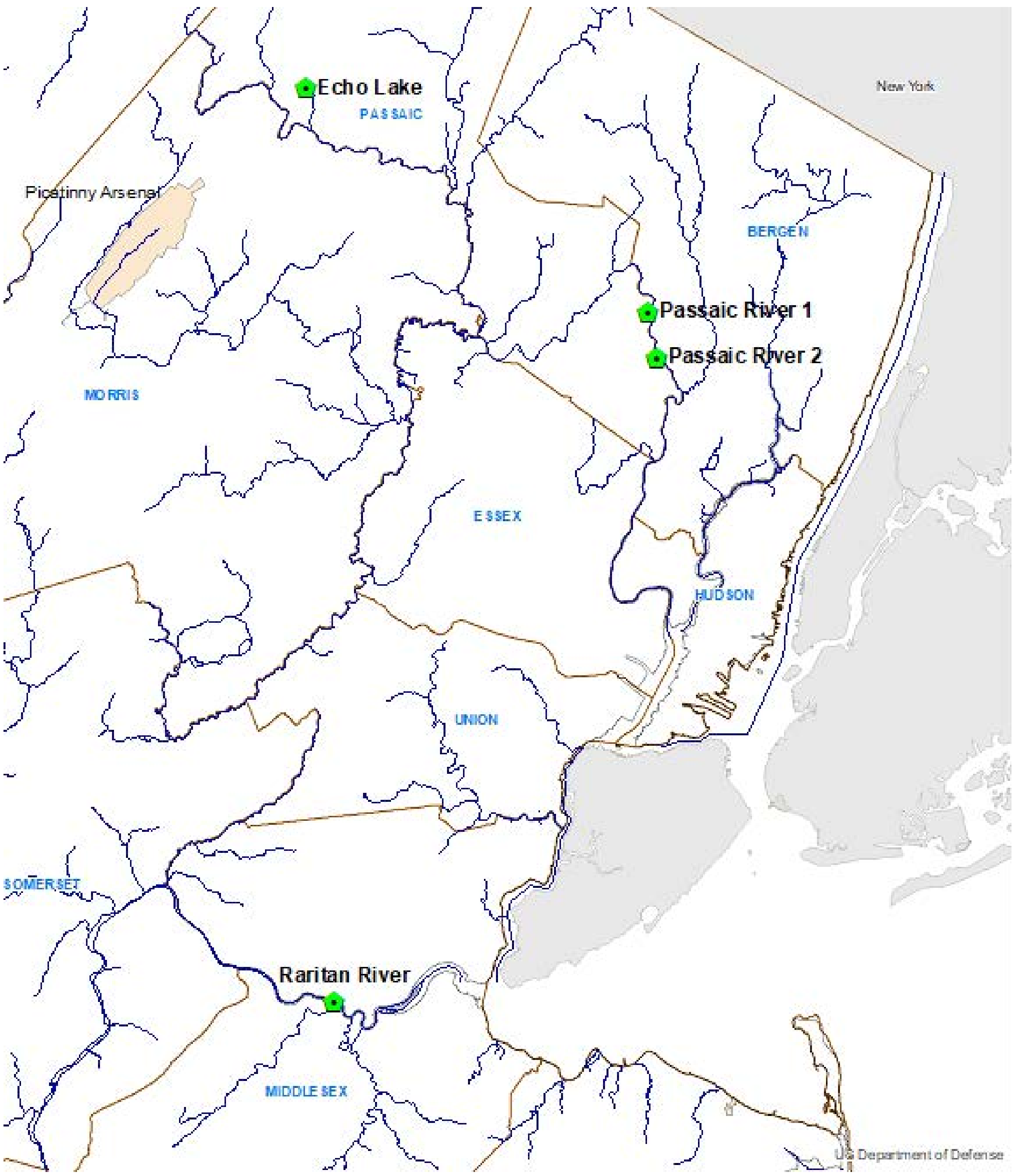

Figure 1: Sampling Sites in Northern New Jersey

Five sampling locations in Central New Jersey (Figure 2):

4. Metedeconk River 1 and 2 (the impoundment known as Forge Pond, and upstream Metedeconk River in Ocean County)
5. Pine Lake (impoundment on the Ridgeway tributary to the Toms River in eastern Manchester, Ocean County)
6. Horicon Lake (upstream of a tributary to Pine Lake, located south of eastern boundary of Joint Base McGuire-Dix-Lakehurst [JB MDL])
7. Little Pine Lake (impoundment upstream of Mirror Lake on a tributary to the Rancocas Creek, just south of the western boundary of the JB MDL)
8. Mirror Lake (an impoundment of a tributary to the Rancocas, slightly southeast of the western boundary of the JB MDL)

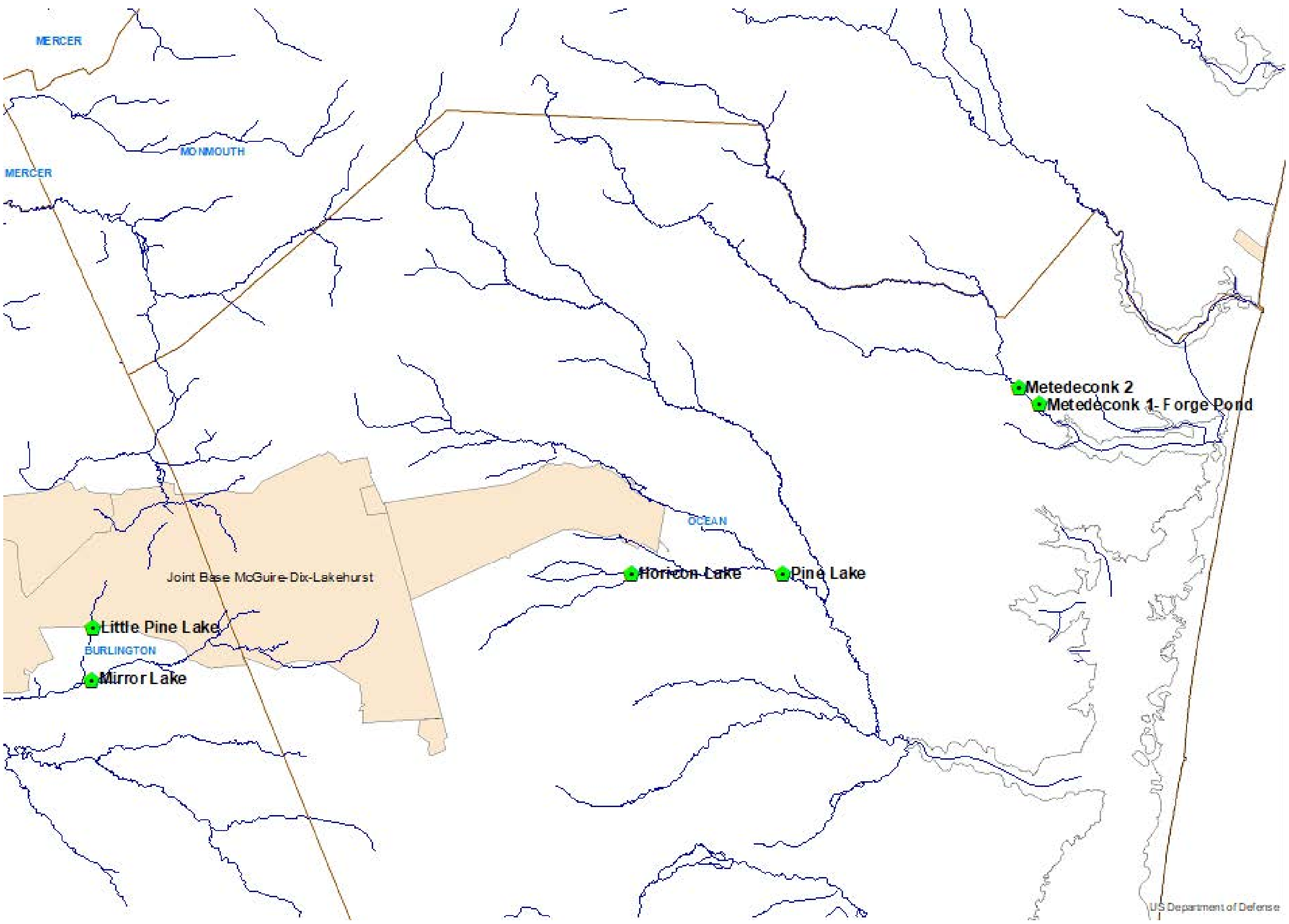

Figure 2: Five Sampling Sites in Central New Jersey

And three Southern New Jersey sampling locations (Figure 3)

9. Woodbury Creek (tributary to the Delaware River in Gloucester County)
10. Fenwick Creek (tributary to the Salem River in Salem County)
11. Cohansey River 1 and 2 (tributary to the Delaware Bay in Cumberland County)

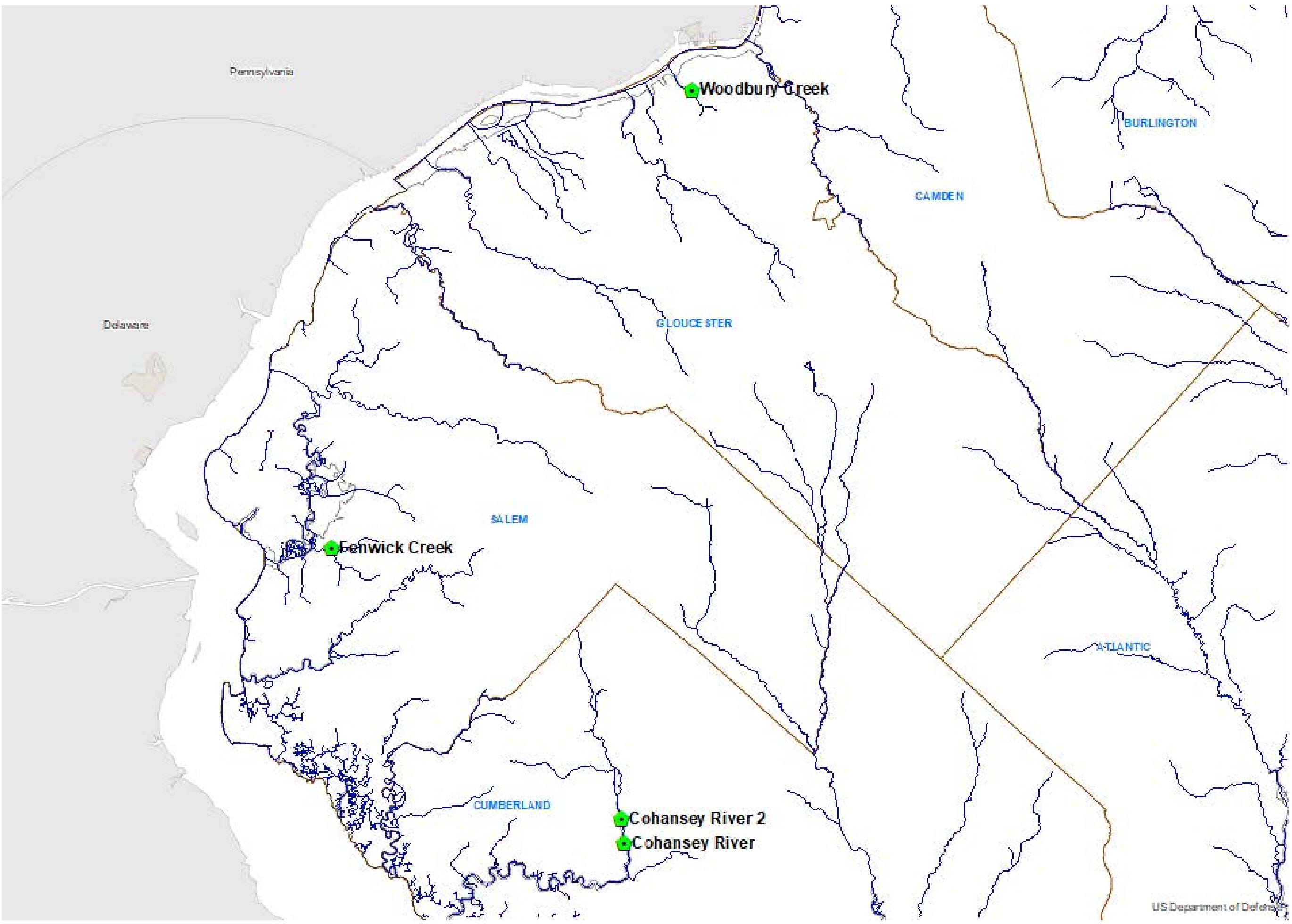

Figure 3: Three Southern New Jersey Sampling Stations

Media Collected

Surface Water

One grab sample of surface water was collected from six (6) inches below the surface to eliminate surface debris at each of the 11 waterbodies. An additional surface water grab sample was collected in a different area of the Cohansey, the Metedeconk River, and the Passaic River identified in Table 1, for a total of 14 surface water samples collected for PFC analysis. These additional samples were collected in areas where varying characteristics of the stream or source indicated the potential for varying concentrations of contaminants. On the Passaic River, a sample was taken upstream of the boat launch by Route 4, and then approximately two miles downstream where the river velocity decreases behind Dundee Dam (See Table 1 coordinates).

Due to differences in flow and impoundment, the sediment deposition rate is expected to vary. At Forge Pond, one grab sample was taken near the drinking water intake for the municipality, and another sample was taken further upstream by a wastewater treatment plant discharge. On the Cohansey, a separate sample was taken near the entry of a tributary, Rocaps Creek, that had industrial runoff.

The surface water grab samples were collected directly into a PFAS-free plastic wide mouth lab-prepared sample bottles.

Sediment

One grab sample of sediment was collected by Ponar dredge from each of the 14 locations that were also sampled for water. The sediment collected from the dredge was emptied into a clean stainless-steel tray, and stones and other large debris were separated from the sediments. Photos were taken of the sediment collected at each location for characterization. The sediment was transferred by a clean sample trowel to 100 ml wide mouth jars provided by the laboratory. Each of the sediment samples were taken from sites representative of deposition areas within each of the waterbodies. The samples were composed primarily of fine-grained sediment material with organic content (dark in color and uniform texture). Laboratory analysis did not include quantifiable evaluation of organic carbon content.

Fish

The fish that were targeted in this study represented those freshwater species typically sought after for consumption by New Jersey anglers and likely inhabiting each of the waterbodies sampled. Fish were often collected by Direct Current (DC) boat electrofishing within a single day of sampling. The reach length provided for the collection area was dependent on the river size and was sampled until the desired number of individuals was obtained.

The species selected for this study, shown in Table 2, were chosen to represent both pelagic and benthic species, as well as to include multiple trophic levels. Table 2 provides details on these descriptors for the species of interest. The fish collected at each site were representative of the types of fish typically taken from the waterbody by anglers who fish for recreation and sustenance.

Table 2: Characteristics of fish species that were studied

Species	Latin Name	Habitat	Trophic Level Descriptors	Trophic Level
Largemouth Bass	*Micropterus salmoides*	Pelagic	Top Trophic Level Piscivore (top Carnivore)	4
Chain Pickerel	*Esox niger*	Pelagic	Top Trophic Level Piscivore (top Carnivore)	4
White Perch	*Morone americana*	Pelagic	Lower Trophic Level Insectivore/Piscivore	3
Yellow Perch	*Perca flavescens*	Pelagic	Lower Trophic Level Insectivore/Piscivore	3
Bluegill Sunfish	*Lepomis macrochirus*	Pelagic	Lower Trophic Level Insectivore/Piscivore	3
Pumpkinseed Sunfish	*Lepomis gibbosus*	Pelagic	Lower Trophic Level Insectivore	3
Channel Catfish	*Ictalurus punctatus*	Benthic	BenthicTrophic Level Insectivore/Piscivore	4
White Catfish	*Ameiurus catus*	Benthic	Benthic Trophic Level Insectivore/Piscivore	4
Yellow Bullhead	*Ameiurus natalis*	Benthic	Benthic Insectivore / Invertivore	3
Brown Bullhead	*Ameiurus nebulosus*	Benthic	Benthic Insectivore / Invertivore	3
Common Carp	*Cyprinus carpio*	Benthic	Benthic Trophic Level Omnivore	2
American Eel	*Anguilla rostrata*	Benthic	Benthic Trophic Level Piscivore/Carnivore	4

The fish were collected through DC boat electrofishing with the assistance of the Bureau of Freshwater and Biological Monitoring, working under a Quality Assurance Project Plan (as amended May 2016) signed by the Division of Science, Research and Environmental Health, the Division of Water Monitoring and Standards, and the Office of Quality Assurance. The fish that were collected and analyzed at each site are presented in Table 3.

Table 3: Number of individual fish collected and analyzed from study sites

Site	Channel Catfish	Largemouth Bass	Pumpkinseed sunfish	Bluegill sunfish	Brown Bullhead	Common Carp	White Catfish	White perch	Yellow Perch	Chain pickerel	Yellow bullhead	American eel
Echo Lake Reservoir		3		3	3							
Passaic River 1 &2*		3		3		3						
Raritan River	3					3	3	3				
Metedeconk 1 &2*		3				3		3				
Pine Lake		1	3									3
Horicon Lake										3	3	
Little Pine Lake		3	3						3			
Mirror Lake		3		3								3
Woodbury Creek	3	3	3									
Fenwick Creek	3					3	3					
Cohansey River 1 & 2*	3							3				

**Fish were collected along reach that included both sediment and water sites.*

Only live, intact fish were collected for this investigation. All targeted fish were kept in an onboard aerated live well until the end of the sampling day. Typically, species from two or three trophic levels were targeted for analysis at each lake. Three similar size specimens for each species were then sorted, kept on wet ice, and transported to the laboratory for further processing. Whole fish were then measured, weighed, tagged and wrapped in clean aluminum foil, and kept frozen until sample preparation at the analytical laboratory. Proprietary AXYS MLA-043 sample preparation and analysis method for PFAS compounds was followed for individual skin-off standard fillets. Collection of fish began on July 22, 2015 at Forge Pond on the Metedeconk, and concluded on November 17, 2016 on the Raritan River. All fish were analyzed within the holding time of one year, as specified in the analytical method.

Analytical Methods

Analysis of water, sediment, and fish tissue samples was conducted according to the documented Standard Operating Procedures by the Axys Analytical Laboratories. The PFAS analysis for fish tissue samples was performed by Axys Method MLA-043, for sediment samples by Axys Method MLA-041 and for surface water samples, by Axys Method MLA-060. Although not currently certified by the NJDEP for regulatory use, these analytical methods rely upon the use of Liquid Chromatography-Tandem Mass Spectrometry (LC-MS/MS) and are based on the EPA 537 method.

Parameters

The analysis of the three media provided results that quantified 13 PFAS compounds. These 13 compounds, considered to be "traditional" PFAS, can all be determined with one analytical test, similar to USEPA Method 537. Twelve of these PFAAs fall into two widely produced categories, defined by the terminal group and widely produced, carboxylates (PFCAs) and sulfonates (PFSAs). The last compound, PFOSA, is a sulfonamide that is a fully fluorinated PFOS precursor.

PFAS can be categorized by not only the terminal functional group, but by the chain length as well. "Short-chain" PFAS include those carboxylates with less than seven fluorinated carbon atoms (i.e. less than eight total carbons; PFHpA and shorter), and those sulfonates with less than six carbons (e.g. PFBS). The "long-chain" compounds are generally more bioaccumulative (Conder et al., 2008) and toxic (Lau, 2012), while solubility in water is inversely proportional to the length of the carbon chain (Prevedouros et al., 2006; Armitage et al, 2009).

Table 4 provides information on the compounds that were quantified in this study, including detection limits in the media analyzed.

Table 4: Chain Length and Detection limits for PFAS analyzed in the study

Carbon chain length	Abbreviation	Parameter Name	PFC Detection Limit		
Carboxylates			*Fish Tissue (ng/g) Method MLA-043*	*Sediment (ng/g) Method MLA-041*	*Surface Water (ng/L) MLA-060*
4	PFBA	Perfluorobutanoate	0.5-1	0.1-0.2	1.0-2.0
5	PFPeA	Perfluoropentanoate	0.5-1	0.1-0.2	1.0-2.0
6	PFHxA	Perfluorohexanoate	0.5-1	0.1-0.2	1.0-2.0
7	PFHpA	Perfluoroheptanoate	0.5-1	0.1-0.2	1.0-2.0
8	PFOA	Perfluorooctanoate	0.5-1	0.1-0.2	1.0-2.0
9	PFNA	Perfluorononanoate	0.5-1	0.1-0.2	1.0-2.0
10	PFDA	Perfluorodecanoate	0.5-1	0.1-0.2	1.0-2.0
11	PFUnA	Perfluoroundecanoate	0.5-1	0.1-0.2	1.0-2.0
12	PFDoA	Perfluorododecanoate	0.5-1	0.1-0.2	1.0-2.0
Sulfonates					
4	PFBS	Perfluorobutane sulfonate	0.5-1	0.1-0.2	1.0-2.0
6	PFHxS	Perfluorohexane sulfonate	0.5-1	0.1-0.2	1.0-2.0
8	PFOS	Perfluorooctane sulfonate	0.5-1	0.1-0.2	1.0-2.0
Sulfonamide					
8	PFOSA	Perfluorooctane sulfonamide	0.5-1	0.1-0.2	1.0-2.0

Results

Surface Water

All of the 14 surface water samples that were collected had detectable levels of at least four perfluorinated compounds, and three compounds, PFHpA, PFOA, and PFPeA, were detected in every sample. The concentration of PFOA ranged from 4.9 ng/L in the Echo Lake sample, to a high of 33.9 ng/L in the Forge Pond/Metedeconk sample that was taken just below the WWTP. It is noted that the Metedeconk River is known to be impacted by groundwater contaminated by an identified industrial source of PFOA (Procopio et al., 2017).

PFDA, PFUnA, and PFDoA were not detected in any surface water samples. These longer carbon chain compounds have higher affinities for organic material and preferentially partition to sediments. It is also noteworthy that, while these compounds may not be detected in the surface water, they may bioaccumulate to detectable levels in biota including fish tissue. PFOSA was also not detected in any surface water samples, potentially because it can convert to PFOS in the environment (Chen et al., 2015).

Shorter chain compounds such as PFBA, PFBS, PFPeA, PFHxA, and PFHpA were found in the majority of the surface water samples. These compounds do not partition as readily to sediment as their longer chain counterparts and are therefore more likely to be found dissolved in the water. Additionally, use of some of these shorter chain PFAS, such as PFBA and PFBS, as well as six carbon PFAS that convert to PFHxA, may be currently increasing, as these have been introduced as replacements for the longer-chain, more biologically persistent perfluorinated compounds that were phased out of production in the United States.

The ratio of the concentrations of the separate PFAS compounds detected with the analytical method may indicate a relation to a source compound. PFNA was found at up to 7.7 ng/L in the Woodbury Creek sample, and the ratio of PFNA to both PFOA and PFOS in this sample was greater than one. In the Fenwick Creek sample, the ratio of PFNA to PFOS was greater than one, but the ratio of PFNA to PFOA was less than one. In all other samples, the ratios of PFNA to PFOA, and PFNA to PFOS, were less than one. PFNA is not generally found to be a primary contaminant of concern statewide or nationally. However, an industrial source of environmental contamination of PFNA has been identified in the area of Woodbury Creek.

Relatively elevated levels of PFOS, a typical component of AFFF, were found in Pine Lake, Mirror Lake, and Little Pine Lake, with levels up to 102.0 ng/L. These waterbodies may be impacted by the hydrologic connection with the DOD site, JB MDL, which has been identified as a source of PFOS due to use of AFFF in training and/or fire-fighting. PFHxS is also known to be a component of AFFF and was also found at elevated levels in these samples.

The highest concentrations of both total PFAS and PFOS in surface water samples were found in Little Pine Lake, Pine Lake, and Mirror Lake (279.5 ng/L, 170.7 ng/L, and 180.9 ng/L, respectively). Fenwick Creek and the Passaic River sites were all found to have relatively high levels of total PFAS (86.5 ng/L, 83.0 ng/L, and 76.3 ng/L) with a lower proportion of PFOS and PFHxS as compared to Pine Lake, Mirror Lake, and Little Pine Lake. Lower levels of total PFAS (<30 ng/L) were observed in Echo Lake Reservoir, Horicon Lake and the Cohansey River.

The concentrations of PFAS detected in all surface water samples is shown in Table 5.

Table 5: Concentrations of PFAS in surface water at study sites (ng/L)

Site Name	PFBA	PFBS	PFPeA	PFHxA	PFHxS	PFHpA	PFOA	PFOS	PFOSA	PFNA	PFDA	PFUnA	PFDoA	*Total PFAS*
Echo Lake Reservoir	2.2	<	2.7	<	<	14.6	4.9	<	<	<	<	<	<	*24.3*
Passaic River 1	6.2	2.4	18.3	14.9	3.8	7.7	14.1	13.0	<	2.5	<	<	<	*83.0*
Passaic River 2	6.6	4.2	17.4	10.8	2.9	8.2	13.0	13.2	<	<	<	<	<	*76.3*
Raritan River	8.2	<	7.6	7.9	4.7	4.2	8.7	6.9	<	1.1	<	<	<	*49.4*
Metedeconk 1	3.5	4.9	5.2	6.1	<	5.0	**28.3**	<	<	<	<	<	<	*53.0*
Metedeconk 2	2.7	4.6	6.7	5.9	<	5.5	**33.9**	2.8	<	<	<	<	<	*62.1*
Pine Lake	3.4	2.6	6.2	10.4	**24.6**	6.2	13.6	**102.0**	<	1.8	<	<	<	*170.7*
Horicon Lake	<	<	1.0	1.5	7.3	1.1	1.9	10.0	<	<	<	<	<	*22.9*
Little Pine Lake	5.2	6.6	10.0	26.0	**95.9**	7.8	**25.9**	**100.0**	<	2.1	<	<	<	*279.5*
Mirror Lake	3.6	5.2	8.1	14.2	**57.0**	5.8	13.2	**72.9**	<	1.0	<	<	<	*180.9*
Woodbury Creek	5.5	<	10.4	8.9	2.9	4.2	7.2	6.4	<	**7.7**	<	<	<	*53.1*
Fenwick Creek	10.0	2.9	17.7	25.0	<	10.6	10.5	3.1	<	**6.7**	<	<	<	*86.5*
Cohansey River	1.9	<	3.1	3.9	<	3.2	4.9	<	<	1.0	<	<	<	*17.9*
Cohansey River 2	3.1	2.1	5.6	5.4	<	4.4	4.3	<	<	2.3	<	<	<	*27.2*

Note: "<" indicates the result was less than the detection limit (See Table 3)/Numbers in bold show higher values

Sediment

Thirteen (13) of the 14 sediment samples collected contained detectable levels of at least one perfluorinated compound, while there were no detections in the sediment samples from the Echo Lake Reservoir site (intended background site). PFOS was the only compound detected in the sediment samples from both Passaic River sites (0.29 ng/g near Route 4 location; higher levels of 0.51 ng/g closer to Dundee Dam).

The shorter-chain compounds such as PFBA, PFBS, PFPeA, PFHxA, and PFHpA were not detected in any of the sediment samples. Nine of the 14 samples did contain detectable levels PFUnA (C11), and seven of the 14 samples contained detectable levels of PFDoA (C12). These results are consistent with the known characteristics of increased partitioning to sediment with increased chain length**.** The levels of PFUnA were highest in the sediment sample from Woodbury Creek, where an industrial source of PFUnA has been identified.

PFNA and PFDA were detected in only three sediment samples: Little Pine Lake (0.19 ng/g), the Cohansey River downstream of WWTP (0.13 ng/g), and Woodbury Creek (1.00 ng/g). Woodbury Creek, a location impacted by a known source of PFNA, was the only site where the ratio of PFNA to PFOS or PFOA in sediment was greater than one.

PFOS was detected in all but three samples - Echo Lake Reservoir, Forge Pond (Metedeconk), and one of the Cohansey River sites; PFOSA, a precursor of PFOS, was also not detected in these three samples. The highest concentrations of PFOS were found in Little Pine Lake (27.1 ng/g) and Pine Lake (19.3 ng/g), likely due to their proximity to the DOD site, JB MDL, a known source. At the remaining sites with detectable PFOS in the sediments, levels ranged from 0.29 ng/g at the Passaic River by Route 4 to 3.07 ng/g in Mirror Lake.

The concentrations of PFAS found in all sediment samples are shown in Table 6.

Table 6: Concentrations of PFAS in sediment at study sites (ng/g)

	PFBA	PFBS	PFPeA	PFHxA	PFHxS	PFHpA	PFOA	PFOS	PFOSA	PFNA	PFDA	PFUnA	PFDoA	Total PFAS
Reservoir	<	<	<	<	<	<	<	<	<	<	<	<	<	0.00
Passaic River 1	<	<	<	<	<	<	<	0.289	<	<	<	<	<	0.29
Passaic River 2	<	<	<	<	<	<	<	0.514	<	<	<	<	<	0.51
Raritan River	<	<	<	<	<	<	0.112	0.643	<	<	<	<	<	0.76
Metedeconk 1	<	<	<	<	<	<	0.097	<	<	<	<	<	<	0.10
Metedeconk 2	<	<	<	<	<	<	0.215	0.517	<	<	<	0.188	0.207	1.13
Pine Lake	<	<	<	<	0.378	<	0.3	**19.3**	**6.53**	<	<	0.395	0.651	27.55
Horicon Lake	<	<	<	<	0.643	<	<	3.25	<	<	<	0.862	<	4.76
Little Pine Lake	<	<	<	<	0.989	<	0.395	**27.1**	0.411	0.186	0.33	1.03	0.493	30.93
Mirror Lake	<	<	<	<	0.2335	<	<	3.07	<	<	<	0.1415	0.106	3.55
Woodbury Creek	<	<	<	<	<	<	<	0.57	0.262	1	0.188	2.14	<	4.16
Fenwick Creek	<	<	<	<	<	<	<	0.462	0.238	<	<	0.46	0.121	1.28
Cohansey River	<	<	<	<	<	<	0.056	<	<	<	<	0.105	0.137	0.30
Cohansey River 2	<	<	<	<	<	<	0.122	0.552	0.479	0.132	0.141	0.412	0.111	1.95

Note: "<" indicates the result was less than the detection limit (See Table 3) /Numbers in bold show higher values

The total PFAS in the sediment was much higher in the samples from Pine Lake and Little Pine Lake than at any of the other sites. The PFAS in sediment at these two sites was dominated by PFOS.

Fish Tissue

Prediction of the bioaccumulative potential of PFAS in specific species of fish is not straightforward. The relative concentrations of specific PFAS in fish tissue at each site is driven by two factors – first, the presence of PFAS in surface water and sediments, and second, the partitioning ability of the PFAS from water, food and sediment to fish tissue (i.e. bioaccumulative potential).

The potential for bioaccumulation in fish tissue of the perfluorinated alkyl acids included in this study is related to both the length of their carbon chain and the identity of their anionic group (carboxylate or sulfonate). In general, bioaccumulation of these compounds is directly related to the length of their fluorinated carbon chain, with sulfonates more bioaccumulative than carboxylates with the same fluorinated carbon chain length. Perfluoroalkyl acids with seven or more fluorinated carbons (i.e. starting with PFNA for carboxylates and with PFOS for sulfonates) have substantial potential for bioaccumulation in fish. However, shorter chain compounds (e.g. PFOA and PFHxS) can also bioaccumulate, although to a much lesser degree, and may also be found in fish tissue when surface water concentrations are high enough (Conder et al., 2008).

Site-specific fish tissue results are discussed later in this report, and Table 6 below presents a summary of these data. The table includes the frequency of occurrence and maximum concentration for the eight PFAS detected in fish tissue in this study (five PFAS analyzed were not detected in any fish tissue samples). The fish tissue data shown are based on averages of detected values from three individual fish of each species analyzed from each site; non-detection values from individual fish were not included in the averages. Two species were collected at two sites, three species at eight sites, and four species at one site, for a total of 32 species-site combinations. Detection limits varied, and were approximately 1 ppb for PFOS and PFHxS, and approximately 0.5 ppb for the other PFAS detected in fish tissue.

The maximum concentration of PFOS in fish tissue was much higher than for the other PFAS, consistent with studies from other locations discussed below (Table 21). PFOS and the longest chain carboxylates (PFDA, PFUnA, and PFDoA) were found at all or almost all sites. Other PFAS that are less bioaccumulative (e.g. PFOA, PFNA, PFHxS) were found much less frequently, at one to three sites that are, in several cases, impacted by known sources of these compounds. Additionally, maximum fish tissue concentrations of PFOA, PFNA, and PFHxS were lower than for the longer chain compounds.

Table 7: Summary of detections of PFAS in fish tissue

Compound	Number of Sites Detected (n=11)	Number of Species-Sites Detected (n=32)	Maximum concentration (ppb; ng/g)
PFOS	11	30	162.5
PFUnA	11	31	27.2
PFDoA	10	28	5.42
PFDA	10	24	3.57
PFOSA	3	5	2.83
PFHxS	3	4	1.66
PFNA	2	4	1.39
PFOA	1	2	0.72

For additional statistical descriptors, see Table 22

DRAFT, Preliminary Fish Consumption Advisory Triggers for PFOA, PFNA and PFOS

As mentioned above, bioaccumulation of PFAS is dependent on their molecular structure, with PFAS with seven or fewer fluorinated carbons (e.g. PFOA and PFHxS) having a lower potential for bioaccumulation (Conder, et al., 2008). For the purposes of this report, draft *preliminary* fish consumption advisory triggers for PFOS, PFOA, and PFNA in fish tissue have been calculated. These preliminary fish consumption triggers are based on currently available New Jersey Reference Doses (the daily dose not expected to pose a risk with lifetime exposure). The PFNA Reference Dose, 0.74 ng/kg/day, is used as the basis for the recently finalized NJDEP Ground Water Quality Standard and proposed NJDEP drinking water Maximum Contaminant Level (MCL) for PFNA, and is final. The PFOA Reference Dose, 2.0 ng/kg/day, is used as the basis for the New Jersey Drinking Water Quality Institute MCL recommendation and NJDEP drinking water guidance for PFOA. The PFOS Reference Dose, 1.8 ng/kg/day, was developed by the New Jersey Drinking Water Quality Institute as the basis for its PFOS MCL recommendation.

The fish consumption advisory triggers are based on the same exposure assumptions (227 gram [8 ounce] meal size and 70 kg body weight) and recommended consumption frequency categories: no limit applied for consumption (**unlimited)**, no more than one meal per week (**weekly**), no more than one meal per month (**monthly**), no more than one meal every 3 months (**once/3 months**), no more than one meal per year (**yearly**), and consumption not recommended (**do not eat**)) used in existing New Jersey fish consumption advisories.

Although preliminary advisory triggers are only available for the three compounds shown in Table 8, all detectable levels of PFAS compounds are presented in the "Site Specific Issues" section, below. As mentioned above, the fish tissue data shown are based on averages of detected values from the individual fish of each species from each site; non-detects from individual fish were not included in the averages. This method was used in order to provide the most conservative analysis and to avoid including non-detectable values potentially resulting from laboratory irregularities.

Table 8: DRAFT Preliminary Fish Consumption Advisory Triggers

	General Population			**High Risk Population***		
	PFOA (ng/g; ppb)	PFNA (ng/g; ppb)	PFOS (ng/g; ppb)	PFOA (ng/g; ppb)	PFNA (ng/g; ppb)	PFOS (ng/g; ppb)
Unlimited	0.62	0.23	0.56	0.62	0.23	0.56
Weekly	4.3	1.6	3.9	4.3	1.6	3.9
Monthly	18.6	6.9	17	18.6	6.9	17
Once/3 months	57	21	51	N/A	N/A	N/A
Yearly	226	84	204	N/A	N/A	N/A
Do Not Eat	**>226**	**>84**	**>204**	**>18.6**	**>6.9**	**>17**

**High risk individuals are considered to be at higher risk from contaminants in fish than members of the general public. This group includes infants, children, pregnant women, nursing mothers and women of childbearing age.*

In the following "Site Specific Results" section, the preliminary advisories for the general population only are shown as an example for each lake. Full advisories will be issued in a separate announcement for the general population and high-risk population and posted on the www.FishSmartEatSmartNJ.org website.

Site Specific Results

Echo Lake Reservoir

Echo Lake Reservoir is located in West Milford, Passaic County and is part of the Newark Watershed Conservation & Development Corporation which provides drinking water for the city of Newark. Located in an isolated area, Echo Lake Reservoir is surrounded by forests and low density residential areas. Echo Lake is often used as a “background” or reference site in contaminant monitoring studies and, as such, was chosen with this intention. Although no known direct source is suspected of being in the area, it should be noted that long-range atmospheric transport of perfluorinated compounds and their precursors has been identified as a source of PFAS contamination in waterbodies in very remote areas (Ahrens et al., 2010; Åkerblom et al., 2017).

One grab sample of surface water and one grab sample of sediment was collected from Echo Lake Reservoir following the procedures described above. Three each of largemouth bass, bluegill and brown bullhead were also collected at this site

The surface water contained detectable levels of four of the 13 perfluorinated compounds, with the PFHpA contributing 14.6 ng/L of the total PFAS level of 24.3 ng/L.

There were no detectable levels of any of the compounds in the sediment sample (See Table 4 for detection levels).

There were detectable levels of PFOS and PFUnA in all three species of fish. The average concentration of PFOS ranged from 2.33 ng/g in the bluegill sunfish to 4.63 ng/g in the largemouth bass. The detected levels of PFUnA ranged from 0.79 ng/g in the bluegill sunfish to 1.327 ng/g in the largemouth Bass. Based on the preliminary consumption triggers presented in Table 8, the fish from Echo Lake Reservoir would have the consumption advisories recommended in Table 9.

Table 9: Echo Lake Reservoir Site Parameter Summary and Preliminary Fish Consumption Advisory

Parameter	Average* (ng/g)	Preliminary Advisory	Detection Ratio	Standard Deviation
Bluegill Sunfish				
PFOS	2.33	Weekly	3/3	0.49
PFUnA	0.798	NA	3/3	0.15
Brown Bullhead				
PFOS	2.43	Weekly	2/3	0.57
PFUnA	0.807	NA	2/3	0.06
Largemouth Bass				
PFDA	0.791	NA	1/3	
PFOS	4.63	Monthly	3/3	0.37
PFUnA	1.327	NA	3/3	0.31

**The average concentration in the fish tissue includes only those fish with detectable levels.*

The observed partitioning regimen is consistent with known properties of these PFAS, with the short chain compounds remaining dissolved in the water and the long chain compounds accumulating in the fish tissue. However, it must be noted that, although there are no detections of the longer chain PFAS in the surface water or sediment, they may be present in these media at levels below detection that are sufficient to bioaccumulate to detectable levels in fish tissue.

Passaic River

The Passaic River is an 80-mile long river that originates near the center of Morris County, and then flows through highly industrialized areas in Passaic, Somerset, Union, Essex and Bergen Counties.

Two grab samples of surface water and two grab samples of sediments were collected from the river. The first sample was collected from just upstream of the Dundee Dam and the second two miles upstream near Route 4 and the boat launch at Elmwood Park. Three each of largemouth bass, bluegill sunfish and common carp were also collected in the two miles of the Passaic River in the area between the two sites.

The two surface water samples appeared similar in detections of perfluorinated compounds, with the upstream site (by Route 4) having nine compounds and a total of 83.0 ng/L PFAS, and the site just near the dam having eight compounds totaling 76.3 ng/L. A low level of PFNA (2.5 ng/L) was detected in the upstream surface water sample, but all other detectable levels in the water column were PFAS with fewer carbons. The higher levels of PFHxA, PFOA, and PFOS in surface water ranged from 10.8 ng/L (PFHxA by Dundee Dam) to 14.9 ng/L (PFHxA upstream by Route 4). No PFOSA, PFDA, PFUnA or PFDoA was detected in either surface water sample.

The Passaic River sediment samples were relatively free of detectable levels of PFAS, with only PFOS detected at levels >1 ng/g in both samples.

Four PFAS were detected in the all three species of fish. The average PFDA and PFDoA concentrations in all three species were less than 3.7 ng/g. The average concentrations of PFUnA were 2.54 ng/g in the common carp, 5.57 ng/g in the largemouth bass, and 6.33 ng/g in the bluegill sunfish. Based on the preliminary consumption triggers presented in Table 8, the Passaic River would have the consumption advisories for the general population recommended in Table 10.

Table 10: Passaic River Site Parameter Summary and Preliminary Fish Consumption Advisory

Parameter	Average* (ng/g)	Preliminary Advisory	Detection Ratio	Standard Deviation
Bluegill Sunfish				
PFDA	3.57	NA	3/3	2.45
PFDoA	3.51	NA	3/3	1.42
PFOS	47.43	Once/3 months	3/3	26.47
PFUnA	6.33		3/3	3.20
Common Carp				
PFDA	0.98	NA	3/3	0.23
PFDoA	1.61	NA	3/3	0.20
PFOS	9.10	Monthly	3/3	1.42
PFUnA	2.54	NA	3/3	0.33
Largemouth Bass				
PFDA	3.09	NA	3/3	0.54
PFDoA	3.69	NA	3/3	1.30
PFOS	39.30	Once/3 months	3/3	7.07
PFUnA	5.57	NA	3/3	1.37

**The average concentration in the fish tissue includes only those fish with detectable levels*

Raritan River

The Raritan River is one of the major rivers of northern New Jersey, beginning with a watershed that drains a large portion of the central mountainous areas in northern New Jersey and traversing highly developed lands with industrial and residential use. The sediment and surface water samples were collected on the border of the Kin-Buc Landfill, along the lower tidal portion of the river.

One grab sample of sediment and surface water was collected at the Raritan River site. Three each of channel carp, common carp, white perch, and white catfish were also collected.

Total PFAS detected in the surface water sample was 49.4 ng/L, with PFOS at 6.9 ng/L and PFOA at 8.7 ng/L. PFBA, PFHxA, and PFPeA were detected at approximately 8 ng/L.

Two compounds were detected in the Raritan River sediment sample, PFOA and PFOS, both at levels below 1 ng/g.

All of the fish species contained detectable levels of four perfluorinated compounds: PFDA, PFDoA, PFOS, and PFUnA. The PFDA ranged from 0.66 in the white catfish to 1.94 ng/g in the common carp. PFDoA ranged from 0.83 in the white catfish to 3.10 in the common carp. The PFOS ranged from 2.27 ng/g in the white catfish to 13.11 in the white perch. The PFUnA ranged from 0.75 ng/g in the white catfish to 4.26 ng/g in the common carp. Based on the preliminary consumption triggers presented in Table 8, the Raritan River would have the for the general population consumption advisories recommended in Table 11.

Table 11: Raritan River Site Parameter Study and Preliminary Fish Consumption Advisory

Parameter	Average* (ng/g)	Preliminary Advisory	Detection Ratio	Standard Deviation
Channel Catfish				
PFDA	1.75	NA	3/3	0.54
PFDoA	1.47	NA	3/3	0.59
PFOS	3.10	Weekly	3/3	0.58
PFUnA	1.56	NA	3/3	0.30
Common Carp				
PFDA	1.94	NA	3/3	0.69
PFDoA	3.10	NA	3/3	0.62
PFOS	11.54	Monthly	3/3	4.45
PFUnA	4.26	NA	3/3	1.36
White Catfish				
PFDA	0.66	NA	3/3	0.18
PFDoA	0.83	NA	3/3	0.15
PFOS	2.27	Weekly	3/3	0.81
PFUnA	0.75	NA	3/3	0.16
White Perch				
PFDA	1.66	NA	3/3	0.31
PFDoA	2.01	NA	3/3	0.85
PFOS	13.11	Monthly	3/3	4.09
PFUnA	1.85	NA	3/3	0.51

**The average concentration in the fish tissue includes only those fish with detectable levels*

Forge Pond

Forge Pond is an impoundment formed by a tidal dam near Route 70 on the Metedeconk River in Brick Township. This impoundment contains an intake for the Brick Township Municipal Utilities Authority (MUA) drinking water treatment plant. This impoundment also serves as a recreational waterbody, allowing fishing and other recreational activities. Residential areas and auto recyclers dot the land northeast of the river, and residential and light industry cover the land on the southwest border. After detection of PFOA at the Brick Township MUA intake in a previous Department study of PFAS occurrence in raw drinking water, an extensive trackdown study to determine its source was completed by the Brick MUA and DSREH. The findings of this study are documented in a report entitled, "Identification of Perfluoroalkyl Compounds (PFCs) in the Metedeconk River Watershed" (Brick Township Municipal Authorities., 2015) and a subsequent publication, "Occurrence and source identification of perfluoroalkyl acids (PFAAs) in the Metedeconk River Watershed, New Jersey (Procopio et al., 2017). A small industrial facility that used PFOA immersions to treat fabrics was found to be unintentionally discharging PFOA and other PFAS to the groundwater, subsequently impacting the Metedeconk River.

Grab samples of surface water and sediment were collected from two locations, Forge Pond and upstream near both the groundwater discharge of the identified source and a proximate wastewater treatment facility discharge point. The species of fish collected in Forge Pond included common carp, largemouth bass, and white perch; three of each species were collected.

The two surface water samples contained between 53.0 and 62.1 ng/L of total PFAS, with the Forge Pond sample having six detectable compounds and the upstream sample having seven compounds detected. In both surface water samples, PFOA was the primary component, with 28.3 ng/L in the impoundment and 33.9 ng/L upstream. PFOS was detected only in the upstream sample, at 2.8 ng/L. The other analytes detected in the two samples were short chain PFAS, from PFBA and PFBS (four carbons) to PFHpA (C7), all with concentrations below 7 ng/L.

Short chain PFAS were not found at detectable levels in the sediment samples. PFOA was detected in both sediment samples, at 0.10 ng/g in the impoundment and 0.22 ng/g in the upstream sample. PFOS was detected only in the upstream site, at 0.52 ng/L. PFDoA and PFUnA were also detected at concentrations less than 1 ng/g.

Four PFAS - PFDA, PFDoA, PFOA, and PFOS - were detected in all three fish species collected at this site. PFUnA was also detected in the largemouth bass and the white perch. PFDA, PFDoA and PFUnA concentrations were below 4 ng/g in all samples.

PFOA, not detected in any other fish species from any other location in this study, and not a frequently reported PFAS in fish tissue in the literature, was detected in the fish tissue at this location. While PFOA was not detected in white perch, the largemouth bass had an average detection of 0.50 ng/g, and the common carp contained an average of 0.72 ng/g.

The average PFOS concentration in the common carp was 6.36 ng/g, and it was 7.51 ng/g in the white perch. The largemouth bass showed a higher average concentration of 21.20 ng/g. Based on the preliminary consumption triggers presented in Table 8, Forge Pond would have the for the general population consumption advisories recommended in Table 12.

Table 12: Forge Pond Site Parameter Study and Preliminary Fish Consumption Advisory

Parameter	Average* (ng/g)	Preliminary Advisory	Detection Ratio	Standard Deviation
Common carp				
PFDA	0.91	NA	3/3	0.13
PFDoA	2.04	NA	2/3	0.10
PFOA	0.72	NA	3/3	0.29
PFOS	6.36	Monthly	3/3	0.21
Largemouth bass				
PFDA	1.71	NA	3/3	0.26
PFDoA	2.17	NA	3/3	0.12
PFOA	0.50	NA	1/3	
PFOS	21.20	Once/3 months	3/3	4.38
PFUnA	3.39	NA	3/3	0.33
White perch				
PFDA	0.72	NA	2/3	0.10
PFDoA	1.50	NA	3/3	0.62
PFOS	7.51	Monthly	3/3	2.69
PFUnA	1.33	NA	3/3	0.48

**The average concentration in the fish tissue includes only those fish with detectable levels*

Pine Lake

Pine Lake is formed at the confluence of the Ridgeway Branch (originating north of the DOD site, JB MDL) and the Union Branch (originating south of the JB MDL) upgradient of a dam located just upstream of the Toms River. The watershed that contributes to the Ridgeway Branch generally drains area north of the eastern portion of the JB MDL. Although the drainage area is relatively low-density development near the sample site and heavily forested in the upper headwaters, the impoundment is likely impacted by the groundwater flow originating near the base, and overland flow from areas around the base. Pine Lake also receives flow from the Union Branch, a stream that originates south of the base. That stream also feeds Horicon Lake first (details below) and then flows in an easterly direction into Pine Lake.

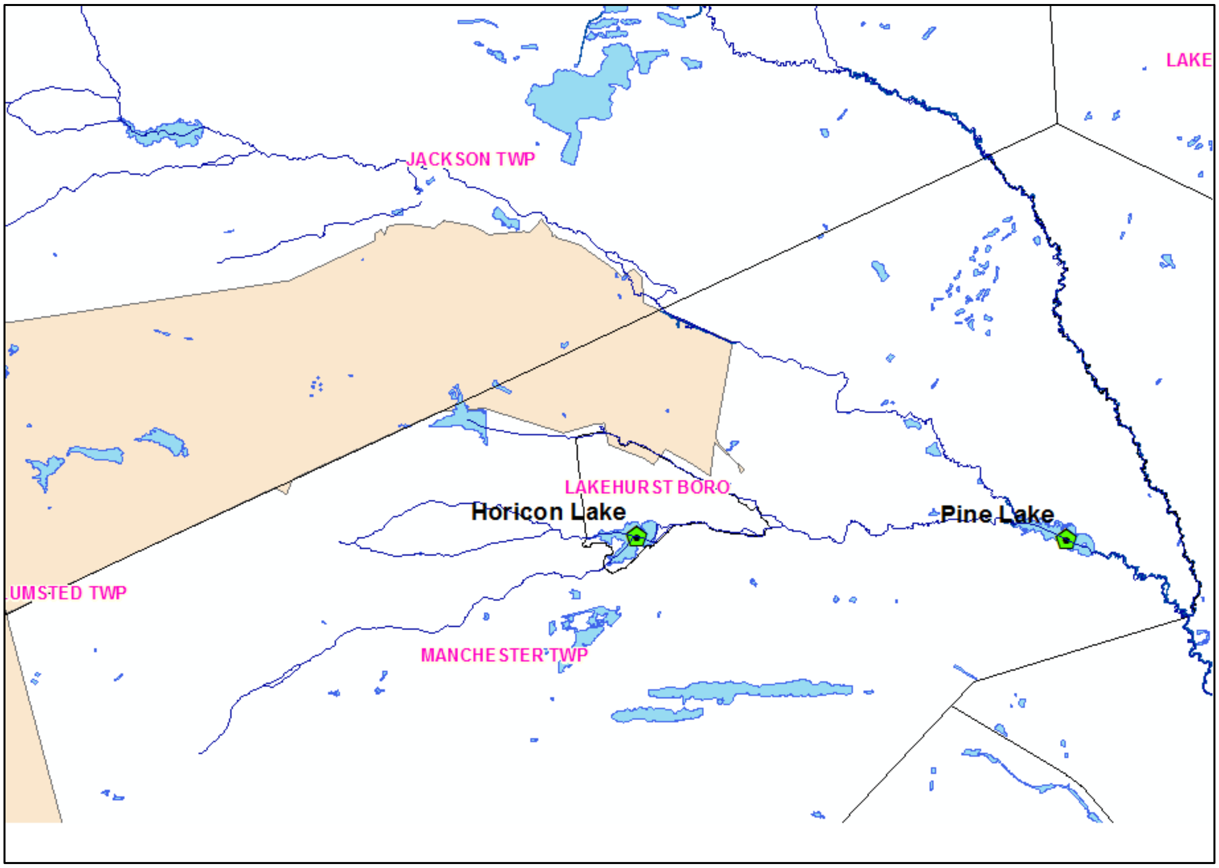

Figure 4: Locations of Horicon and Pine Lake

Grab samples of surface water and sediment were collected to represent the conditions of Pine Lake. The species of fish collected in Pine Lake included American eel, largemouth bass, and pumpkinseed. Three each of the American eel and the pumpkinseed sunfish were caught, while only one largemouth bass was collected.

Pine Lake contained detectable levels of nine of the 13 compounds, including those with four through eight carbons, and had the third highest total of PFAS at 170.7 ng/L. PFOS was detected in the surface water at Pine Lake at 102.0 ng/L. This was the highest reported concentration of any PFAS in surface water in this project. PFHxS in Pine Lake was also among the higher surface water concentrations of PFAS in the study, with a level of 24.6 ng/L, which was the third highest for this compound, after Little Pine Lake and Mirror Lake, both of which reside along the western portion of the base.

Six of the 13 analytes were detected in the sediment from Pine Lake. Along with levels of less than 1 ng/g of PFHxS, PFOA, PFDoA, and PFUnA, PFOSA was detected at 6.53 ng/g and PFOS was detected at 19.30 ng/g, the second highest sediment concentration in the study. It is evident from these results that the shorter chain compounds are more soluble and detected in the surface water samples, and the longer chain compounds partition to sediment to a higher degree. Although less than 1 ng/g, there were quantifiable levels in sediment of two longer chain compounds, PFDoA and PFUnA, as well as the precursor PFOSA.

Consistent with its relatively high concentration in the surface water and sediment, PFOS was the dominant analyte in the fish tissue. The average PFOS concentration in the American eel was 162.5 ng/g, while the largemouth bass had a concentration of 114 ng/g and the pumpkinseed had an average concentration of 119.2 ng/g. There was also evidence of bioaccumulation of other longer chain compounds, with PFHxS, PFDA, PFDoA, and PFUnA at detectable levels in the fish tissue. Based on the preliminary consumption triggers presented in Table 8, Pine Lake would have the for the general population consumption advisories recommended in Table 13

Table 13: Pine Lake Site Parameter Summary and Preliminary Fish Consumption Advisory

Parameter	Average* (ng/g)	Preliminary Advisory	Detection Ratio	Standard Deviation
American Eel				
PFDA	0.41	NA	1/3	
PFDoA	1.24	NA	3/3	0.27
PFOS	162.50	Yearly	2/3	7.50
PFUnA	2.44	NA	3/3	0.33
Largemouth Bass				
PFDoA	0.60	NA	1/1	
PFOS	114.00	Yearly	1/1	
PFUnA	1.49	NA	1/1	
Pumpkinseed Sunfish				
PFDoA	1.10	NA	1/3	
PFHxS	1.88	NA	2/3	0.92
PFOS	119.20	Yearly	3/3	62.81
PFOSA	2.83	NA	3/3	0.93
PFUnA	1.91	NA	1/3	

**The average concentration in the fish tissue includes only those fish with detectable levels*

Horicon Lake

As mentioned in the Pine Lake section, above, and shown in Figure 4, Horicon Lake is located just south of the easterly end of the JB MDL. It is an impoundment on the Union Branch upstream of Pine Lake and drains low density developed area that contains the Heritage Minerals sand quarry that was inactivated in 1984. The contributing streams receive groundwater at or near the JB MDL.

One grab sample of surface water and sediment was collected to represent the conditions of Horicon Lake. Two species were collected at Horicon Lake, consisting of three each of chain pickerel and yellow bullhead.

Six of the 13 compounds were detected in Horicon Lake. The concentrations of PFAS in the surface water in Horicon Lake are much lower than in Pine Lake, with PFOS concentration of 10.0 ng/L, PFHxS of 7.3 ng/L and a total PFAS of 22.9 ng/L.

Sediment concentrations were similarly much lower than in Pine Lake, with PFOS at 3.25 ng/g, and PFHxS and PFUnA detected at 1 ng/g. These were the only three PFASs detected in the sediments of Horicon Lake.

Four compounds, PFOS, PFUnA, PFDoA and PFDA, were detected in the fish tissue. The highest PFAS concentrations in fish tissue from Horicon Lake were for PFOS in the chain pickerel, which had an average of 15.21 ng/g. PFUnA in the chain pickerel was also detected with an average of 2.02 ng/g, and PFDoA and PFDA were also at detectable levels in this species. The yellow bullhead had lower tissue concentrations, with an average PFOS of 1.43 ng/g, and lower levels of PFDoA and PFUnA. Based on the preliminary consumption triggers presented in Table 8, the consumption advisories for the general population contained in Table 14 would be recommended for Horicon Lake.

Table 14: Horicon Site Parameter Summary Preliminary Fish Consumption Advisory

Parameter	Average* (ng/g)	Preliminary Advisory	Detection Ratio	Standard Deviation
Chain pickerel				
PFDA	0.52	NA	1/3	
PFDoA	0.70	NA	2/3	0.06
PFOS	15.21	Monthly	3/3	5.13
PFUnA	2.02	NA	3/3	0.70
Yellow bullhead				
PFDoA	0.90	NA	1/3	
PFOS	1.43	Weekly	2/3	0.41
PFUnA	1.10	NA	3/3	0.28

**The average concentration in the fish tissue includes only those fish with detectable levels*

Little Pine Lake

The Little Pine Lake in Pemberton is a body of water formed within Jacks Run, a tributary to the North Branch Rancocas Creek. The large number low-order tributaries that feed Little Pine Lake are located in areas in New Hanover Township that are known to be impacted by the use of aqueous film forming foam (AFFF) on the JB MDL (Joint Base McGuire-Dix-Lakehurst website: http://www.jointbasemdl.af.mil/PFCs/). Little Pine Lake serves as a recreational and fishing spot for area residents. Jacks Run flows into Mirror Lake and ultimately into the North Branch Rancocas Creek.

One grab sample each of sediment and surface water was collected at Little Pine Lake. Three largemouth bass, three pumpkinseed sunfish, and three yellow perch made up the fish species that were collected at this site.

Nine out of the 13 compounds were detected in the surface water sample taken from Little Pine Lake, with the highest total PFAS of any surface water sample in this study of 279.5 ng/L. The two compounds that are the largest components of this total concentration are PFOS (100.0 ng/L) and PFHxS (95.9 ng/L), both common components of AFFF.

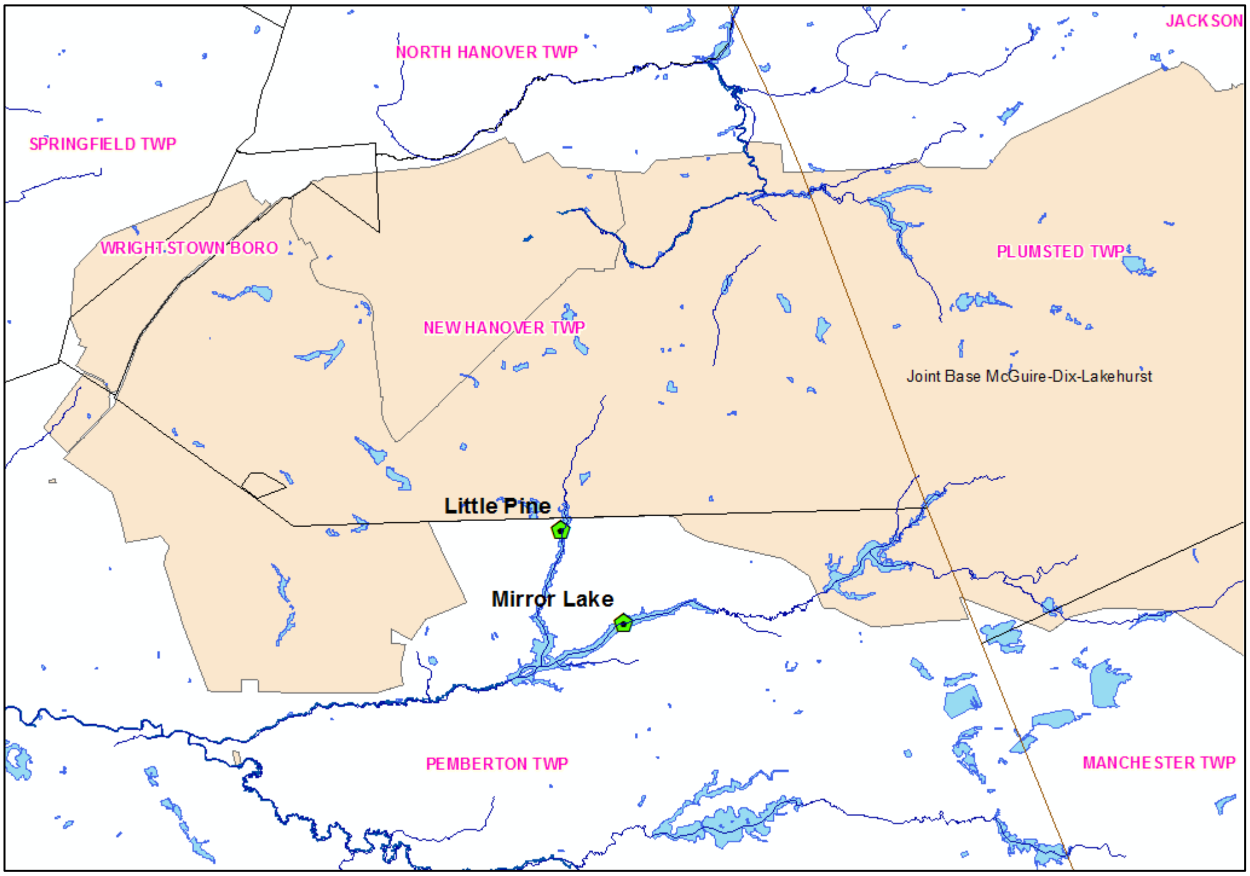

Figure 5: Locations of Little Pine and Mirror Lakes

The sediment from Little Pine Lake also had the highest total concentration of PFAS in this study, 30.93 ng/g, with 28.10 ng/g of that total being PFOS. PFHxS and PFUnA contributed approximately 1 ng/g to the total. Consistent with known partitioning, the longer chain compounds predominated in the sediment, with detectable sulfonates with six carbons (PFHxS) or more and carboxylates with eight carbons (PFOA) or more.

The largemouth bass and the yellow perch contained an average PFOS concentration of 73.67 ng/g and 118.60 ng/g, respectively. The PFAS concentrations in tissue from largemouth bass in Little Pine Lake were second only to the largemouth bass concentrations in Pine Lake, on the eastern boundary of JB MDL. It is noted that the largemouth bass collected from Pine Lake were substantially larger (1500 grams) than those from Little Pine Lake (350 grams). The pumpkinseed sunfish contained an average PFOS concentration of 31.8 ng/g. Detectable levels of other PFAS, such as PFDA, PFDoA, PFUnA and PFHxS was also found in the fish tissue samples. Based on the preliminary consumption triggers presented in Table 8, Little Pine Lake would have the consumption advisories for the general population recommended in Table 15.

Table 15: Little Pine Lake Site Parameter Summary and Preliminary Fish Consumption Advisory

Parameter	Average* (ng/g)	Preliminary Advisory	Detection Ratio	Standard Deviation
Largemouth Bass				
PFDA	0.56	NA	3/3	0.03
PFDoA	0.74	NA	3/3	0.07
PFOS	73.67	Yearly	3/3	6.22
PFUnA	2.33	NA	3/3	0.08
Pumpkinseed Sunfish				
PFOS	31.80	Once/3 months	3/3	9.10
PFUnA	1.03	NA	3/3	0.27
Yellow Perch				
PFDA	1.13	NA	3/3	0.33
PFDoA	0.71	NA	3/3	0.13
PFHxS	1.03	NA	1/3	
PFOS	118.60	Yearly	3/3	23.68
PFUnA	3.80	NA	3/3	0.97

**The average concentration in the fish tissue includes only those fish with detectable levels*

Mirror Lake

Mirror Lake is an impoundment on the North Branch of the Rancocas Creek, downstream of the confluence with the Little Pine/Big Pine Lakes. Some of Mirror Lake's contributing tributaries originate near the JB MDL and some originate to the south. Mirror Lake is a recreational area where residents swim, boat, and fish.

One grab sample each of sediment and surface water was collected from Mirror Lake. In addition, three largemouth bass, three bluegill sunfish, and three American eels were collected.

The surface water sample from Mirror Lake contained detectable levels of nine of the 13 analytes, including PFOA (13.2 ng/L), PFOS (72.9 ng/L), and a low concentration of PFNA (1 ng/L). All other detected compounds were shorter chain homologues, for a total PFAS concentration of 180.9 ng/L, the second highest total PFAS in surface water in this study, next to Little Pine Lake.

The sediments from Mirror Lake contained four detectable PFAS with a total of 3.55 ng/g. PFOS contributed the largest percentage of the total (3.07 ng/g), and PFHxS, PFDoA, and PFUnA all contributing less than 1 ng/g.

The American eel and the largemouth bass contained detectable levels of five of the 13 PFAS compounds, with the average PFOS concentration of 33.73 ng/g in the eel and 39.63 ng/g in the bass. PFDA, PFDoA, PFHxS, and PFUnA were reported at less than 3 ng/g. The bluegill contained only two analytes, with an average PFOS concentration of 22.20 ng/g and an average PFUnA concentration of 1.04 ng/g. Based on the preliminary consumption triggers presented in Table 8, the recommended advisories for the general population for Mirror Lake would be those contained in Table 16.

Table 16: Mirror Lake Site Parameter Summary and Preliminary Fish Consumption Advisory

Parameter	Average* (ng/g)	Preliminary Advisory	Detection Ratio	Standard Deviation
American Eel				
PFDA	0.66	NA	3/3	0.10
PFDoA	1.55	NA	3/3	0.35
PFHxS	1.66	NA	1/3	
PFOS	33.73	Once/3 months	3/3	9.82
PFUnA	2.94	NA	3/3	0.42
Bluegill Sunfish				
PFOS	22.20	Once/3 months	3/3	9.30
PFUnA	1.04	NA	3/3	0.42
Largemouth Bass				
PFDA	0.54	NA	1/3	
PFDoA	0.69	NA	3/3	0.07
PFHxS	0.96	NA	1/3	
PFOS	39.63	Once/3 months	3/3	6.19
PFUnA	1.47	NA	3/3	0.30

**The average concentration in the fish tissue includes only those fish with detectable levels*

Woodbury Creek

Woodbury Creek is a tributary to the Delaware River that is located in Gloucester County. It is located just north of a known industrial source of PFNA and PFUnA located on the tidal portion of the Delaware River. The tidal nature of the river at this location contributes to mixing of fresh and saline waters.

One grab sample each of sediment and surface water was collected from Woodbury Creek upstream of the Grove Street Bridge. Three each of channel catfish, largemouth bass, and pumpkinseed sunfish were also collected from this waterbody.

Eight of the 13 PFAS analytes were detected in the surface water samples. The total PFAS concentration at this site was 53.1 ng/L with most of the eight compounds detected at 10 ng/L or lower. This is the only site where the concentration of PFNA (7.7 ng/L) was higher than PFOA (7.2 ng/L) and PFOS (6.4 ng/L). The PFNA concentration in the surface water at this location was also higher than at any other site in the study. All PFAS detected in the surface water had nine or fewer carbons.

The PFAS detected in the sediment were five long chain compounds, including PFOS, PFOSA, PFNA, PFDA, and PFUnA, totaling 4.16 ng/g. The PFUnA in this sample was the highest detected in sediment in this study (2.14 ng/g) and was more than twice the level of the next highest PFUnA sediment concentration.

The largemouth bass and the pumpkinseed sunfish contained detectable levels of six long-chain analytes, including PFOS, PFOSA, and the nine to 12 carbon carboxylates (PFNA to PFDoA). While PFNA partitions to fish tissue to a lesser extent than do PFOS and PFUnA, levels of all three of these compounds were elevated at this site. The average PFOS concentrations in the largemouth bass was 21.30 ng/g, and in the pumpkinseed, it was 21.91 ng/g. PFNA was detected in all three fish species, but was reported in only one other species, the channel catfish from the Delaware River tributary site located approximately 30 river miles south of the Woodbury Creek site. As mentioned above, both PFNA and PFUnA was discharged by the industrial facility located in this vicinity, and the average concentrations of PFUnA were the highest detected in fish tissue in this study, 27.2 ng/g in largemouth bass and 22.3 ng/g in the pumpkinseed sunfish. Based on the preliminary consumption triggers presented in Table 8, Woodbury Creek would have the consumption advisories for the general population recommended in Table 17.

Table 17: Woodbury Creek Site Parameter Summary and Preliminary Fish Consumption Advisory

Parameter	Average* (ng/g)	Preliminary Advisory	Detection Ratio	Standard Deviation
Channel Catfish				
PFDoA	0.74	NA	2/3	0.07
PFNA	0.44	Weekly	1/3	
PFUnA	1.91	NA	2/3	0.48
Largemouth Bass				
PFDA	1.49	NA	3/3	0.19
PFDoA	5.43	NA	3/3	0.94
PFNA	0.78	Weekly	1/3	
PFOS	21.30	Once/3 months	3/3	2.94
PFOSA	0.67	NA	1/3	
PFUnA	27.20	NA	3/3	5.19
Pumpkinseed Sunfish				
PFDA	2.31	NA	2/3	0.56
PFDoA	3.83	NA	3/3	1.71
PFNA	1.39	Weekly	2/3	0.78
PFOS	21.91	Once/3 months	3/3	9.80
PFOSA	1.04	NA	2/3	0.47
PFUnA	22.33	NA	3/3	16.39

**The average concentration in the fish tissue includes only those fish with detectable levels*

Fenwick Creek

Fenwick Creek is a stream located in Salem County located approximately 0.5 miles downstream of a potential source and south-southeast of two known industrial sources of PFAS to the Delaware River.   Fenwick Creek is a low-order tributary to the Salem River.

One grab sample each of sediment and surface water was collected at the Fenwick Creek site, along with three channel catfish, three common carp, and three white catfish.

The surface water sample contained detectable levels of eight of the 13 analytes, with a total PFAS of 86.5 ng/L. This was the highest total PFAS in surface water in the study outside of the sites surrounding the JB MDL. PFNA was detected at 6.7 ng/L, the second highest surface water level next to Woodbury Creek, the site to the north. The other detected analytes were homologues with lower numbers of carbons in the fluorinated chain, such as PFOA (10.5 ng/L), PFHxA (25.0 ng/L), PFPeA (17.7 ng/L), and PFBA (10 ng/L; the highest detected in surface water in this study).   The high proportion of the shorter chain compounds in total surface water PFAS at this site could potentially result from release of replacement PFAS compounds from nearby industrial sources.

The PFAS concentration detected in the sediment sample from Fenwick Creek totaled 1.28 ng/g, and included detectable levels of PFOS, PFOSA, PFDoA, and PFUnA, all at levels below 1 ng/g.

All three fish species contained detectable levels of PFDA, PFDoA, PFOS, and PFUnA. The white catfish also had detectable levels of PFOSA, and the channel catfish had both PFOSA and PFNA. The PFOS concentrations were highest in the common carp (12.39 ng/g), while the reported levels in both channel catfish and the white catfish were below 3 ng/g. Based on the preliminary consumption triggers presented in Table 8, the recommended advisories for the general population found in Table 18 would be in place for Fenwick Creek.

Table 18: Fenwick Creek Site Parameter Summary and Preliminary Fish Consumption Advisory

Parameter	Average* (ng/g)	Preliminary Advisory	Detection Ratio	Standard Deviation
Channel Catfish				
PFDA	1.20	NA	3/3	0.25
PFDoA	3.08	NA	3/3	0.90
PFNA	0.57	Weekly	1/3	
PFOS	1.70	Weekly	2/3	0.63
PFOSA	1.40	NA	3/3	0.76
PFUnA	3.28	NA	3/3	0.61
Common Carp				
PFDA	3.77	NA	3/3	0.32
PFDoA	4.60	NA	3/3	1.21
PFOS	12.39	Monthly	3/3	4.06
PFUnA	8.36	NA	3/3	1.94
White Catfish				
PFDA	0.93	NA	2/3	0.18
PFDoA	2.86	NA	3/3	1.35
PFOS	2.53	Weekly	3/3	1.11
PFOSA	0.53	NA	1/3	
PFUnA	3.51	NA	3/3	1.09

**The average concentration in the fish tissue includes only those fish with detectable levels*

Cohansey River

The sampling location on the Cohansey River is in Cumberland County and is a tributary to the Delaware Bay. The drainage area that contributes to the Cohansey River contains a high proportion of agriculture and no direct PFAS sources have been previously identified.

Two grab samples of surface water and two samples of sediment were collected along the Cohansey River (Table 1). The first sampling site was close to the mouth of the Cohansey River, and the second site was upstream near an effluent discharge from a wastewater treatment plant. Three channel catfish and three white perch were collected from the Cohansey River between the two sites.

The total PFAS in the surface water sample collected by the mouth of the river was 17.9 ng/L, whereas the total PFAS reported in the sample upstream near the WWTP was 27.2 ng/L. The analytes detected in the surface water sample consisted of those with 8 fluorinated carbons (PFNA) or less.

The concentrations of analytes in the two sediment samples showed a larger variation, with the sample by the river mouth containing a total of 0.30 ng/g and the sample by the WWTP containing a total of 1.95 ng/g. The sample by the WWTP contained seven different long chain analytes, while the sample by the mouth contained only three analytes.

Three PFAS were detected in the channel catfish, with PFUnA having the highest concentration at 1.88 ng/g. The white perch contained four detectable compounds, with an average of 2.70 ng/g of PFUnA and 3.04 ng/g of PFOS. Based on the preliminary consumption triggers presented in Table 8, recommended advisories for the general population contained in Table 19 would be in place.

Table 19: Cohansey River Site Parameter Summary and Preliminary Fish Consumption Advisory

Parameter	Average* (ng/g)	Preliminary Advisory	Detection Ratio	Standard Deviation
Channel Catfish				
PFDA	0.56	NA	1/3	
PFDoA	1.08	NA	3/3	0.02
PFUnA	1.88	NA	3/3	0.44
White Perch				
PFDA	0.96	NA	3/3	0.26
PFDoA	1.29	NA	3/3	0.39
PFOS	3.04	Weekly	3/3	0.22
PFUnA	2.70	NA	3/3	0.60

**The average concentration in the fish tissue includes only those fish with detectable levels*

Total PFAS Concentration in Fish Tissue

As discussed above, the potential for bioaccumulation of each PFAS in fish tissue is determined by both its functional group and the number of fluorinated carbons. Past studies have found that bioconcentration factors (BCFs) increase with increasing carbon chain length, and that sulfonates had greater BCFs than carboxylates (Martin et al., 2003; Conder et al., 2008). These bioaccumulative properties are illustrated by the surface water and fish data from the Forge Pond site (on the Metedeconk). The primary PFAS of previous concern in the area was PFOA, with contamination of surface water used for drinking water by a known source. At this site, the surface water concentrations of PFOA was 28.3 ng/L, while PFOS was not detected. However, the PFOS levels in the fish tissue were much higher than the levels of PFOA (Table 11), and they exceed the triggers for preliminary PFOS fish consumption advisories in Table 8.

The total average carboxylate and sulfonate concentrations found in each species can be a useful indicator of the presence of a potential point source and overall bioaccumulation of PFAS in a system. These values are determined by adding the average concentrations of all carboxylates or sulfonates found in each species at a given site. Table 20 and Table 21 provide these values.

Specific characteristics of the designated site, including the potential for direct sources and the magnitude of those sources, would play the largest role in determining the fish tissue concentration that was detected in the fish. The age and size of the fish would also likely play a role, as older, larger fish would be expected to bioaccumulate a greater amount of PFAS. In this section, however, the statistical descriptors have been presented for the fish as grouped by

*Table 20: Total Carboxylates in Fish Tissue in Each Species at Each Site**

Total Carboxylates	Echo Lake Reservoir	Passaic River 1 &2*	Raritan River	Metedeconk 1 &2*	Pine Lake	Horicon Lake	Little Pine Lake	Mirror Lake	Woodbury Creek	Fenwick Creek	Cohansey River 1 & 2*
Largemouth Bass	2.12	12.35		7.77	2.09		3.62	2.71	34.91		
Chain Pickerel						3.24					
White Perch			5.52	3.54							4.95
Yellow Perch							5.63				
Bluegill Sunfish	0.80	13.41						1.04			
Pumpkinseed Sunfish					3.01		1.03		29.87		
Channel Catfish			4.78						2.65	8.13	3.52
White Catfish			2.24							7.30	
Yellow Bullhead						2.00					
Brown Bullhead	0.81										
Common Carp		5.12	9.29	9.31						16.73	
American Eel					4.09			5.15			

Trophic Level 2
Trophic Level 3
Trophic Level 4

*Based on average values for each species at each site (not including "non-detects").

*Table 21: Total Average Sulfonate in Fish Tissue in Each Species at Each Site**

Total Sulfonates	Echo Lake Reservoir	Passaic River 1 &2*	Raritan River	Metedeconk 1 &2*	Pine Lake	Horicon Lake	Little Pine Lake	Mirror Lake	Woodbury Creek	Fenwick Creek	Cohansey River 1 & 2*
Largemouth Bass	4.63	39.30		21.20	114.00		73.67	40.60	21.97		
Chain Pickerel						15.21					
White Perch			13.11	7.51							3.04
Yellow Perch							119.63				
Bluegill Sunfish	2.33	47.43						22.20			
Pumpkinseed Sunfish					123.91		31.80		22.96		
Channel Catfish			3.10						0.00	3.10	0.00
White Catfish			2.27							3.06	
Yellow Bullhead						1.43					
Brown Bullhead	2.43										
Common Carp		9.10	11.54	6.36						12.39	
American Eel					162.50			40.60			

Trophic Level 2
Trophic Level 3
Trophic Level 4

*Based on average values for each species at each site (not including "non-detects").

species. With these caveats, the average, standard deviation, maximum concentration and minimum concentration of each PFAS for each species of fish collected for this study are shown in Table 22, below. This table clearly demonstrates that PFOS, PFDA, PFUnA, and PFDoA are the predominant PFAS detected in the fish species included in this study.

Table 22: Statistical descriptors per species

		PFHxS	PFOA	PFOS	PFOSA	PFNA	PFDA	PFUnA	PFDoA
American eel (n=6)	**Average**	**1.66**		**85.24**			**0.60**	**2.69**	**1.40**
	StdDev			71.24			0.16	0.58	0.38
	Minimum	1.66		20.30			0.41	1.97	1.03
	Maximum	1.66		170.00			0.79	3.67	1.88
Bluegill (n=9)	**Average**			**23.99**			**3.57**	**2.72**	**3.51**
	StdDev			26.05			3.00	3.35	1.74
	Minimum			1.70			1.64	0.54	2.15
	Maximum			84.50			7.03	10.80	5.47
Brown Bullhead (n=2)	**Average**			**2.43**				**0.81**	
	StdDev			0.81				0.09	
	Minimum			1.86				0.75	
	Maximum			3.00				0.87	
Chain pickerel (n=3)	**Average**			**15.21**			**0.52**	**2.02**	**0.70**
	StdDev			6.28				0.85	0.08
	Minimum			8.04			0.52	1.20	0.64
	Maximum			19.70			0.52	2.90	0.76
Channel Catfish (n=11)	**Average**			**2.54**	**1.40**	**0.50**	**1.35**	**2.18**	**1.67**
	StdDev			1.02	0.93	0.09	0.61	0.87	1.11
	Minimum			1.07	0.79	0.44	0.56	1.20	0.67
	Maximum			3.92	2.47	0.57	2.35	4.13	4.32
Common carp (n=12)	**Average**		**0.72**	**9.85**			**1.90**	**4.28**	**2.84**
	StdDev		0.15	4.06			1.28	2.90	1.40
	Minimum		0.62	5.33			0.75	1.73	1.44
	Maximum		0.83	17.50			4.23	11.10	6.17
Largemouth Bass (n=19)	**Average**	**0.96**	**0.50**	**37.54**	**0.67**	**0.78**	**1.56**	**6.60**	**2.42**
	StdDev			28.95			1.00	9.54	2.01
	Minimum	0.96	0.50	4.24	0.67	0.78	0.52	0.91	0.60
	Maximum	0.96	0.50	114.00	0.67	0.78	3.53	31.50	6.68
Pumpkinseed (n=9)	**Average**	**1.88**		**57.64**	**2.11**	**1.39**	**2.31**	**10.29**	**3.15**
	StdDev	1.30		60.80	1.31	1.10	0.79	16.17	2.19
	Minimum	0.96		8.64	0.57	0.61	1.75	0.78	1.10
	Maximum	2.80		208.00	3.90	2.17	2.87	45.50	5.83
White Catfish (n=6)	**Average**			**2.40**	**0.53**		**0.77**	**2.13**	**1.84**
	StdDev			1.07			0.25	1.73	1.53

		PFHxS	PFOA	PFOS	PFOSA	PFNA	PFDA	PFUnA	PFDoA
	Minimum			1.25	0.53		0.52	0.62	0.71
	Maximum			4.04	0.53		1.11	4.60	4.04
White Perch (n=9)	**Average**			**7.89**			**1.16**	**1.96**	**1.60**
	StdDev			5.30			0.51	0.82	0.76
	Minimum			2.74			0.62	0.98	0.96
	Maximum			18.40			1.92	3.16	3.15
Yellow bullhead (n=6)	**Average**			**1.43**				**1.10**	**0.90**
	StdDev			0.57				0.35	
	Minimum			1.02				0.77	0.90
	Maximum			1.83				1.46	0.90
Yellow perch (n=3)	**Average**	**1.03**		**118.60**			**1.13**	**3.80**	**0.71**
	StdDev			29.00			0.40	1.19	0.16
	Minimum	1.03		99.80			0.74	2.60	0.52
	Maximum	1.03		152.00			1.54	4.97	0.81

Comparison with other U.S. studies of PFAS in fish

PFAS have been reported in fish and other wildlife in studies from many locations throughout the world. In general, PFOS is the PFAS found in fish most often and at the highest concentrations (Houde et al., 2011), although other PFAS have also been frequently reported.

Studies of PFAS in fish vary in their reporting levels and the tissues and organs analyzed. PFAS levels in fish muscle tissue are generally about 10-20 times lower than in liver (Faxneld et al., 2014). PFAS may be present in the environment in developed areas from sources that include industrial production and use, release of aqueous firefighting foams, wastewater treatment plant effluents and sludge, and landfill leachate (USEPA, 2014); they are found more frequently and at higher concentrations in fish from developed areas than in remote areas (Delinsky et al., 2010; Stahl et al., 2014). Additionally, PFAS reach remote areas through atmospheric transport. When detection levels are sufficiently low, they have been detected at some level in liver, muscle, and/or other tissues of fish from remote locations not known to be impacted by a point source of PFAS (e.g. Ahrens et al., 2010; Åkerblom et al., 2017).

Two publications (Delinsky et al., 2010; Stahl et al., 2014) report results of U.S. studies of PFAS in fish that can be compared to this study's data on PFAS in New Jersey fish. Delinsky et al. (2010) reports data from a statewide study of Minnesota lakes and several Upper Mississippi River locations in Minnesota. Stahl et al. (2014) reports on a study of fish from urban rivers nationwide and a study of fish from the Great Lakes. Details of these studies and the New Jersey study are shown in Table 23, below.

It should be noted that detection level and other study details differ among these studies. The Reporting Levels in the NJ study were somewhat lower than in the MN study, substantially lower than in the U.S. urban river study, and substantially higher than in the Great Lakes study. Additionally, composites of fillets with skin were analyzed in the MN, urban river, and Great Lakes studies, while individual fillets without skin were analyzed in the NJ study.

Because of the differences in reporting levels among studies, comparison of reporting frequencies between the studies is not meaningful in some cases. However, it is noteworthy that PFOS was detected at 1.08 ppb or higher in only 22% of 59 Minnesota lakes, including both lakes in remote locations and lakes impacted by PFAS. In contrast, PFOS was detected at 1.43 ppb or higher in fish tissue at all 11 sites, including the intended control, Echo Lake. These results remind us that even areas of New Jersey considered to be "remote" are actually relatively close to industrialized and urbanized areas, as compared to remote areas in much larger states such as Minnesota.

Comparisons of maximum detected levels among studies also provide useful information, although there are differences in the species included and the sample type (e.g. fillet with or without skin). For PFOS, the most frequently detected PFAS, the maximum fish tissue concentration in the New Jersey study (162.5 ppb), is somewhat higher, but generally comparable to, the maximum levels in the Minnesota statewide lakes study (52.4 ppb), nationwide urban rivers study (127 ppb), and the Great Lakes study (80 ppb). It should be noted that PFAS levels in fish may be extremely high (much higher than in any New Jersey fish analyzed in this study) in locations impacted by major industrial or military PFAS contamination (e.g. Minnesota Upper Mississippi, up to 2,000 ppb, Delinsky et al., 2010; Decatur, AL, average PFOS – 806 ppb, USEPA, 2013; Wurtsmith AFB, MI, fish with highest PFOS – 9,580 ppb, MDHHS, 2015; Barksdale AFB, LA, fish with highest PFOS [dry weight] – 9,349 ppb, Lanza et al., 2017).

Table 23: Comparison of New Jersey, Minnesota statewide, and U.S. urban rivers, and Great Lakes studies of PFAS in fish

Study	**Minnesota – Statewide Lakes**	**Minnesota -Upper Mississippi River**	**U.S. Urban Rivers**	**Great Lakes**	**New Jersey**
Citation	Delinksy et al. (2010)		Stahl et al. (2014)		Goodrow, Ruppel, Lippincott, and Post (NJDEP DSREH), 2018
Year sampled	2007		2008-09	2010	2017
Sites	59 lakes (including impacted by PFCs and remote)	11 sites including some with historically high PFCs and others up to several hundred miles upstream	164 urban rivers in 38 states	157 randomly selected nearshore locations of 5 Great Lakes	11 waterbodies selected for potential vulnerability to PFC contamination
Sample type	Fillets - skin on		Fillets – skin on with belly flap		Fillets – skin off
Sample description	Composites (n=1-17) of same species		Composites of up to 5 fish of same species 162 composites including 682 fish	157 composites including 423 fish	3 individual fish from 2 (n=2), 3 (n=8), or 4 (n=1) species at each site
Species	Bluegill, sunfish, crappie, pumpkinseed		25 species (smallmouth bass – 43%; largemouth bass – 25%; channel catfish – 11%)	18 species (lake trout – 31%; smallmouth bass – 14%; walleye – 13%)	12 species: largemouth bass (7 sites), channel catfish and common carp (4 sites), bluegill, pumpkin seed, and white perch (3 sites), American eel, white catfish (2 sites), chain pickerel, yellow bullhead, yellow perch (1 site)
Reporting Levels (ppb)	LOQ: PFOS – 1.11 ppb Other PFCs – in similar range		MDL: PFOS - 5.35 ppb Other PFCs - 1.25-10.45 ppb	MDL: PFOS – 0.13 ppb; Other PFCs – 0.06 – 0.13 ppb	Detection Limits: Variable: PFOS, PFHxS - ~ 1 ppb. Other PFCs - ~ 0.5 ppb.
Results	• PFOS detected in fish from 22% of lakes (1.08-52.4 ppb). 12% greater than 3 ppb. • PFDA (C10) only other PFC found (5%), only when PFOS 10 ppb or greater.	• Highest PFOS levels (144-2000 ppb) and lower levels (≤ 15 ppb) of several other PFCs in two sites impacted by known PFC contamination. • PFOS only (3.06 -20 ppb) in upstream sites. • No detections in 3 sites furthest upstream.	• PFCs detected in 80% of samples. • PFOS – 73% (>5.35 ppb). Max. – 127 ppb • PFUnA (C11) – 33% (>2.76 ppb). Max -45.6 ppb • PFDA (C10) – 20% (>2.63 ppb). Max. – 28.5 ppb • PFDoA (C12) = 20% (>1.38 ppb). Max. -23.8 ppb)	• PFCs detected in 100% of samples. • PFOS – 100% (>0.13 ppb). Max. 80 ppb. • PFDA (C10) – 92% >0.06 ppb). Max.- 13.0 ppb. • PFUnA (C11) – 90% (>0.11 pbb). Max. 18.0 ppb. • PFDoA (C12) – 76% (>0.12 ppb). Max. – 3.10 ppb	• PFCs detected in 100% of species from all sites (n=32 species-sites) •Data reported as average for those fish with detections for each species from each site. •PFOS – 94% of 32 species-sites. 1.43-162.5 ppb. •PFDA (C10) – 69% of 32 species-sites. 0.41-3.57 ppb.. •PFUnA (C11) – 97% of 32 species-sites. 1.03-27.2 ppb. •PFDoA (C12) – 88% of 32 species-sites. 0.6-5.42 ppb. •PFNA (C9)-13% of 32 species-sites (2 sites): 0.44-1.39 ppb •PFOA (C8) – 6% of 32 species-sites (2 species at 1 site). 0.50-0.72 ppb •PFHxS - 13% of 32 species-sites (3 sites), 0.96-1.66 ppb. •PFOSA - 16% of 32 species-site. (3 sites). 0.53-2,83 ppb.

Conclusions

The class of compounds known as PFAS is used in many products and processes and is widely distributed around the world. These compounds are currently the focus of increased attention from both scientists and regulators because of their environmental occurrence and persistence, and their bioaccumulation and potential adverse effects on humans and other species.

As this study shows, environmental media often contain a mix of various PFAS homologues, differentiated by chain length and functional group, arising from the PFAS compounds present in the products that have been discharged to the environment. In some cases, the ratios of the compounds in environmental samples may be a useful factor for identification of the source. In addition, less bioaccumulative short-chain perfluorinated compounds and PFAS with other structures (e.g. perfluoroethers) are being introduced as replacements for longer-chain perfluorinated compounds of concern due to their bioaccumulation and toxicity. As these newer compounds enter the environment, it will become increasingly difficult to detect them and to identify new and old sources of PFAS. There are also a large number of per- and polyfluorinated compounds found in AFFF, and only specialized research analytical techniques can identify and quantify many of these compounds (Barzen-Hanson et al., 2017).

Based on the distribution in environmental media for the 13 PFAS quantified by a modified EPA Method 537 in this study, we see the somewhat predictable partitioning, with the shorter carbon chain compounds being detected more often in the water and the longer chain compounds partitioned to the sediments and/or bioaccumulated into the fish tissue. Because of the much greater affinity of longer chain compounds for fish than the other environmental media, certain compounds are often found in the fish tissue, but not in the water or sediment, at the same site. For compounds such as PFUnA (C11), even low concentrations that are below the detection level of the lab (approximately 1 ng/L) in the sediment or surface water can result in observable levels in the fish tissue. As illustrated by the data from Echo Lake, even a more commonly detected compound, PFOS, may not be detected in surface water or sediment, but can be present in the fish tissue at levels of concern.

More generally, PFOS is the compound that has generated the most concern in fish due to its frequent occurrence in the environment, its bioaccumulation in fish tissue, its potential human health risk, and the availability of health effects information needed to develop fish consumption advisories. In all but one species at one site (channel catfish in the Cohansey River), the average levels of PFOS in fish tissue generated some level of fish consumption advisory, based on the draft preliminary fish consumption triggers included in this report. Additionally, PFUnA, which has a higher bioaccumulative potential than PFOS, was detected in all but one species at one site (common carp at Forge Pond), 0.75 ng/g (white catfish at the Raritan River) and 27.20 ng/g (largemouth bass at Woodbury Creek).

The PFAS included in this study are known not to partition in biota in the same way as typical bioaccumulative organic compounds, and they did not show a distinctive pattern of species-specific bioaccumulation. As expected, the sites with higher levels of environmental contamination, as indicated by detections in surface water and sediment, had higher fish tissue concentrations. However, fish from a higher trophic level did not necessarily have higher levels of PFAS contamination. For example, in Fenwick Creek and Raritan River, the total carboxylates and total sulfonates were higher in the common carp (trophic level 2) than in the catfish (trophic level 4). On the other hand, in Passaic River and Pine Lake, these totals were higher in fish from the higher trophic levels.

In summary, perfluorinated compounds are widely distributed in the State of New Jersey due to historic and current industrial activities, as well as the presence of military facilities. These compounds are of concern because they do not break down in the environment, bioaccumulate in humans and biota, and may pose risks to human receptors. This initial study indicates the presence of some of these compounds in fish tissue at levels that might impact human health. Given the distribution of potential sources of these compounds in the State of New Jersey, additional studies are recommended to more fully understand sources at each site included in this study and occurrence of PFAS at additional sites around the state. The results of this study also suggest that it would be beneficial to the State to develop health-based triggers for additional PFAS, such as PFUnA, that have been detected in fish, when the necessary health effects data are available. Such additional information is essential to better understand the occurrence and potential risks of these compounds in the fish tissue that is consumed by the public.

References

Ahrens, Lutz, Nicolas Marusczak, Janne Rubarth, Aurelien Dommergue, Rachis Nedjai, Christophe Ferrari, and Ralf Ebinghaus (2010) "Distribution of perfluoroalkyl compounds and mercury in fish liver from high-mountain lakes in France originating from atmospheric deposition.", Environmental Chemistry, 7:422–428.

Arias, Victor A., Megharaj Mallavarapu, and Ravi Naidu (2015) "Identification of the sources of PFOS and PFOA contamination at a military air base site" Environmental Monitoring and Assessment, 187: 4111.

Åkerblom Staffan, Nesrin Negm, Pianpian Wu, Kevin Bishop, Lutz Ahrens (2017) "Variation and accumulation patterns of poly- and perfluoroalkyl substances (PFAS) in European perch (Perca fluviatilis) across a gradient of pristine Swedish lakes." Science of the Total Environment, 599-600:1685-1692.

Backe, Will J., Thomas C. Day, and Jennifer A. Field (2013) "Zwitterionic, Cationic, and Anionic Fluorinated Chemicals in Aqueous Film Forming Foam Formulations and Groundwater from U.S. Military Bases by Nonaqueous Large-Volume Injection HPLC-MS/MS". Environmental Science and Technology, 47 (10), 5226-5234.

Barber, Jonathan L., Urs Berger, Chakra Chaemfa, Sandra Huber, Anika Jahnke, Christian Temme, and Kevin C. Jones (2007) "Analysis of per- and polyfluorinated alkyl substances in air samples from Northwest Europe." Royal Society of Chemistry Journal of Environmental Monitoring 9, 530-541.

Barzen-Hanson KA, Roberts SC, Choyke S, Oetjen K, McAlees A, Riddell N, McCrindle R, Ferguson PL, Higgins CP, Field JA. (2017) "Discovery of 40 Classes of Per- and Polyfluoroalkyl Substances in Historical Aqueous Film-Forming Foams (AFFFs) and AFFF-Impacted Groundwater." Environmental Science & Technology 51(4):2047-2057.

Brick Township Municipal Utilities Authority, 2015. "Identification of Perfluoroalkyl Compounds (PFCs) in the Metedeconk River Watershed" Final Report for the New Jersey Department of Environmental Protection, online at: http://www.nj.gov/dep/dsr/research/BTMUA%20PFOA%20Final%20Report.pdf Accessed 5/22/2018.

Chen, Meng, Liwen Qiang, Xiaoyu Pan, Shuhong Fang, Yuwei Han, and Lingyan Zhu (2015) "In Vivo and in Vitro Isomer-Specific Biotransformation of Perfluorooctane Sulfonamide in Common Carp (Cyprinus carpio)" Environmental Science & Technology, 49, 13817-13824.

Conder JM, Hoke RA, De Wolf W, Russell MH, Buck RC. (2008) "Are PFCAs bioaccumulative? A critical review and comparison with regulatory criteria and persistent lipophilic compounds." Environmental Science & Technology 42(4):995-1003.

Delinsky AD, Strynar MJ, McCann PJ, Varns JL, McMillan L, Nakayama SF, Lindstrom AB. (2010) "Geographical distribution of perfluorinated compounds in fish from

Minnesota lakes and rivers." Environmental Science & Technology 44(7):2549-54.

Faxneld, S., Danielsson, S., Nyberg, E. (2014). "Distribution of PFAS in liver and muscle of herring, perch, cod, eelpout, arctic char, and pike from limnic and marine environments in Sweden." Swedish Museum of Natural History. Online at: https://www.diva-portal.org/smash/get/diva2:767385/FULLTEXT01.pdf Accessed 5/22/2018.

Fujii, Yukiko, Tsukasa Sakurada, Kouji H. Harada, Akio Koizumi, Osamu Kumura, Tetsuya Endo, Koichi Haraguchi (2015) "Long-chain perfluoroalkyl carboxylic acids in Pacific cods from coastal areas in northern Japan: A major source of human dietary exposure." Environmental Pollution 199, pp. 35-41.

Houde M, De Silva AO, Muir DC, Letcher RJ. (2011) "Monitoring of perfluorinated compounds in aquatic biota: an updated review." Environmental Science & Technology 45(19):7962-73.

Joint Base McGuire-Dix-Lakehurst website: http://www.jointbasemdl.af.mil/PFCs/Understanding PFCs, Accessed 5/3/2018.

Labadie, Pierre, and Marc Chevreuil (2011) "Partitioning behavior of perfluorinated alkyl contaminants between water, sediment and fish in the Orge River (nearby Paris, France)." Environmental Pollution 159, 391-397.

Lanza HA, Cochran RS, Mudge JF, Olson AD, Blackwell BR, Maul JD, Salice CJ, Anderson TA. (2017) "Temporal monitoring of perfluorooctane sulfonate accumulation in aquatic biota downstream of historical aqueous film forming foam use areas." Environmental Toxicology and Chemistry, 9999:1-8.

Lau Christopher (2012) "Perfluorinated compounds." EXS 101:47-86.

Lindstrom, Andrew B., Mark J. Strynar, and E. Laurence Libelo (2011) "Polyfluorinated Compounds: Past, Present, and Future." Environmental Science & Technology, 45, 7954-7961.

Martin, Jonathan W., Scott A. Mabury, Keith R. Solomon, and Derek C.G. Muir (2003), "Bioconcentration and tissue distribution of perfluorinated acids in rainbow trout (*Oncorhynchus mykiss*)." Environmental Toxicology and Chemistry, Vol. 22, No. 1, pp. 196-204.

Michigan Department of Health and Human Services (2015). "MDHHS Activities at the Former Wurtsmith Air Force Base. Updated April 2015. PFOS - Fish Sampling Results" https://www.michigan.gov/documents/mdch/fish_data_handout_449030_7.pdf Accessed 5/22/2018.

Moody, Cheryl A. and Jennifer A. Field (1999) "Determination of Perfluorocarboxylates in Groundwater Impacted by Fire-Fighting Activity," Environmental Science & Technology 33, pp. 2800-2806.

Post, Gloria, Perry D. Cohn, Keith R. Cooper (2012) "Perfluorooctanoic acid (PFOA), an emerging drinking water contaminant: A critical review of recent literature." Environmental Research 116, 93-117.

Post GB, Louis JB, Cooper KR, Boros-Russo BJ, Lippincott RL. (2009) "Occurrence and potential significance of perfluorooctanoic acid (PFOA) detected in New Jersey public drinking water systems." Environmental Science & Technology 43(12):4547-54.

Post GB, Louis JB, Lippincott RL, Procopio NA. (2013) "Occurrence of perfluorinated compounds in raw water from New Jersey public drinking water systems." Environmental Science & Technology 47(23):13266-75.

Prevedouros, Konstantinos, Ian T. Cousins, Robert C. Buck, and Stephen H. Korzeniowski (2006) "Sources, Fate and Transport of Perfluorocarboxylates," Environmental Science & Technology, Vol. 40, No. 1, pp. 32-44.

Procopio NA, Karl R, Goodrow SM, Maggio J, Louis JB, Atherholt TB. (2017) "Occurrence and source identification of perfluoroalkyl acids (PFAAs) in the Metedeconk River Watershed, New Jersey." Environmental Science Pollution Research International 24(35):27125-27135.

Renner, Rebecca (2001) "Growing Concern Over Perfluorinated Chemicals." Environmental Science & Technology 35 (7), pp 154A-160A.

Stahl LL, Snyder BD, Olsen AR, Kincaid TM, Wathen JB, McCarty HB. (2014) "Perfluorinated compounds in fish from U.S. urban rivers and the Great Lakes." Science of the Total Environment 499:185-95.

Taniyasu, Sachi, Nobuyoshi Yamashita, Hyo-Bang Moon, Karen Y. Kwok, Paul K.S. Lam, Yuichi Horii, Gert Petrick, Kurunthachalam Kannan (2013) "Does wet precipitation represent local and regional atmospheric transportation by perfluorinated alkyl substances?" Environment International 55, 25-32.

USEPA (2013). Perfluorochemical (PFC) Contamination Near Decatur, AL. Fact Sheet. https://archive.epa.gov/pesticides/region4/water/documents/web/pdf/epa_decatur_fact_sheet_final.pdf Accessed 5/22/2018.

USEPA (2014). Emerging Contaminants – Perfluorooctane Sulfonate (PFOS) and Perfluorooctanoic Acid (PFOA). March 2014 https://nepis.epa.gov/Exe/ZyPDF.cgi/P100LTG6.PDF?Dockey=P100LTG6.PDF Accessed 5/22/2018.