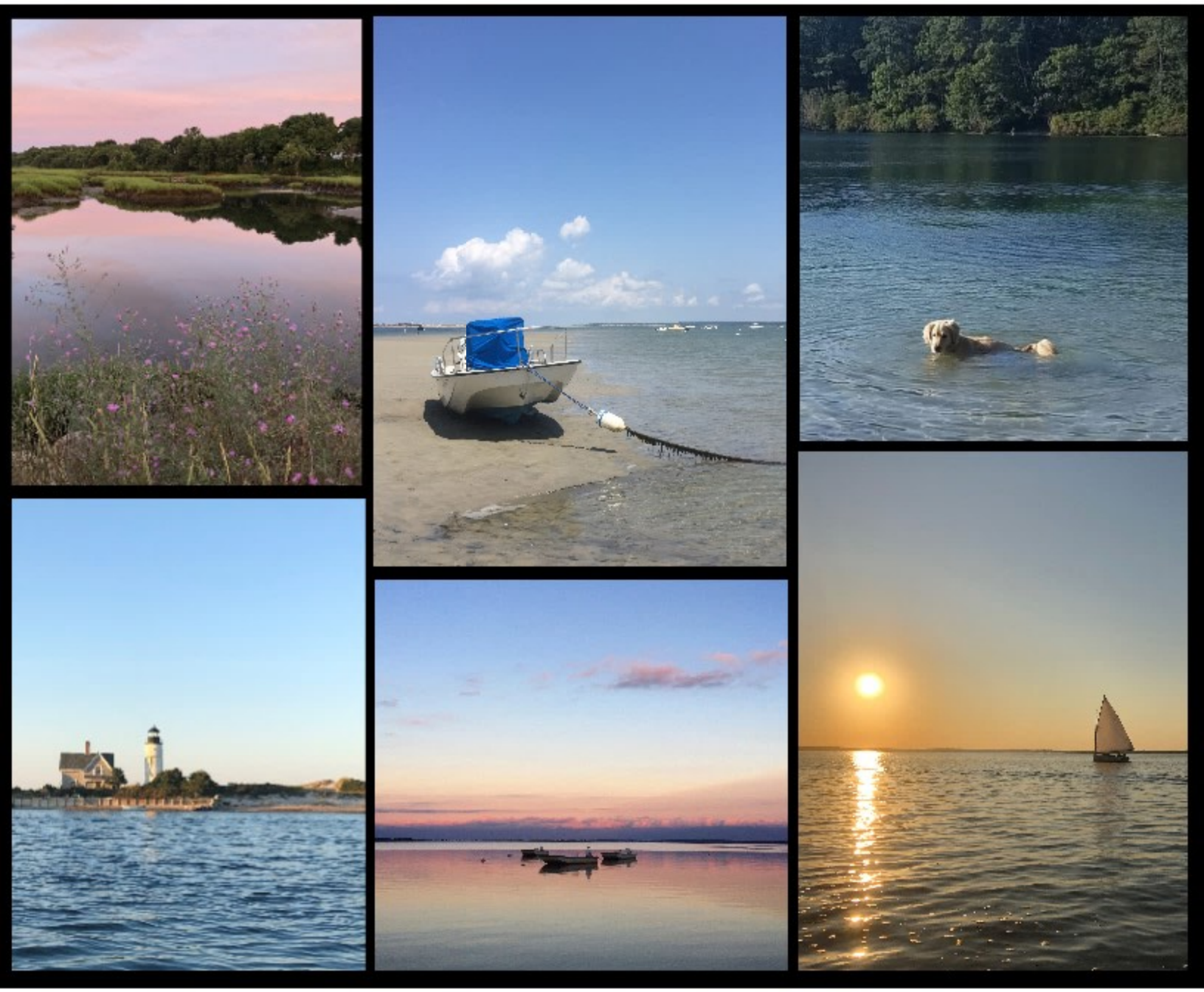
HYDROGEOLOGICAL TECHNICAL REPORT #1

THE DISTRIBUTION AND COMPOSITION OF PFAS IN SELECT WATER SUPPLY WELLS AND SURFACE WATERS OF BARNSTABLE, MA



Prepared by
Tom Cambareri
Sole Source Consulting, LLC

Prepared for
Hans Keijser, Supervisor
Water Supply Division

FINAL REPORT

The Distribution and Composition of PFAS in Select Water Supply Wells and Surface Waters of Barnstable, MA

Hydrogeological Tech Report #1

Prepared for
Hans Keijser, Supervisor
DPW Water Supply Division
Old Yarmouth Road
Hyannis, Ma 02601

Prepared by
Tom Cambareri
Sole Source Consulting, LLC
62 Joan Road
Centerville, MA 02632

December 31, 2020
Updated September 20, 2021

Executive Summary

Since the detection of per- and polyfluoroalkyl substances (PFAS) in the Hyannis Water System, the Town of Barnstable DPW Water Supply Division (WSD) has taken measures to implement treatments to remove PFAS to non-detect levels. To meet future demands the WSD has begun the process of investigating new well sources. To supplement known data on PFAS concentrations in public water supplies, WSD requested that Sole Source Consulting conduct a study of a selection of ponds and other surface water bodies in Barnstable. Sole Source Consulting sampled 21 surface water bodies in Barnstable. PFAS compounds were present in every surface water body tested and of the 24 compounds analyzed, 11 were detected.

The Hyannis area ponds; St. Francis Pond, Fawcetts Pond, Aunt Bettys Pond, Bens Pond, Dunns Pond, and the Hyannis and Yarmouth Creeks are significantly impacted with PFAS with an average Total PFAS of 200 ng/l, ranging from 138 ng/l to 252 ng/l with PFAS6 ranging from 159ng/l to 71 ng/l. A second tier of ponds to the north and west of the WPCF; Shallow Pond, Fresh Hole Pond, Indy Pond-West, Gooseberry, Wequaquet, Hathaways and Long Pond have an average Total PFAS concentration of 28 ng/l, ranging from 51ng/l to 13ng/l with PFAS6 concentrations ranging from 30ng/l to 11ng/l. A third tier of Ponds tested in remote areas away from the Hyannis area including Spruce, Garrets, Joshua, Eagle, Shubaels, and Mystic have an average Total PFAS concentration of 13 ng/l, ranging from 29ng/l to 3 ng/l with PFAS6 ranging from 14ng/l to Non-Detect and generally no detections of PFOS.

WSD analyzed their eleven wells for PFAS concentrations in groundwater using the same A2-537 isotope method for 24 PFAS compounds. These results, plus previously gathered data from the five Barnstable Fire District (BFD) wells were used to assess the overall occurrence of PFAS in the Hyannis area. Total PFAS and PFAS6 concentrations in WSD wells ranged from 854 ng/l to 61 ng/l and 526 ng/l to 50 ng/l with an average PFAS6 of 211 ng/l. The Mary Dunn Wells 2 and 3 under direct influence of the Barnstable County Fire Training Academy PFAS plume, and the Airport Well, detected the highest concentrations of PFAS6 at 274 ng/l, 526 ng/l and 466 ng/l, respectively. The Maher Wells with concentrations ranging from 274 ng/l to 190 ng/l is downgradient of both the BCFTA and Municipal Airport . The Hyannis Port Wellfield consisting of the Straightway, Simmons Pond and Hyannisport wells have lower PFAS6 concentrations ranging from 122 ng/l to 58 ng/l. The Hyannis Port Wellfield is downgradient of the WPCF with contribution from septic systems. PFAS6 concentrations in BFD wells were no higher than 23 ng/l. The Mass-DEP drinking water standard for the PFAS6 is 20 ng/l. All WSD wells are treated to non-detect for PFAS.

The presence and composition of PFAS in wells and ponds in the Hyannis area are strikingly similar indicating that the use of ponds is a good surrogate for evaluating groundwater quality. PFAS from the primary sources of groundwater contamination at the BCFTA and Airport that impacted supply wells was subsequently transported by the water system and redistributed by the WPCF and Hyannis area septic systems as secondary sources. As a result, the range of PFAS concentrations in the Town's surface waters is positively correlated to the proximity and distance to the WPCF and high-density septic systems in the Hyannis area.

While the WSD is taking necessary steps to treat PFAS in drinking water to non-detect levels now, PFAS known as "forever compounds" will persist for decades in contaminated soils and groundwater challenging the selection of clean sites for future water supply. By taking account of the extent of PFAS in surface waters and wells and the behavior of contamination plumes from multiple sources, several future well sites can be ruled out. For example, two of the most convenient potential future well sites located within Hyannis, thus requiring the shortest transmission mains, have a high degree of risk because of the presence of multiple PFAS sources.

Table of Contents

List of Tables

List of Figures

Acknowledgement

We extend our acknowledgement to Hans Keijser Water Supervisor of the Town of Barnstable DPW Water Supply Division for his direction on this report, Michael Leahy, Kevin Sampson and Joe Messier of Suez for assistance in the field, Matt Sumner of the DPW for GIS assistance and Jeremy Thebodo of Alpha Analytical Labs for coordinating the chemical analysis.

Overview

Since the detection of per- and polyfluoroalkyl substances (PFAS) in the Hyannis Water System the Town of Barnstable DPW Water Supply Division (WSD) took measures to implement treatments to remove PFAS to non-detect levels. Interim seasonal granular activated carbon (GAC) filters were installed to treat PFAS to non-detect levels at three Mary Dunn Wells in 2015 and 2016. Since then, additional interim seasonal GAC filters have also been installed to treat PFAS to non-detect levels at Airport, Straightway, Simmons Pond, and Hyannis Port wells. Construction of the Maher Filtration Plant is complete and water from three Maher wells is treated to reduce PFAS to non-detect levels.

To meet future demands, WSD has begun the process of investigating new well sources. A New Sources Alternative Evaluation report was prepared by Weston & Sampson for the Town in 2019, followed by an exploration program of potential new sources in the spring of 2020. The program included the installation of test wells and pumping tests at seven sites on Town-owned land with samples taken for various water quality parameters including PFAS. To supplement known data on PFAS concentrations in public water supplies, WSD requested that Sole Source Consulting conduct a study of a selection of ponds and other surface water bodies in Barnstable. With a more comprehensive understanding of the presence of PFAS throughout Barnstable, Sole Source Consulting is assisting the Town in selecting the most suitable and cost-effective future well sites, focusing on those with a lower risk of finding high concentrations of PFAS.

Sole Source Consulting sampled 21 surface water bodies in Barnstable, with the majority of testing performed during the summer of 2020. Samples were obtained by kayak in the middle of ponds for a representative sample from the water column to limit influences from up-gradient discharges and possible point sources. Samples were delivered to Alpha Analytical Laboratory in Mansfield, MA and analyzed using the A2-537 isotope method on a broad compound list of 24 PFAS. The reporting limit for each PFAS compound using this method is <2 nanograms per liter (ng/l). The newly adopted maximum contaminant level set by MassDEP for "PFAS6" (the sum of six specific PFAS compounds: PFOS, PFOA, PFHxS, PFNA, PFHpA, and PFDA) is 20 ng/l.

PFAS compounds were present in every surface water body tested and of the 24 compounds analyzed, 11 were detected. Total PFAS concentrations in ponds ranged from 3 ng/l to 252 ng/l with an average of 72 ng/l. PFOA was detected most frequently, at 18 out of 21 of the surface water locations. Of the six regulated PFAS compounds, PFOS was detected in 14 ponds, and had the highest concentration at 75 ng/l. PFBA, a presently unregulated PFAS compound was detected in 12 ponds and had the highest PFAS concentration detected at 82 ng/l. The highest PFAS concentrations were detected at Hyannis Ponds, with surface waters north and west of Hyannis detecting lower levels of PFAS. In 2019 and 2020, the WSD analyzed their eleven wells for PFAS concentrations using the same A2-537 isotope method for 24 PFAS. This data plus previously gathered PFAS6 data from five Barnstable Fire District (BFD) wells were used for

comparison purposes of this study. PFAS6 concentrations in WSD wells ranged from 526 ng/l to 50 ng/l, with PFAS6 concentrations in BFD wells no higher than 23 ng/l.

When comparing contamination data of surface water to wells, it is apparent that there is a relationship between the two, i.e. areas with high concentrations of PFAS contamination in surface water bodies also have similarly high concentrations of contamination in wells. For example, in the southern portion of Hyannis at Hyannis Creek, Aunt Betty's Pond, Fawcett's Pond, and Ben's Pond, total PFAS concentrations ranged from 138 ng/l to 252 ng/l. WSD wells in the same area, Straightway 1, Straightway 2, Simmons Pond, and Hyannis Port, had concentrations detected ranging from 169 ng/l to 83 ng/l.

Furthermore, in areas with lower concentrations, a similar pattern emerged: at Hathaway's Pond north and south, total PFAS detections were 22 ng/l and 3 ng/l, respectively, while BFD Wells 3 and 4 adjacent to these ponds detected PFAS6 levels of 2 ng/l and 20 ng/l, respectively. Because of this relationship we can assume that development of wells in an area with high concentrations of PFAS in surface water would result in high concentrations of PFAS in wells, thus resulting in higher treatment costs.

In the western portion of Barnstable, surface waters generally have detections of PFAS6 at concentrations less than 10 ng/l, which is likely due to residential septic systems in the area. Where concentrations exist above this threshold, point sources are likely the cause of contamination. Hydrology investigations by Cape Cod Commission in 2015 indicated that the Barnstable County Fire Training Academy (the Academy) was a point source of PFAS owing to extended use of aqueous film-forming foam (AFFF) containing PFAS. The PFAS plume from the Academy had Total PFAS concentrations ranging from 167,510 ng/l to 921 ng/l. The groundwater flow time from the Academy to the downgradient Mary Dunn Wells is three years.

Mary Dunn Wells 2 and 3 under direct influence of the Academy plume, and the Airport Well, detected the highest levels of Total PFAS in all wells sampled at 733 ng/l, 274 ng/l and 854 ng/l, respectively. The BCFTA plume of PFAS that is flowing to the wells presently has PFAS concentrations in the 1,000s of ng/l. Groundwater models show that ground water flows past the Mary Dunn Wells to the downgradient Maher Wells and Mill Creek.

The Maher Wells have PFAS6 concentrations ranging from 130 ng/l to 213 ng/l. The Municipal Airport, is an identified point source of PFAS that is directly upgradient to the Maher Wells. Maximum Total PFAS concentrations in groundwater at the Airport is 15,583 ng/l. The composition of PFAS in the Maher well ME-1 that is closest to the Airport has the highest percent of the Per Fluoro Carboxylic Acids (PFCAs) and FTS that are associated with the Airport AFFF source. The WSD-Airport Well has the second highest concentrations of PFCAs and FTS of the WSD wells indicating it may also be impacted by both sources.

Results of this study indicates that primary PFAS sources that impacted downgradient wells were redistributed through the water system to septic systems and the Town's Water Pollution Control Facility (WPCF) as a secondary source of PFAS in groundwater that has impacted the

Hyannis area ponds and wells. Studies performed by the USGS and others, simulated groundwater flow and mapped particle paths from the WPCF under average discharge conditions. These paths show a treated effluent plume extending from the southwest to the east with primary flow to the southeast of WPCF which corresponds to data collected in Sole Source's study showing high concentrations of PFAS contamination in surface water and wells downstream of the WPCF and unsewered areas. Groundwater flow to the northeast of the WPCF is more diffuse, and the flow paths to wells and ponds to the northeast are longer and migration takes more time. PFAS6 concentrations less than 25 ng/l detected at BFD Wells and less than 30 ng/l in Ponds to the north of WPCF are considerably less than WSD wells and surface water to the south.

The chemical variation of PFAS detected at ponds and wells throughout Barnstable can be used to make distinctions about the sources of PFAS. For example, PFAS in impacted groundwater at the BCFTA consists of 67% PFOS associated with ECF-AFFF. PFOS is also present in groundwater at the Municipal Airport, but at relatively lower concentrations than the Perfluoroalkyl Carboxylic Acids (PFCAs) and Fluoro Telmer Sulfonates. Both sources have relatively high concentrations of the 6:2 FTS associated with Telomerization-AFFF.

PFAS detected in the remote Barnstable Ponds to the west is dominated by PFCAs and PFOA and generally have no PFOS or FTS. PFOA is used in numerous household products so groundwater impacted solely from septic systems would be expected to have higher PFOA and PFCAs concentrations than PFOS. Shubaels Pond in Marstons Mills with only high density septic systems in its watershed has a low total PFAS concentration of 4.99 ng/l (comprised of 50% of PFOA without any PFOS). The low PFAS concentration in Shubaels, and other remote Ponds, with only septic system sources supports the finding that the Hyannis Ponds with much higher PFAS detections that include PFOS and high PFCAs are impacted by primary and secondary AFFF sources.

Based on Sole Source's findings, ponds with high levels of PFAS concentrations also have high concentrations of PFAS in groundwater and therefore should be considered less favorable for the development of future well sites given the costs to treat PFAS contamination to non-detect levels. While the WSD is taking necessary steps to treat PFAS in drinking water to non-detect levels now, PFAS known as "forever compounds" will persist for decades in contaminated soils and groundwater challenging the selection of clean sites for future water supply. By taking account of the behavior of contamination plumes from multiple sources, several future well sites can be ruled out. For example, two of the most convenient potential future well sites located within Hyannis, thus requiring the shortest transmission mains, have a high degree of risk because of the presence of multiple PFAS sources. .

To gain a deeper understanding of the behavior of the WPCF plume and its redistribution of PFAS in Hyannis, testing should be performed to confirm levels entering, passing through, and exiting the WPCF facility. Since WSD now treats PFAS to non-detect levels, it stands to reason that if there is still PFAS entering WPCF, it is coming from unidentified or household sources.

The Distribution and Composition of PFAS in Select Water Supply Wells and Surface Waters of Barnstable, MA

Introduction

The Town of Barnstable DPW Water Supply Division (WSD) took preemptive action after the detection of PFAS in its supply wells between 2013 and 2020 in a changing setting of more stringent regulatory requirements. Treatment by activated carbon filters is now installed at the Mary Dunn Wellfield (2015-2016) and the Airport Well (2020), and the Hyannis Port Wellfield from the Straightway, Simmons Pond and Hyannisport Wells (2020). Construction of a treatment facility at the Maher Wells is complete (2020). Performance testing indicates that there are no is PFAS compounds in the Hyannis public water supply.

The Town of Barnstable DPW Water Supply Division is now working to secure adequate drinking water supplies for Hyannis' future needs. This includes a significant Water Supply Exploration Test Well program at seven sites on government-owned land being conducted by the Weston and Sampson engineering firm. The Test program included the installation of test wells and pumping tests with samples taken for a suite of water quality parameters including PFAS. The Hyannis Water Division is reviewing the results to select the most suitable sites for additional future wells.

To avoid costly water treatment, WSD is evaluating the presence of PFAS in the groundwaters of the Town to better characterize its extent and potential sources. To supplement the known PFAS data-base beyond those tests in the public water supplies, the WSD requested that Sole Source Consulting sample a selection of ponds to characterize the distribution of PFAS in the surface waters and, by extension, the groundwaters of the Town of Barnstable. This report provides the background and results of the study to characterize the distribution of PFAS in the Town's waters to assist the Town in selecting the most suitable future well sites.

What Are PFAS?

Poly and Per Fluorinated Alkyl Substances (PFAS)

Per- and poly fluoroalkyl substances (together, PFASs) are a class of man-made chemicals. They are not found naturally in the environment. Perfluoroalkyl sulfonic acid (PFOS) and Perfluorooctanoic acid (PFOA) have been the most extensively produced and studied of the PFASs chemicals. Both chemicals are very persistent in the environment and in the human

body. Due to their persistence, PFASs can travel long distances through the environment and are referred to as "forever compounds." https://www.mass.gov/info-details/per-and-polyfluoroalkyl-substances-pfas

PFASs have been used in the manufacture of products that:

- keep food from sticking to cookware,
- make upholstered furniture, carpets and clothing resistant to soil, stains and water,
- make shoes, clothes and mattresses more waterproof,
- keep food packaging from sticking to food, and
- help fight fires at airfields and other places where petroleum-product-based fires are a risk.

In the mid-1960s, the 3M Company developed aqueous film-forming foam (AFFF) for the United States Navy. It became a standard tool in the arsenal of firefighting for airport and automobile crashes and smothering spilled hydrocarbons to prevent likely flames. Training in the use of AFFF became a required training experience for firefighting safety officials

The use of AFFF in firefighting training activities occurred at the Barnstable County Fire Training Academy (BCFTA) for an extended period from 1960's to 2015. Regular training events with AFFF also occurred at the Barnstable Municipal Airport every three years because the Federal Aviation Administration requires that airport fire operations have regular training in the use of foam. (Part 139 Airport Certification Status List.)

Two major processes have been used to manufacture PFAS for AFFF formulations: electrochemical fluorination (ECF) and telomerization. ECF-AFFF typically contains high concentrations of PFOS which ceased being produced in 2000's. Telomerization-AFFF which began to be used in 1980s is primarily comprised of PFCA precusors like the 6:2 FluoroTelomer Sulfonic Acids (FTS).

Since the discovery that PFAS are found in many of the Nation's water supplies, EPA and states have been developing updated guidance, health advisories and maximum contaminant limits for their presence in drinking water.

The Massachusetts Department of Environmental Protection (DEP) recently adopted a PFAS Maximum Contaminant Limits (MCLs) for drinking water, and hazardous waste site cleanup standards for PFAS (DEP 2020-Fact Sheet). There are numerous PFAS compounds that are difficult to comprehend and typically referred to in studies by their acronyms, as listed in the Tables below. The "Sum of Six" PFAS compounds (PFOS, PFOA, PFHxS, PFHpA, PFDA and PFNA) are referred to as PFAS6. The MA-DEP Drinking Water Standard for any single compound of the PFAS6 or the sum of the PFAS6 is 20 ng/l (parts per trillion). DEP also advises that any detection of 10 ng/l and over requires an investigatory response by the water supplier.

Table 1 Sum of Six PFAS (PFAS6) compounds

Perfluoroheptanoic Acid	(PFHpA)
Perfluorohexanesulfonic Acid	(PFHxS)
Perfluorooctanoic Acid	(PFOA)
Perfluorononanoic Acid	(PFNA)
Perfluorooctanesulfonic Acid	(PFOS)
Perfluorodecanoic Acid	(PFDA)

PFAS in Groundwater from Identified Sources

PFAS was first detected in Cape Cod Supply wells in 2009 as part of a survey of emerging compounds of concern by Silent Spring Institute (Schaider, et al, 2010). At the time, the detections were below the Health Advisory (HA) of 200 ng/l (parts per trillion) with the highest concentration at the Maher wells at 130 ng/l. Early testing for PFAS was conducted at academic institutions because the popular knowledge about PFAS was not widespread and the equipment and expertise at commercial laboratories were not available at the time. In 2013 the EPA instituted the Unregulated Compound Monitoring Rule for water suppliers to test their wells for a suite of compounds, including PFAS, which brought commercial labs' testing ability up to par. UCMR-3 tests from November of 2013 detected PFAS in the Mary Dunn Wells and groundwater samples at the Barnstable County Fire Training Academy just 1,500 ft upgradient from the wellfield detected concentrations into the 100,000s of ng/l. In 2017 mapping of PFAS in groundwater identified high PFOS concentrations in a plume from the BFTA (Figure 1) and sampling in 2020 indicates concentrations still in the 10,000s ng/l. Both EFC-AFFF and Telomerization-AFFF PFAS compounds are detected in the BFTA plume core include PFOS at 66%, PFHxS at 11%, 6:2 FluoroTelomer at 9%, PFHxA at 3%, 8:2 Telomer at 2.5%, PFPeA and PFOA at 1.5% and 10 additional compounds below 1 %.

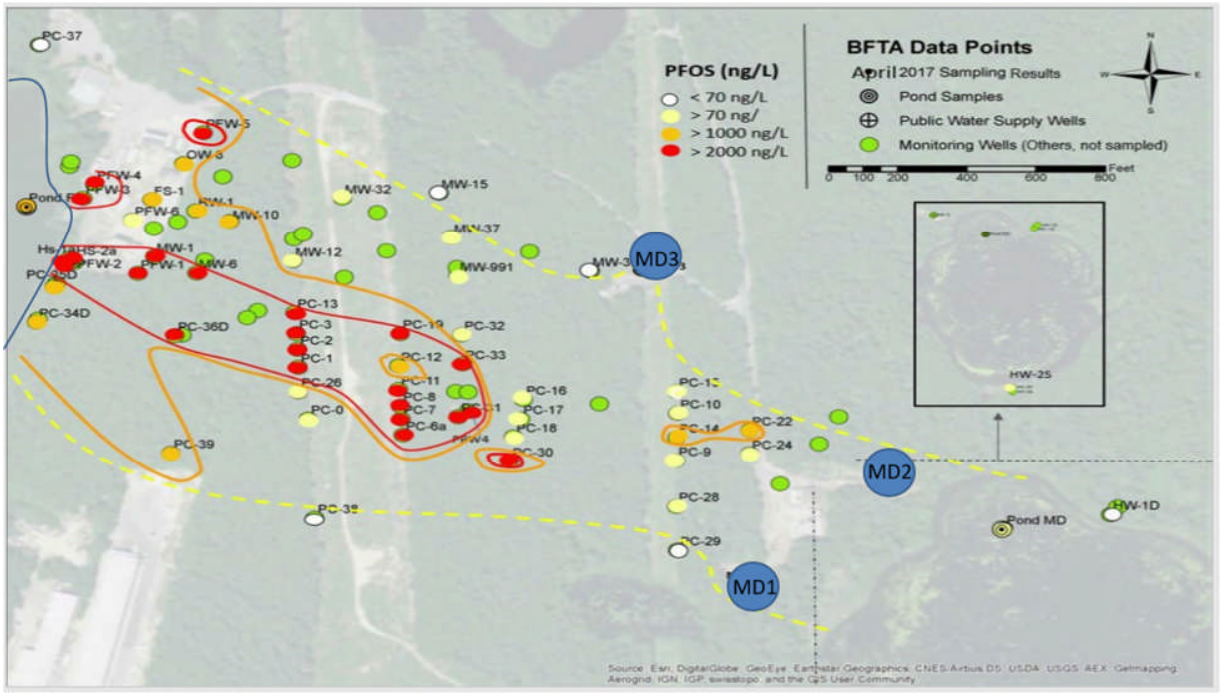


Figure 1 PFOS in Groundwater as a Contaminant Plume from the BCFTA

Significant work was conducted to evaluate the extent and composition of PFAS contamination in groundwater during 2014 and in 2015 treatment was installed at the Mary Dunn 1 and 2 wells and an interim pump and treat was installed at the BCFTA. In response to community input, the County shutdown the BCFTA to prevent further significant leaching of PFAS from soil due to training water in late 2019.

When EPA lowered the Health Advisory of PFOS and PFOA to 70 ng/l in 2016, the Town installed treatment on the Mary Dunn 3 Well. The concentration of PFOS, a primary component of PFAS, in the Mary Dunn Wells was as high as 1,600 ng/l in 2013, but presently averages approximately 500 to 250 ng/l (Cambareri, 2015). The lowering of the HA to 70 ng/l also meant that the Maher Wells were above the limit and shut off until a treatment system could be provided through a $12 million Town Council appropriation.

The DEP also issued orders to the Municipal Airport to conduct investigations of PFAS in soil and groundwater. The investigations detected PFAS concentrations at former airport training areas in the 1,000's of ng/l (Figure 2).

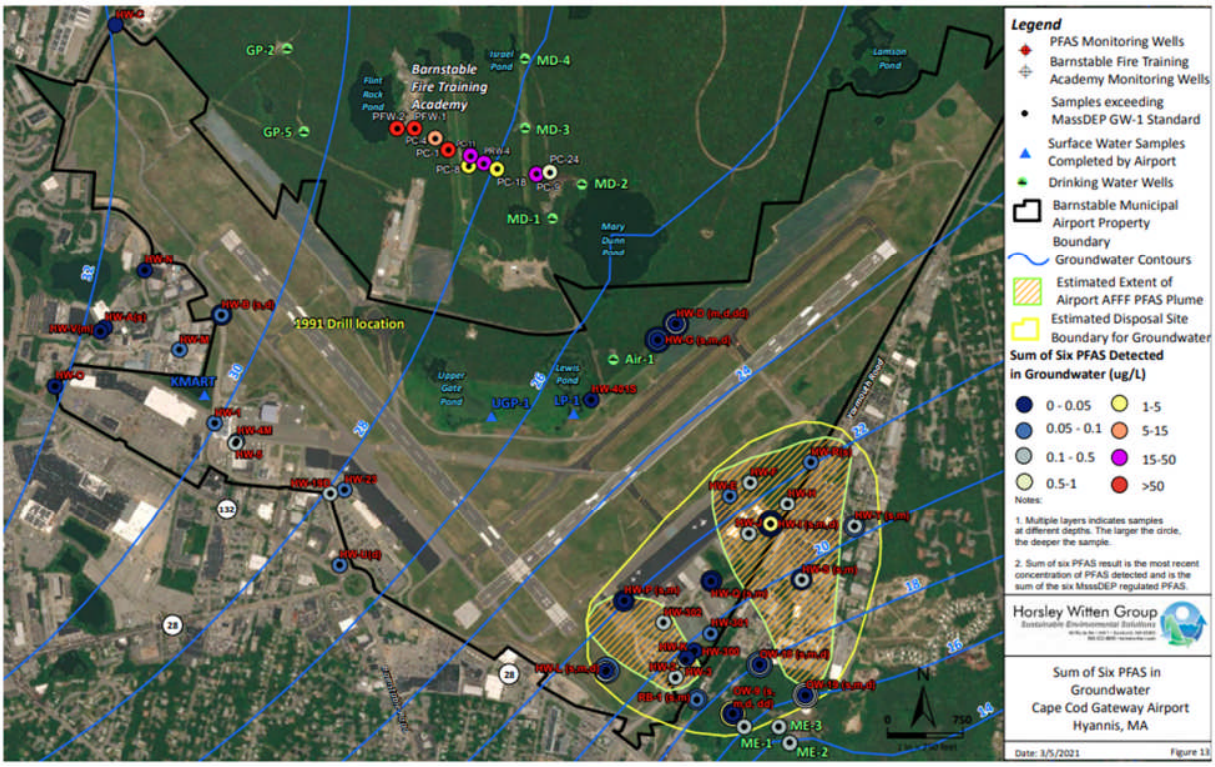


Figure 2 PFAS Detections at the Municipal Airport

The investigation into the hydrology of the Hyannis area indicates that both the Airport (Horsley-Witten 2019, 2021) and the BCFTA (Cambareri 2015) are upgradient sources of PFAS to the Maher Wells. The use of AFFF at the BCFTA and Airport likely began in the 1960s, but there are no historical records. The last documented use of AFFF at the BCFTA was October 2015, where residual foam discovered at the site had PFOS at 32,000 ng/l. Uncontrolled training with AFFF at the Airport also ceased after 2015. The Airport Assessment indicates that since 2000, the Telomerization-AFFF primarily used at the Airport was Chem-Guard 3% mil spec foam that contains polyfluorinated precursors or C6 foam that is known to degrade to 6:2 FTS and other PFCAs like PFHxA, PFPeA, , but not PFOS (Avendaño 2013) (ITRC https://pfas-1.itrcweb.org/3-firefighting-foams/#3). Activities earlier than 2000 or involving other local Fire Departments at the Airport may have included AFFF with PFOS. The Maher Well ME-1 which is closest to the Airport has a detection of 6:2 FTS of 70 ng/l. The fundamental understanding is that PFAS emanated from these two primary point sources in Hyannis and, as a result, the downgradient Mary Dunn and Maher water supply wells became contaminated. The Airport's consultants assert that the PFAS plumes comprised of the 6:2 FTS has not yet migrated to the Maher Wells (Horsley-Witten, 2021).

Groundwater Modeling

Once contaminants enter the groundwater, they migrate with groundwater flow. Groundwater models are used to simulate groundwater conditions and groundwater flow. The USGS 2004 Groundwater Model of the Sagamore Lens was used for a preliminary analysis of particle paths

and the interaction of identified Airport and BFTA sources with the Mary Dunn and Maher Wells. This particular model has been used for a number of applications in Barnstable and is well described in the 2009 BFD #5 New Source Approval report and the 2010 Draft Barnstable Town-Wide Zone II analysis. The watertable contours reflect the 2008 to 2010 average annual pumping of the Barnstable wells. This is considered a pre-PFAS response condition.

The model was used to simulate groundwater flow and track particle paths from the BCFTA and identified Municipal Airport sources (Figure 3a & b). The particle paths show that groundwater flows from the BFTA to the Mary Dunn Wells and then further to the Maher Wells and Mill Creek. Figure 3b shows the particle paths from the identified Municipal Airport sites to the Maher Wells and Mill Creek. Estimates can be made about the time of travel for a contaminate to migrate from a source to a receptor with the model. The BCFTA is only 3-years travel time from the Mary Dunn Wells and approximately 21 years travel time from the Maher Wells (Sole Source Consulting, 2020). The Airport Well was not used until recently. When it started pumping its PFAS concentrations increased significantly by likely drawing in asouthern lobe of the BFTA contamination that has not been assessed or an unidentified source from the Airport. The Municipal Airport identified Telomerization-AFFF-PFAS sources at the Deployment Area and the Fire Rescue Station have a 5 and 3 year groundwater travel time, respectively, from the Maher Wells.

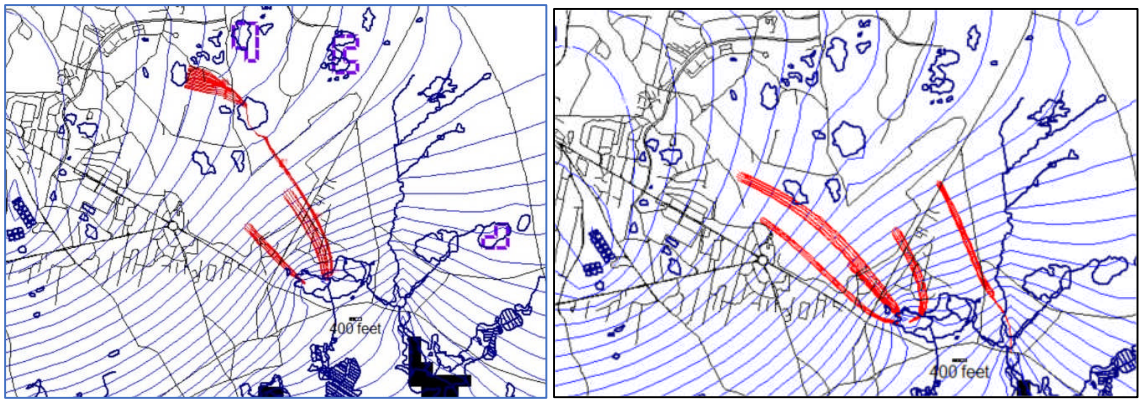


Figure 3 Groundwater Modeling Particle Tracks from: a) BFTA to Mary Dunn Wells, and b) Multiple Airport PFAS source areas to the Maher Wells

Consequences of PFAS Contamination in the Hyannis Area

The BCFTA and Municipal Airport are primary sources of PFAS that have impacted groundwater in the Mary Dunn and Maher wellhead protection areas. PFAS concentrations in groundwater from these sources presently range up into the 10,000 ng/l level. But PFAS is also ubiquitous in residential and commercial products including food product packaging, clothing, and stain guards to name just a few. Research of groundwater downgradient of dense residential areas served by septic systems in other areas, without primary AFFF sources, has detected PFAS in

private wells from normal household use (Schaider, 2008, Ruyle, 2021). PFAS in groundwater impacted by septic sources has been detected at concentrations of 2 to 25 ng/l; significantly lower concentrations than what is detected at the BCFTA and Municipal Airport. Nevertheless, septic systems are important sources of PFAS to consider.

Prior to the general knowledge of PFAS in the environment with the EPA Unregulated contaminant Monitoring Rule UCMR testing of 2013, PFAS contaminated well water was transported by the water system to the Hyannis service area. In some areas PFAS laden water would be redistributed through septic systems to groundwater. In sewered commercial and residential areas PFAS laden wastewater would have been collected and redistributed to the Water Pollution Control Facility (WPCF) at Bearses Way for treatment and disposal where it discharges to groundwater.

The redistribution of primary PFAS sources in Hyannis resulted in widespread secondary groundwater contamination in the Hyannis area aquifer. This had major consequences when the EPA and DEP revised the Health Advisory for PFAS compounds down to 20 ng/l in 2018. The Hyannis Port Wellfield, comprised of the Straightway, Simmons Pond and Hyannisport wells, is downgradient from the WPCF and high density residential and commercial areas that are largely unsewered. PFAS detected at the Hyannis Port Wellfield was at 2 to 3 times higher than the new health advisory of 20 ng/l. The Town preemptively moved to install treatment by Summer 2020 to meet peak seasonal demands.

Water Supply Exploration

During the Spring and Summer of 2020, the Water Supply Division received preliminary results of its test well drilling effort (Weston and Sampson, 2020). Seven sites in the Town were evaluated for water production and water quality. Due the impact of the presence of PFAS compounds on the existing supplies, the WSD is prioritizing water supply site selection to areas with a low probability of contamination. While there is significant site data at the Airport, BCFTA and Hyannis supply wells, there is a dearth of information about the potential for PFAS contamination at other areas. Kettlehole ponds on Cape Cod are windows on the aquifer because they are connected to the groundwater. Subsequent to an initial sampling of six ponds on May 25, 2020, the WSD in conjunction with Sole Source Consulting concluded that testing of surface water bodies in the Town provided an opportunity for an efficient survey of PFAS in groundwaters. Fresh water ponds of the Cape are connected to the aquifer and receive groundwater on its upgradient side and discharges water on its downgradient side. The ponds are used by hydrologists including the USGS for evaluating the groundwater system of the aquifer (Weber, 2017). In 2008 Silent Spring reported on their research of emerging Compounds of Concern in freshwater ponds. The ponds with dense residential development in the upgradient watershed had higher concentrations of Emerging Compounds than ponds with little development in their upgradient watershed (Schaider, 2008).

Methodology

Over the course of three days in July 2020, Sole Source Consulting sampled 15 surface water bodies in the Town for a total of 21 surface waters, including the 6 samples collected in May (Figure 4). The samples were obtained by kayak in the middle of the ponds to ensure a representative sample from the water column to limit influences from either upgradient discharges or potential local sources. Where a kayak was not feasible a shore sample was collected at Spruce and St Francis Ponds and Hyannis Creek and Mills River. The samples were kept on ice and refrigerated and delivered to Alpha Analytical Laboratory in Mansfield, MA. Trip blanks or water samples carried during the course of sampling were collected for each sampling day to test for the potential of contamination from miscellaneous sources or sampling errors.

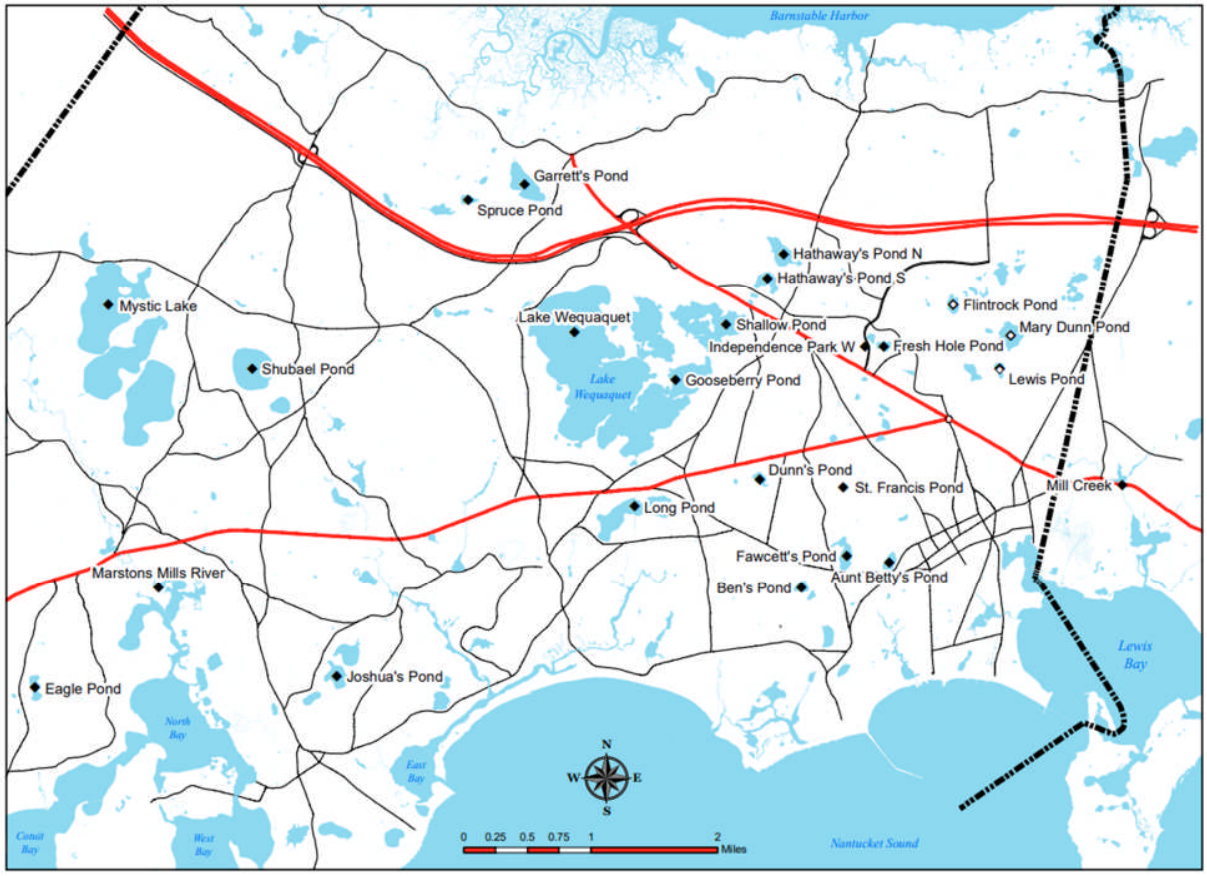


Figure 4 Ponds sampled for PFAS in July 2020 (PFAS results from others have open markers)

Water supply testing for PFAS typically uses a straight EPA Method 537 that reports the detection of six regulatory PFAS compounds (PFAS6). The samples collected for the pond study were analyzed by Alpha Analytical using the A2-537 isotope method that detects 24 PFAS compounds to gather a broader survey of possible PFAS compounds present (Table 2). This method was also used in an earlier sampling event in October 2019 for most of the Hyannis Water Supply Wells. The Reporting Limit for the analytical method for each component is approximately 2 ng/l, depending on the sample.

The project method resulted in PFAS results from 21 surface water bodies and 10 Hyannis WSD wells. Those results are supplemented with information from the BCFTA and Airport site investigations, the Barnstable Fire District Well testing and other researchers.

Findings: Surface Waters

PFAS Detections

The results of the sampling fo ponds for PFAS are presented in tables, maps, bar graphs and chemical composition Radar Plots found in the Appendix. Of the 24 compounds analyzed, 11 PFAS compounds were detected (Table 2). A PFAS compound was detected in every pond. Out of the 21 sampled ponds PFOA was detected 18 times with an average and maximum concentration of 9.8 ng/l and 28.80 ng/l, respectively, followed by PFHxA at 17 times and PFHpA at 15 times. These are variations of the perfluoronated carboxylic acid (PFCA) compounds with 8, 6 and 7 carbon chains respectively. PFOS, a sulfonic acid variety of PFAS and the prime component of ECF-AFFF, was detected in 14 ponds with the highest <u>average</u> concentration of 23.8 ng/l and a maximum concentration of 75 ng/l. PFBA had the highest detected concentration (a 4-carbon chain perfluoronated-carboxyl acid) at 82.4 ng/l was detected in 12 Ponds. PFBA is not one of the six regulated compounds because it is thought to be less toxic. It was detected in a similar study of Minnesota's waters in 100% of their sample pool. PFBA has been characterized as a non-AFFF source (Ruyle, 2021). Radar Plots comparing the composition of PFAS compounds in ponds and wells are included in the Technical Appendix..

The regulated 10 and 9 carbon chain PFAS Perfluorodecanoic Acid and Perfluorononanoic Acid with detections of 24% and 14% respectively, were less prevalent than the lower carbon 5-chain Perfluoropentanoic and the 6-chain Perfluorohexanoic (PFHxA) and Perfluorohexanesulfonic Acids (PFHxS) and the 4- carbon chain butanes Perfluorobutanoic Acid (PFBA) and Perfluorobutanesulfonic Acid (PFSA).

The A2-537 isotope method regularly detected 5 PFAS compounds (PFHxA, PFHPeA, PFBA, PFBS, and PFPeS) in addition to the PFAS6, in Pond water. Thirteen PFAS compounds were not detected in ponds including the Telefluoromers or precursors like the 6:2 FTS which is found in groundwater at the BCFTA and Airport and several of the more impacted wells.

Table 2 Summary Statistics of PFAS Detections in Ponds (PFAS6 in Yellow)

PFAS Compounds in Ponds	# of Detects	% of Detects	Max ng/l	Ave ng/l	Median ng/l	Carbon Chain
Perfluorooctanoic Acid (PFOA)	18.00	86%	28.80	9.79	4.80	8
Perfluorohexanoic Acid (PFHxA)	17.00	81%	33.40	12.39	7.07	6
Perfluoropentanoic Acid (PFPeA)	15.00	71%	36.60	14.07	9.51	5
Perfluorooctanesulfonic Acid (PFOS)	14.00	67%	75.00	23.82	10.85	8
Perfluorobutanoic Acid (PFBA)	12.00	57%	82.40	15.56	8.52	4
Perfluorobutanesulfonic Acid (PFBS)	12.00	57%	23.10	7.81	6.57	4
Perfluoroheptanoic Acid (PFHpA)	12.00	57%	13.80	6.40	4.05	7
Perfluorohexanesulfonic Acid (PFHxS)	12.00	57%	33.40	14.23	11.24	6
Perfluorononanoic Acid (PFNA)	5.00	24%	7.46	5.88	6.81	9
Perfluorodecanoic Acid (PFDA)	3.00	14%	2.87	2.21	1.88	10
Perfluoropentanesulfonic Acid (PFPeS)	2.00	10%	3.00	2.92	2.92	5
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	1.00	0%	2.82	2.82	2.82	8
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	0.00	0%	na	na	na	6
Perfluoroheptanesulfonic Acid (PFHpS)	0.00	0%	na	na	na	7
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	0.00	0%	na	na	na	10
Perfluorononanesulfonic Acid (PFNS)	0.00	0%	na	na	na	9
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	0.00	0%	na	na	na	8
Perfluoroundecanoic Acid (PFUnA)	0.00	0%	na	na	na	11
Perfluorodecanesulfonic Acid (PFDS)	0.00	0%	na	na	na	10
Perfluorooctanesulfonamide (FOSA)	0.00	0%	na	na	na	8
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	0.00	0%	na	na	na	8
Perfluorododecanoic Acid (PFDoA)	0.00	0%	na	na	na	12
Perfluorotridecanoic Acid (PFTrDA)	0.00	0%	na	na	na	13
Perfluorotetradecanoic Acid (PFTA)	0.00	0%	na	na	na	14
PFAS6 Regulated in Yellow						

PFAS in Surface Waters

PFAS detections in sampled surface water is shown on Table 3 and is grouped by Tier from high to low Total PFAS concentration in ng/l. Also shown are the PFAS6, PFOS, and PFOA concentrations,their respective percent of Total PFAS and the sum of PerFluoroCarboxylic Acids (PFCA) and PerFluoroSulfonic Acids (PFSA). PFAS results at several other Ponds from other investigations are also included separately.

The highest Total PFAS concentrations are nearly equivalent to the highest PFAS6 regulated compounds including PFOS and PFOA, but not always. Dunns Pond and Spruce Pond have high Total PFAS concentrations because of the high concentration of PFBS and other non-regulated compounds (Table3).

Table 3 Summary PFAS Detected in Ponds Arranged High to Low by Tier and Total PFAS (ng/l).

PONDS	PFOS	PFOA	SUM of 6	Total PFAS	% PFOS	% PFOA	PFCAs	PFSAs
Tier 1								
HYANNIS CREEK	75.0	28.8	159.3	252.4	30%	11%	128.98	123.44
AUNT BETTYS POND	56.8	28.6	141.4	237.9	24%	12%	131.38	106.50
FAWCETS POND	63.2	23.6	132.2	217.8	29%	11%	120.68	97.09
DUNNS POND	10.1	7.8	44.4	177.1	6%	4%	117.35	59.70
ST FRANCIS POND	51.6	23.0	104.6	167.9	31%	14%	91.39	76.55
BENS POND	29.2	18.5	71.4	138.0	21%	13%	81.34	56.70
Average	**47.7**	**21.7**	**108.9**	**198.5**	**23%**	**11%**	**111.9**	**86.7**
Tier 2								
SHALLOW POND	11.6	5.4	30.0	50.9	23%	11%	29.30	21.60
FRESH HOLE POND	3.4	5.1	14.8	44.1	8%	12%	35.51	8.63
INDY PARK WEST	5.2	5.0	17.0	43.2	12%	11%	31.10	12.06
LONG POND CVILLE	5.2	4.6	14.3	24.5	21%	19%	14.93	9.58
HATHAWAYS POND	2.2	4.2	14.4	21.9	10%	19%	16.03	5.86
GOOSEBERRY POND	2.9	4.0	11.1	19.8	15%	20%	12.88	6.95
WEQUAQUET	3.3	3.5	6.8	13.3	25%	26%	9.93	3.34
LITTLE HATHAWAYS	ND	ND	ND	2.8	0%	0%	2.81	0.00
Average	**4.8**	**4.5**	**15.5**	**27.6**	**14%**	**15%**	**19.1**	**8.5**
Tier 3								
SPRUCE POND	ND	ND	ND	29.2	0%	0%	29.20	0.00
JOSHUA POND	ND	3.3	6.9	23.7	0%	14%	23.67	0.00
MYSTIC LAKE	13.9	ND	13.9	13.9	100%	0%	0.00	13.90
EAGLE POND	ND	3.5	3.5	11.5	0%	31%	9.58	1.92
SHUBAELS POND	ND	2.7	2.7	4.9	0%	56%	4.87	0.00
M MILLS RIVER	ND	2.2	2.2	4.2	0%	52%	4.23	0.00
GARRETS POND	ND	2.5	2.5	2.5	0%	100%	2.51	0.00
Average	**13.9**	**2.9**	**5.3**	**12.8**	**14%**	**36%**	**10.6**	**2.3**

By Others	PFOS	PFOA	PFAS-6	% PFOS	% PFOA
FLINTROCK	2700 to 266	160 to 24	6850 to 414	39%	2%
MARY DUNN POND	150 to 82	12 to 11	224 to 188	67%	5%
MILL CREEK	45	13	104	43%	13%
LEWIS POND	12	4.6	40.5	30%	11%

The Tier 1 Group has the highest Total PFAS concentrations due to the redistribution of PFAS through the WPCF and septic systems. The highest Total PFAS surface water concentration of 252 ng/l is found in Hyannis Creek which flows into Aunt Bettys Pond (Figure 5). The creek is a perennial groundwater-fed creek that is downgradient from the WPCF in its mapped and projected effluent plume within an area of unsewered development. The Total PFAS and PFOS concentrations in St Francis, Aunt Bettys, Fawcetts, Dunns and Bens Pond and creek average of 200ng/l and 48 ng/l respectively and range from 252 ng/l to 138 ng/l and 75 ng/l to 29 ng/l respectively. The percent of PFOS in the Hyannis area surface waters is generally high ranging from 31 to 21%. PFOS is a prime constituent of ECF-AFFF, indicating these high percentages are linked to the primary sites and the redistribution PFAS through the WPCF and septic systems. The only two occurrences in surface waters of the Telomerization-AFFF derived 6:2

FTS are in Hyannis Creek at 2.86 ng/l and Mill Creek, on the Yarmouth Line at 30.02 ng/l (see discussion on streams below). The percentage of PFOA in the Hyannis Area Ponds, ranges from 11 to 14% and averages 12% lower than PFOS. PFOA is prevalent in numerous residential and commercial products.

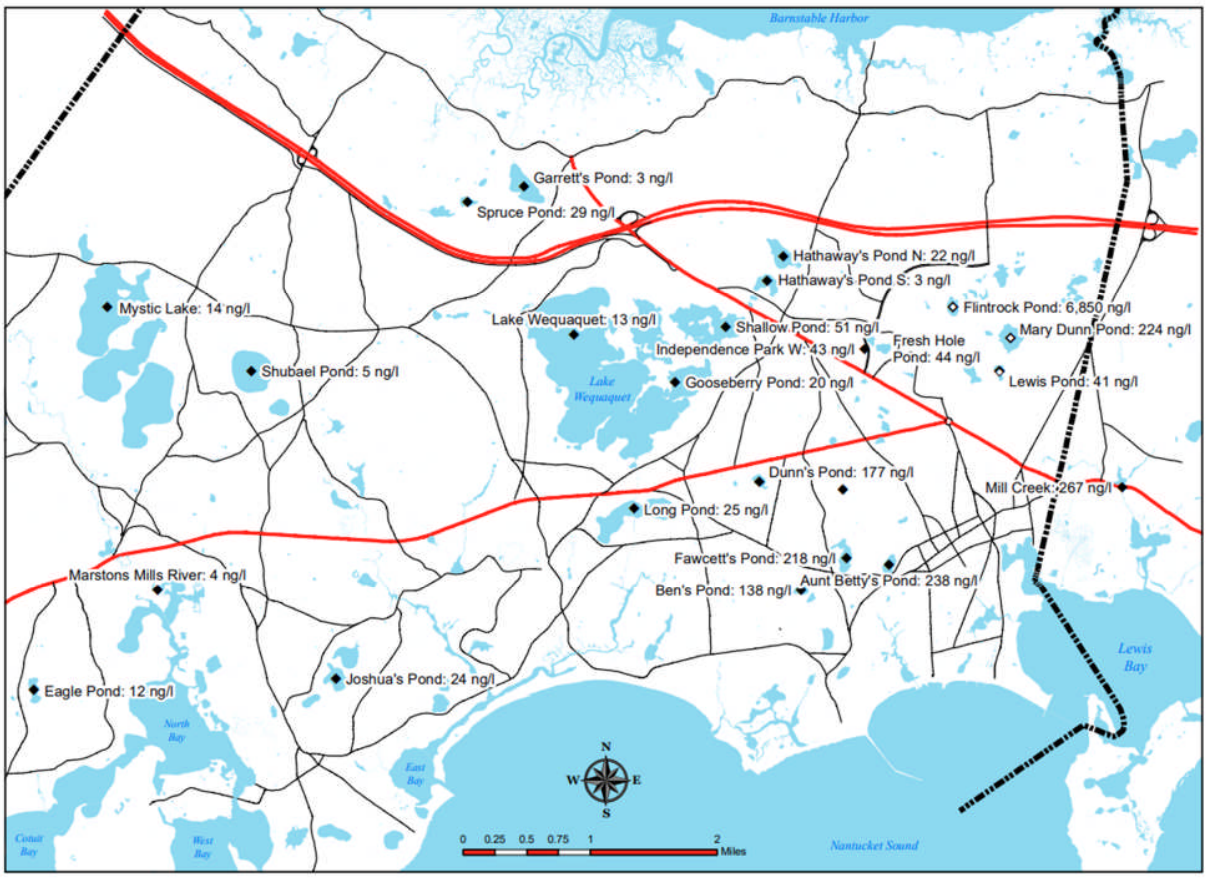


Figure 5 Map of the Total PFAS compounds in Barnstable Surface Waters (open symbols denote data from others)

The Second Tier of Ponds are located to the northwest and northeast of the WPCF. Theyhave Total PFAS concentrations ranging from 50.9 to 2.8 ng/l. Th Total PFAS average concentration of 27.5 ng/l is lower than the Hyannis pond group with an average Total PFAS of 198.5 ng/l. The average PFOS in these ponds of 4.8 ng/l is an order of magnitude less than the Tier 1Hyannis area ponds of 47.7 ng/l. Little Hathaways is an outlier with no PFOS detected and the lowest Total PFAS. Hathaways Pond in comparison has a Total PFAS of 29.2 and nominal PFOS of 2.2 ng/l. Hathaway Pond has a much greater depth and volume than Little Hathaways indicating it has a greater groundwater input resulting in high PFAS concentrations.

Shallow Pond has the highest PFAS concentrations at 30 ng/l Total PFAS and 12 ng/l PFOS. The other Tier 2 Ponds are appreciably lower that Shallow Pond. Shallow Pond is closest to the WPCF with dense development along its northern shore served by the WSD. the percent of

PFOA in the lower overall detections at Lake Wequaquet, Gooseberry Pond , Hathaways Pond and Long pond ranges from 19% and 26% which is distinctly higher than the Hyannis area ponds indicating a greater contribution of septic sources. Long Pond receives direct flow from the Wequaquet Pond system and is surrounded by septic system sources with residential water service from COMM which is not considered to to be impacted by primary AFFF sources.

Dunns Pond is an outlier in the Hyannis area. Although it has the fourth highest Total PFAS concentration, its percent of PFOS and PFOA is only 6 and 4% respectively. The concentration of PFBA is 82.4 ng/l which is 47% of the Total PFAS (Figure 7, Table 5). Dunns Pond is located laterally from the WPCF downgradient area and due to its shallow depth may not capture the effluent. PFBA is associated with a variety of products including floor cleaners and other products that may be from the upgradient Senior Center and residential septics.

Fresh Hole and Indy Pond West have Total PFAS of 43.1 and 44.2 ng/l and and PFOS of 3.4 and 5.2 ng/l respectively. These concentrations are similar to Shallow Pond which is in proximity to the WPFC and with upgradient development served by the WSD and the more downgradient BFD Wells.

The Tier 3 Ponds are remote to the Hyannis area with an average Total PFAS of 12.8 ng/l. There is generally no detection of PFOS in these Tier 3 remote ponds. (Table 3 and Figure 6). Shubaels Pond with high density residential development in its watershed has a Total PFAS concentration of only 4.87 ng/l which is exclusively PFCAs with PFOA at 2.7 ng/l. The low PFAS concentration in Shubaels with only septic system sources supports the finding that the Hyannis Ponds with much higher PFAS detections that include PFOS and high PFCAs are impacted by primary and secondary AFFF sources. PFOA is the dominant compound of the PFAS detections in these Tier 1 ponds ranging from 14 to 100%. While it may be temping to consider these "background," groundwater samples taken elsewhere on Cape have had no detections of PFAS (Schaider, 2015), so true "background" is likely zero

The detection of PFOS in Mystic Lake at 13.9 ng/l is an exception to this group (Figure 7). The PFOS detection may indicate a legacy source at the Municipal Airfield on Route 149 which is immediately upgradient in the Mystic Lake watershed. Spruce Pond with sparse development and an electric right of way in its assumed watershed, has neither PFOS or PFOA and its PFAS concentration of 29.2 ng/l is totally PFBA (Figure 6 and 7).

An average Total PFAS concentration of nearly 200 ng/l defines highly contaminated Tier 1 Ponds in the Hyannis Area. The Tier 2 Ponds on the outskirts of Hyannis to the northwest and northeast of the WPFC have Total PFAS concnetrations of 28 ng/l. Tier 3 ponds remote to Hyannis have an average Total PFAS concentration of 13 ng/l. Average PFAS6 concentrations for the Tier 1, 2, and 3 Ponds is 109 ng/l, 16 ng/l and 5 ng/l respectively. There is a relation between a pond's PFAS concentration and the distance from the WPCF (Figure 8). An average T-PFAS background concentration of 5 ng/l identifies ponds with on-site septic sources sources of PFAS in their watershed. Ponds with an average PFAS6 above 10 are likely to have sources

associated with the primary PFAS point sources of the BFTA and Airport and the redistributed secondary sources.

Streams and Other Ponds

Two surface water creeks/rivers were also sampled because they are fed by groundwater along their linear distance. Brigg, et al., 2017 found significant PFAS in the Quashnet River in Mashpee from a variety of sources, including the Joint Base Cape Cod. The Hyannis Creek had the highest overall detection of Total PFAS at 256 ng/l. The Hyannis Creek is directly down gradient of the secondary source of the WPFC and high-density septic systems. Mill Creek in Yarmouth is downgradient of BCFTA, Airport and septic systems. Harvard investigators reported Total PFAS concentration of 243 ng/l in Mill Creek (Ruyle, 2021) (Figure 2). The percent of PFOS in Hyannis and Mill Creek is 30 to 43 %, whereas the percent of 6:2 FTS is 1% and 11 % 6:2 FTS respectively. Mill Creek is an outlier on the distance graph because it is impacted by primary sources (Figure 8). The higher percentages of PFOS and 6:2 FTS in Mill Creek are indicative of its downgradient location from the BCFTA and Airport. The Marstons Mill River in comparison had only 4.23 ng/l Total PFAS with no PFOS. The Mills River drains a significant rural watershed area and the three Indian Ponds. Flintrock Pond and Mary Dunn Pond are impacted by the BCFTA and are comprised of 39 to 67% of PFOS respectively as reported by others (Table 3 & Figure 5).

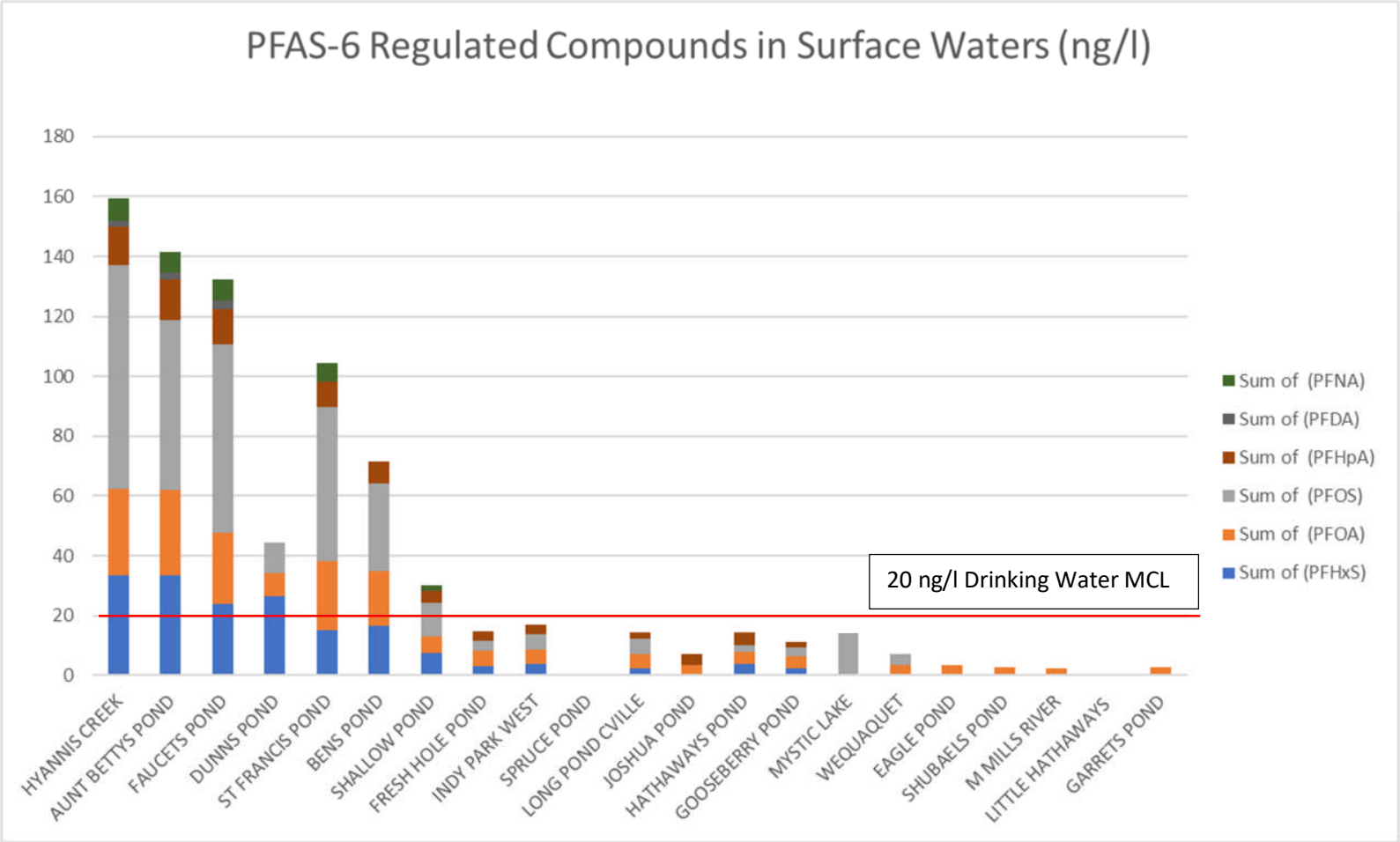


Figure 6 Bar Chart of the PFAS6 in Barnstable Surface Waters

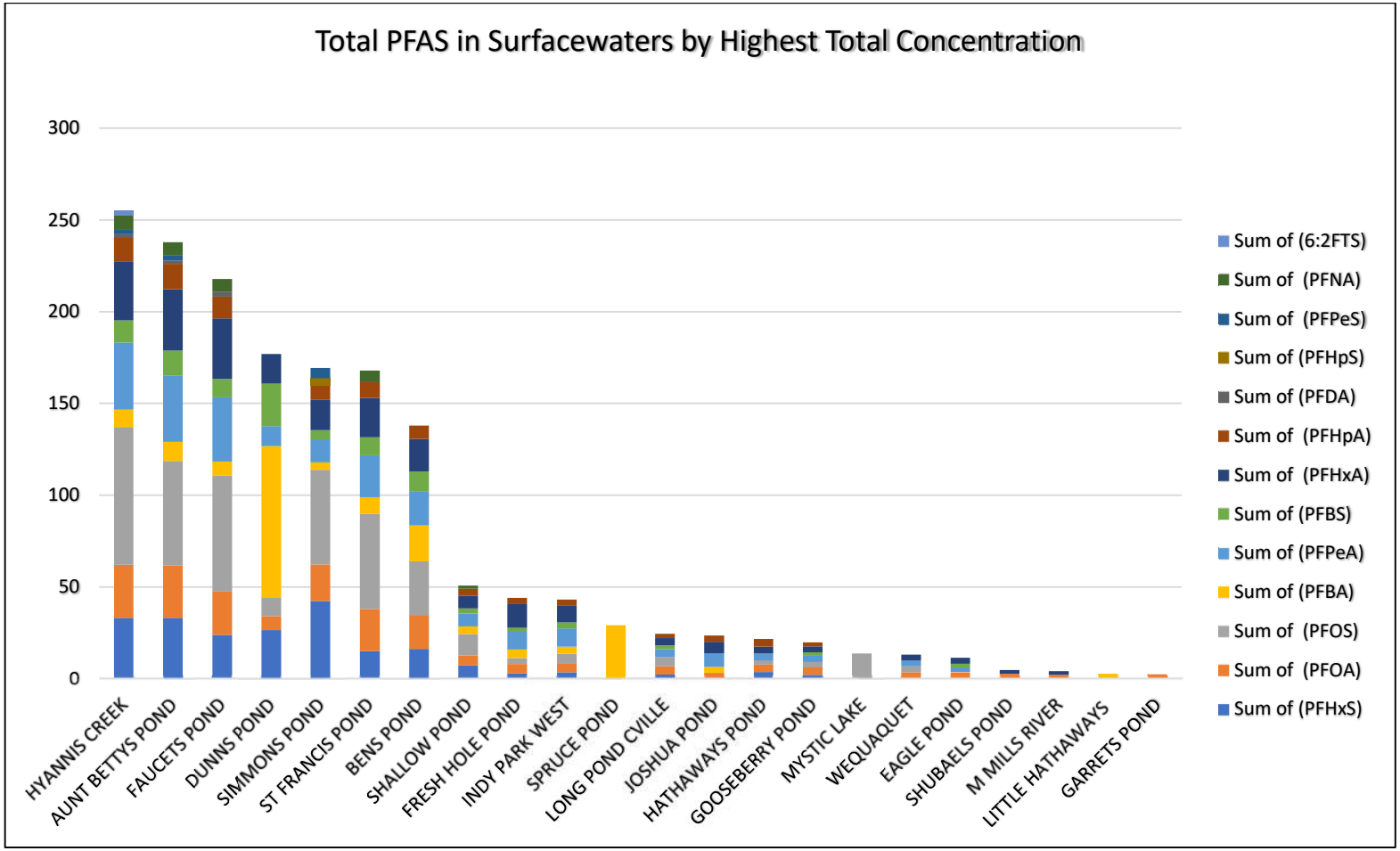


Figure 7 Bar Chart of Total PFAS compounds in Barnstable Surface Waters

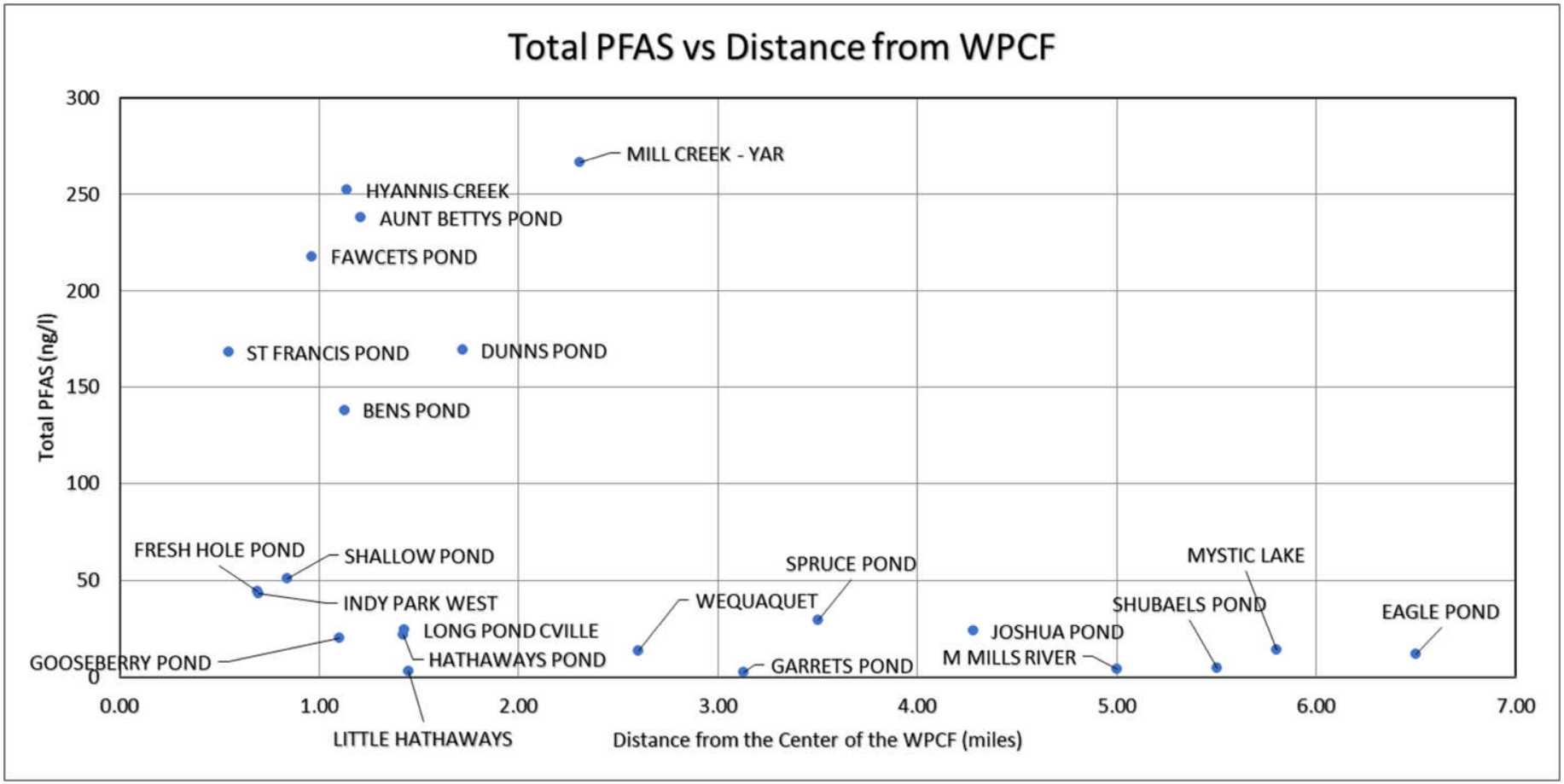


Figure 8 Total PFAS in Ponds vs Distance from the WPC

Health and Ecological Risks and Atmospheric Deposition

Six of the shallow ponds in the Hyannis area have PFAS detections that exceed the DEP PFAS6 Drinking water standard of 20 ng/l. Owing to their unhealthy ecological condition and shallow depth, they are not typically used for swimming and if so used, the intake or human dosage would be extremely low. The PFAS6 concentrations in the deeper ponds where swimming is expected all are below the 20 ng/l drinking water standard except for Shallow Pond at 30 ng/l. Risk assessments that take eating of fish regularly from PFAS contaminated Ponds into account have estimated severely low concentration threshold for PFOS of 0.05 ng/l which has a substantial bio-accumulation factor (Preimesberger, 2020). Other states have issued fish consumption warnings for PFAS contaminated surface waters similar to the case for methyl-mercury in Massachusetts.

Where drinking water is not a factor, there is a lack of information to establish detailed aquatic toxicological standards for PFAS in surface waters for various freshwater biota. Studies have found that PFAS compounds accumulate in fish tissue (Interstate Technology Regulatory Council, 2020). MA-DEP has Site Cleanup standards for groundwater that is not in drinking water areas but in an area that contributes only to surface water for ecological protection. Those standards are typically less stringent than Drinking water standards. The DEP Method 1 GW-3 Standards for groundwater that feed surfaces waters is 40,000 ug/l for 4 of the PFAS6 Compounds and 500 ug/l for PFOS and PFOA. Because 40% of the groundwater in the aquifer passes through ponds (USGS, 1998), a more stringent PFAS cleanup standard for surface water should be applicable on Cape Cod.

Research has found PFAS compounds in global precipitation (Wang, et al 2015). According to Martin Shafer of the National Atmospheric Deposition Program-National Trends Network, concentrations of the detectable PFAS species were low, generally less than 1 ng/L, though the sum of the quantified species exceeded 4 ng/L at many sites. The carboxylic acid species were by far the most frequently detected, with PFHxA, PFHpA, PFOA and PFNA each present in nearly 70% of all samples. Shorter-chain PFAS compounds dominated, with no PFAS compounds with carbon numbers greater than nine detected (Shafer, 2019). Sites from the mid-Atlantic states generally had the greatest number of detectable PFAS species and highest concentrations. Although these findings are similar to the trace level detections found in the remote Barnstable Ponds, site specific sources cannot be discounted, particularly when samples containing no PFAS in groundwater have been reported (Schaider, 2015).

Water Supply Wells

The summary statistics of PFAS results from the September 27, 2019 sampling of Hyannis Water Supply Wells using the same A2-537 Isotope method, is supplemented by November 5, 2020 sampling round for the Maher Wells (Table 4). PFAS were detected in every well sampled. Eight PFAS compounds of 24 were not detected. Four of the regulated compounds, PFOS, PFHxS, PFHpA and PFOA were detected at significant maximum concentrations above the PFAS6 20 ng/l. The average concentration of 3 of the PFAS; PFOS, PFHxS, and PFOA were above the PFAS6 of 20 ng/l.

Table 4. Summary PFAS Detected in Wells Arranged by Number of Detections

PFAS Compound	# of Detections	Max ng/l	Min ng/l	Ave Ng/l
(PFOS)	11	307.00	19.80	112.90
(PFPeA)	11	150.00	4.06	36.75
(PFHxS)	11	146.00	10.20	54.17
(PFHxA)	11	115.00	4.67	31.04
(PFHpA)	11	60.40	2.83	15.90
(PFBA)	11	50.70	2.01	11.65
(PFOA)	11	41.90	2.77	20.59
(PFPeS)	9	9.74	2.28	5.23
(PFBS)	9	7.17	1.86	4.51
(PFNA)	8	25.50	2.04	10.02
(PFHpS)	7	5.26	0	2.98
(6:2FTS)	5	70.00	0	31.44
(PFDA)	3	0	0	0
(FOSA)	2	27.20	13.20	20.20
(PFUnA)	2	2.97	2.72	2.85
(8:2FTS)	1	4.84	4.84	4.84
(4:2FTS)	0	0	0	0
(PFNS)	0	0	0	0
(NMeFOSAA)	0	0	0	0
(PFDS)	0	0	0	0
(NEtFOSAA)	0	0	0	0
(PFDoA)	0	0	0	0
(PFTrDA)	0	0	0	0
(PFTA)	0	0	0	0
PFAS6 Regulated Compounds in Yellow				

The PFAS well data was combined with earlier results obtained separately from the Barnstable Fire District (Table 5). The untreated well water was sampled prior to carbon treatment that removes the PFAS before it is distributed into the water supply. The location of the wells (Figure 9) and bar graphs compare the amounts of PFAS relative to PFAS6 and Total PFAS detected (Figure 10 and 11). Radar plots showing graphic depictions of thePFAS composition are in the Appendix. There were 5 detections of the 6:2 FTS, two at the Maher wells , two at the Mary Dunn wells and one a the Airport well.

Table 5 Summary Statistics of PFAS in Hyannis Area Wells arranged high to low by PFAS6 Detections

Hyannis Wells	ng/l						ng/l		
	PFOA	PFOS	PFAS-6	Total PFAS	% PFOS	% PFOA	PFCAs	PFCS	6:2 FTS
MD3	39.10	307.00	525.70	733.11	42%	5%	201.60	455.65	45.94
AIRPORT	41.90	214.00	465.74	853.60	25%	5%	421.44	374.16	58.00
MD2	11.00	188.00	273.90	353.97	53%	3%	87.88	251.92	11.20
MAHER 1	26.00	139.00	251.30	467.45	30%	6%	212.20	185.25	70.00
MAHER 2	11.90	107.00	189.71	248.00	43%	5%	79.40	168.60	ND
MAHER 3	20.40	110.00	182.87	263.33	42%	8%	90.00	151.80	8.33
SIMMONS POND	19.90	51.70	122.06	169.40	31%	12%	60.88	108.52	ND
STRAIGHTWAY 2	24.10	49.00	116.95	159.99	31%	15%	65.30	94.69	ND
STRAIGHTWAY 1	20.60	21.40	83.26	148.21	14%	14%	88.47	59.74	ND
HYANNISPORT	8.94	19.80	57.74	83.38	24%	11%	29.83	53.55	ND
MD1	2.77	32.30	50.14	60.88	53%	5%	18.38	42.50	ND
Average	20.60	112.65	210.85	321.94	35%	8%	123.22	176.94	38.69

Barnstable Fire	NG/L				% PFOS	% PFOA
District- May 2019	PFOA	PFOS	PFAS-6	Total PFAS	to PFAS-6	to PFAS-6
BFD #1	ND	ND	ND	NA	NA	NA
BFD #2 - Breeds H	3.6	2.5	11.21	NA	22%	32%
BFD #5 - Breeds H	4.9	11.2	23.32	NA	48%	21%
BFD #3-Hathaway	ND	4.0	8.00	NA	50%	NA
BFD #4-Hathaway	ND	17.0	20.28	NA	84%	NA

BFD #1	ND	ND	ND	NA	NA	NA
BFD #5	4.9	11.2	23.32	NA	48%	21%
BFD #4	ND	17.0	20.28	NA	84%	NA
BFD #2	3.6	2.5	11.21	NA	22%	32%
BFD #3	ND	4.0	8.00	NA	50%	NA

The Mary Dunn and Airport Wells

The Mary Dunn Wells are 1,500 ft immediately downgradient of the BCFTA. MD3 has the highest PFAS6 detection at 525 ng/l (Figure 9). MD2 has PFAS6 at 274 ng/l. Owing to their proximity and high pumping rates during this sampling event, they capture more of the BCFTA PFAS plume than MD1, which has the lowest PFAS concentrations at 50 ng/l. PFAS6 concentrations in the Airport Well located to the south near Lewis Pond has increased dramatically over the last few years from less than 10 ng/l through 2017-2018 to a detection of 106 ng/l in Spring 2019 and to 465 ng/l in July 2019. Pumping increased at the Airport Well recently to make up for a supply deficit due to other wells being shut off. The greater pumping results in a probable capture of the BCFTA PFAS plume. However, it is also possible that potential undetected contamination from the Airport contributed to the increase. PFOS accounts for 40% to 53% of PFAS in the Mary Dunn Wells (Figure 11 Table 4). The Airport Well

has only 25% PFOS but the highest percentages of the 6:2 FTS and Per FluoroCarboxylic Acids (PFCAs). The 6:2 Fluoro Telomer Sulfonate PFAS was used to replace PFOS in AFFF formulations in the 1990's. The 6:2 FTS AFFF was used after 2000 exclusively at the Airport. All water from the WSD Wellfields are treated to Non-Detect by the Carbon Filters.

The Maher Wells

The Maher Wells have high PFAS6 concentrations, ranging from 218 to 130 ng/l (Figure 10 Table 4). PFAS6 in groundwater at the Maher wells is likely due to the nearby upgradient sources at the Municipal Airport; BCFTA, potential secondary redistributed PFAS along an extended flow path from the WPCF and septic system on the WSD service. The Maher wells are placed along a line that is perpendicular to groundwater flow. This means groundwater flow to ME-2 on the east end is different from ME-1 on the west end depending on pumping rates. The percentage of PFOS ranges from 30% to 43% in the Maher wells (Table 4). However, the highest percentage of the 6:2 FTS and other Perfluoroalkyl Carboxylates is detected in groundwater from ME-1 that is closest and most downgradient well to the Airport which made exclusive use of the Telomerization-AFFF (Figure 11) (Radar Plot in Appendix A). Treatment for the Maher Wells to remove PFAS began in September 2020.

Hyannis Port Wellfield

The Straightway 2 Well is a deep well, adjacent to Striaghway 1, that is screened below a clay layer in a formation that acts like a confined aquifer. The presence of PFAS6 and the co-occurrence of 1-4 Dioxane in the deep well is an indicationof leakage of the redistributed PFAS from the WPCF through the clay layer. The Hyannis Port well itself has the lowest PFAS concentrations since it is located downgradient of the other 3 wells that have captured the bulk of the contamination. The percentage of PFOS in the Hyannis Port wellfield ranges from 30 to 14%, but the percentage of PFOA is nearly double of the other wells ranging from 11 to 15% (Table 4) indicating a higher percentage of household sources. The Hyannis Port Wellfield is impacted by secondary PFAS sources from the WPCF and septic systems. Treatment to remove PFAS from the Hyannis Port wells started in the Spring of 2020.

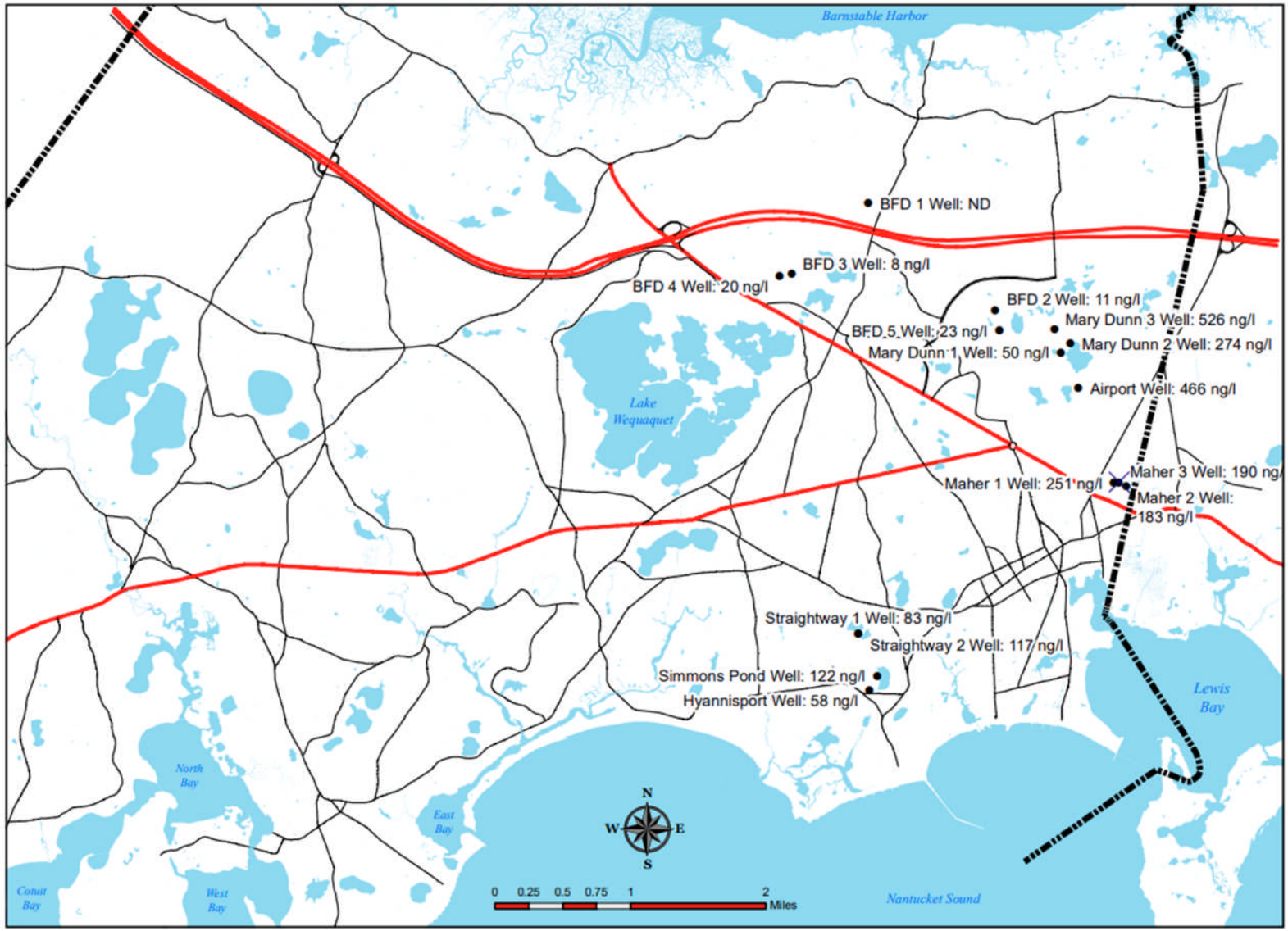


Figure 9 PFAS6 in Public Water Supply Wells sampled on September 27, 2019

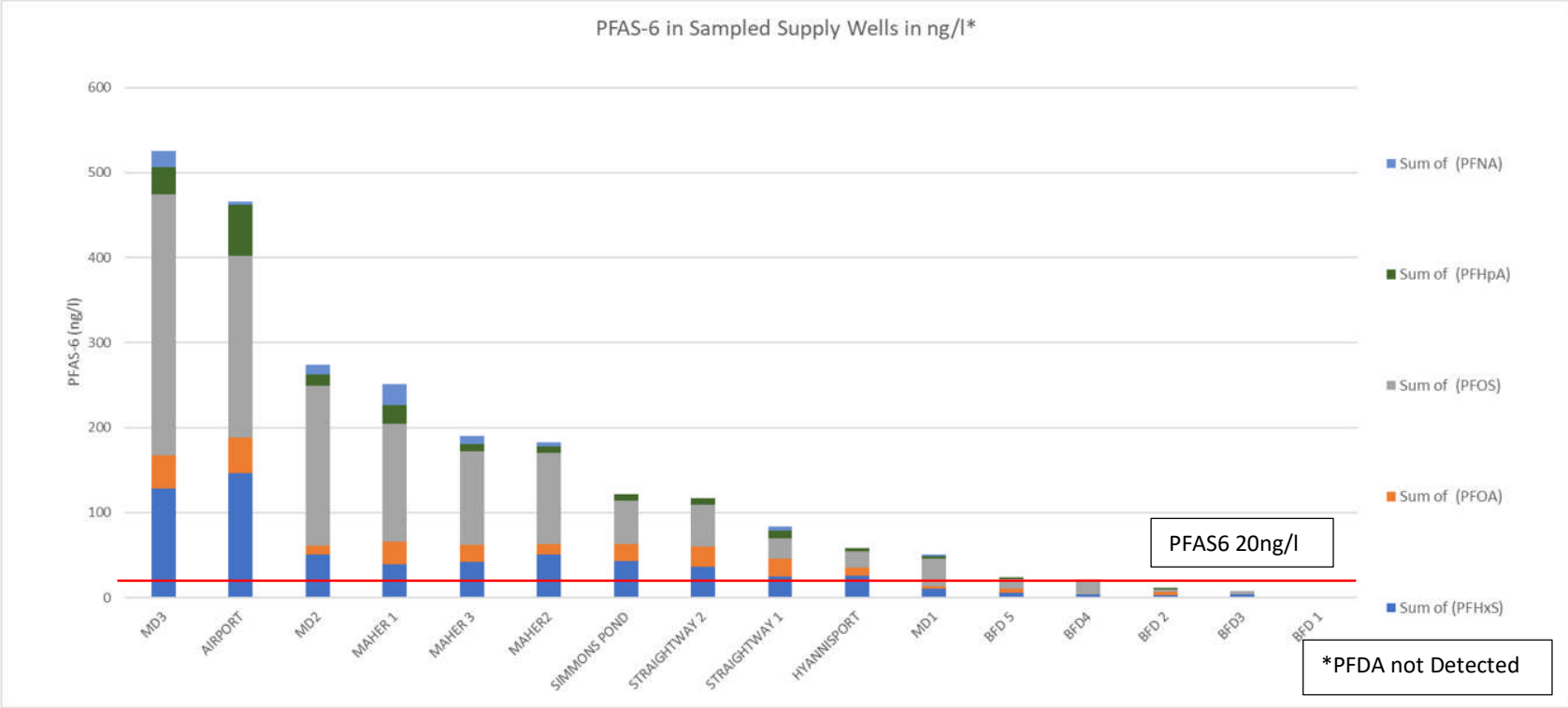


Figure 10 PFAS6 in Groundwater at Public Supply Wells

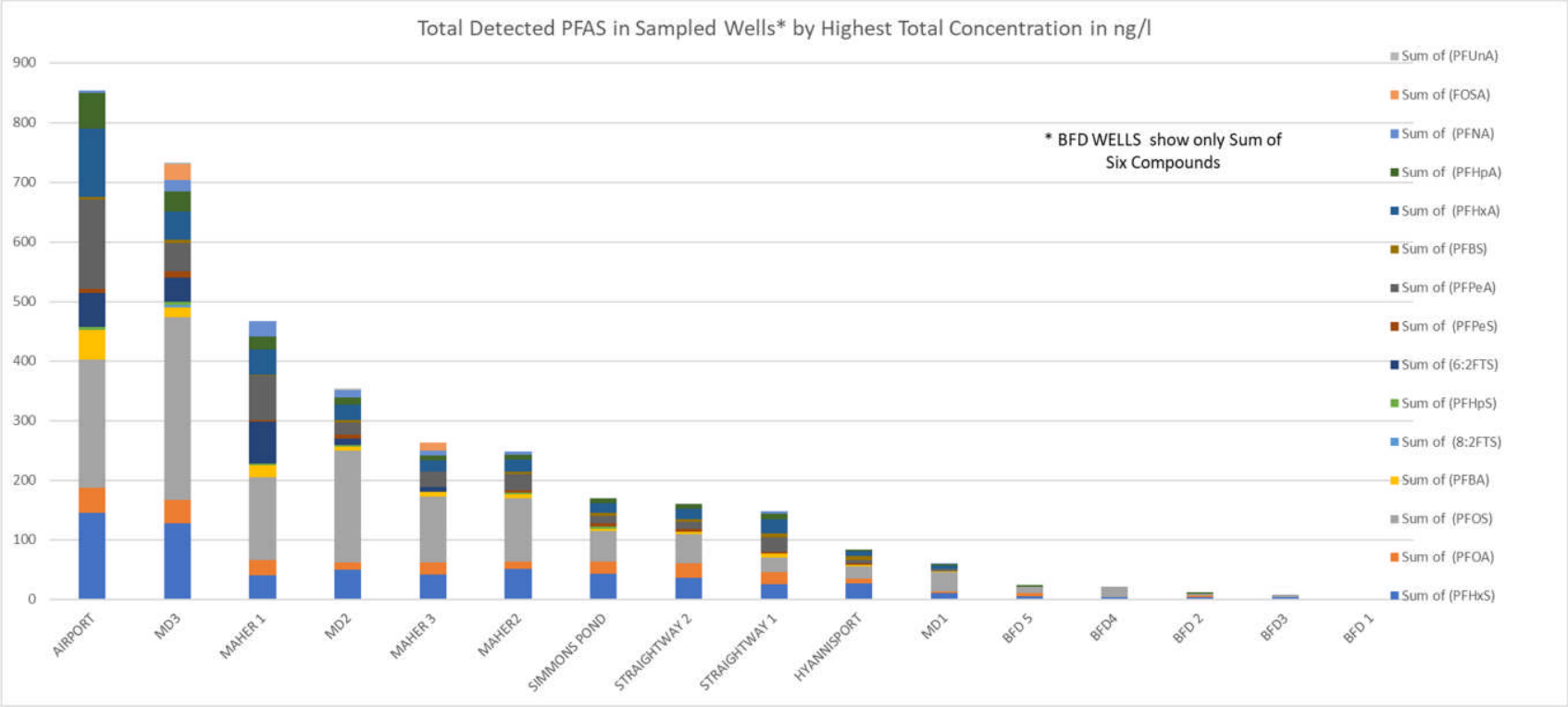


Figure 11 Total PFAS in Groundwater at Supply Wells

Barnstable Fire District Wells

The Barnstable Fire District Wells off Breeds Hill Road (BFD2 and BFD5) are upgradient of the BCFTA on the west side of Flintrock Pond (Figure 9). The Pond was a direct recipient of PFAS-laden training water for decades with PFAS concentrations ranging from 2,700 to 266 ng/l (Table 4). The BFD Breeds Hill wells had low detections of PFAS in their pumped water initially. PFAS6 in BDF2 and BFD5 in May 2019 increased to 11.21 and 23.32 ng/l, respectively. The PFAS concentrations at BFD#5 well have increased above the DEP Drinking Water MCL for PFAS6 of 20 ng/l. The level of impact is similar to PFAS detections in the upgradient Fresh Hole and Indy Park-West Ponds. The potential sources of the PFAS contamination to the Breeds Hills wells include septic systems and unidentified sources including the Airport and potentially the WPCF under certain pumping regimes. The BFD2 Well is located north of BFD5 and further from the Municipal Airport and the anddirect flow paths from the WPCF and upgradient septic systems and may explain its lower concentration. A pump test of Well 5 for its Zone II delineation indicated negligible drawdown at Flintrock Pond (Cambareri and Michaud, 2009). It is not likely that Flintrock Pond is the source of PFAS to these wells. The BFD maintains PFAS6 concentrations below the Drinking Water standard of 20 ng/l by blending water from the higher concentration wells with water from the low concentration wells.

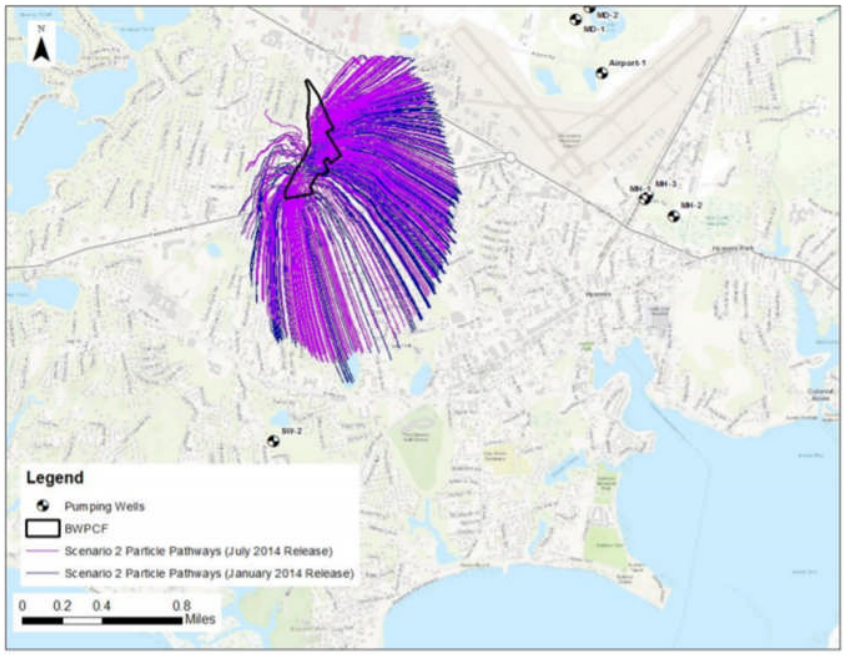
The Hathaway Pond wells, BFD 3 and BFD 4 wells have PFAS6 concentrations of 8.0 ng/l and 20.28 ng/l respectively. BFD4 is located further to the west away from the Ponds and potentially closer to potential sources. The difference in concentration between the two wells and ponds indicates both the variable nature of contaminants in the groundwater and likely preferential flow paths through the deeper Hathaway Pond (60+ ft), which has 21.9 ng/l PFAS than shallow Little Hathaway Pond (<15 ft) which has 2.8 ng/l PFAS. There was no detected PFOA in the Hathaways Pond wells.

WPCF and Groundwater Flow

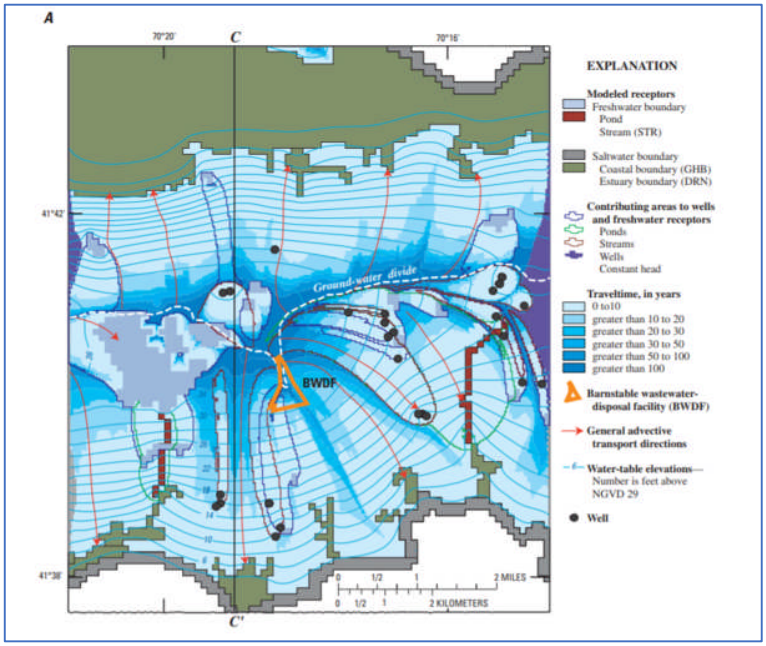
The BFD Hathaways wells and Tier 2 ponds are located north of the WPCF. The extent of the source of PFAS from the WPCF is subject to changing conditions. The WPFC is located at the top of the eastern Sagamore Lens east of Lake Wequaquet. There are distinct primary groundwater flow paths from the facility to the Southeast (Figure 12a). Moving radially away from those southerly paths to the east and west the plume becomes more diffuse and dilute. Groundwater flow to the north is diffuse, the flow paths to wells are longer, and the migration of contaminants takes more time.

Modeling by the USGS (2008) under average conditions indicates a groundwater divide that separates groundwater flow from the linear ridge of the water table to the south and north (Figure 12b) and that the Hathaway Pond wells capture groundwater originating from the northern and eastern shore of Shallow Pond (Walter, 2007) which has the highest PFAS concentrations in the Tier 2 Group. A map of nitrogen hot spots originating from septic systems indicates significant septic sources near the northeast shore of Shallow Pond

(Barnstable CWMP, 2020). The water table north of the WPCF is flat and sensitive to seasonal changes in precipitation and discharge that could result in groundwater flow to the north under certain conditions that are not evident in a groundwater model. Considerations for increasing flow to the WPCF under future conditions are likely to change the groundwater divide dynamic and result in effluent flow to the north.



a)



b)

Figure 12 a) Five -Year Particle Paths from the WPCF under Average Discharge Conditions from CDM-Smith Effluent Discharge Study, May 2020 and b) Simulated water-table elevations, travel times, and general advective-flow paths showing the groundwater divide from the USGS Report (Walter, 2008)

Conclusions and Recommendations

The presence and composition of PFAS in wells and ponds in the Hyannis area is strikingly similar and indicating that Ponds are a good surrogate to evaluate nearby groundwater quality. A Total PFAS concentration of 138 ng/l in Bens Pond is similar to Total PFAS concentrations detected in Straightway 2 and Simmons Pond Well of 122 to 116 ng/l respectively.

The Mary Dunn Wells are 1,500 ft immediately downgradient of the BCFTA. MD3 has the highest PFAS6 detection at 525 ng/l (Figure 9). MD2 has PFAS6 at 274 ng/l. Owing to their proximity and high pumping rates during this sampling event, they capture more of the BCFTA PFAS plume than MD1, which has the lowest PFAS concentrations at 50 ng/l. PFOS accounts for 40% to 53% of PFAS in the Mary Dunn Wells. The Airport Well has only 25% PFOS but the highest percentages of the 6:2 FTS and Per FluoroCarboxylic Acids (PFCAs). The 6:2 Fluoro Telomer Sulfonate PFAS was used to replace PFOS in AFFF formulations in the 1990's. The 6:2 FTS AFFF was used after 2000 exclusively at the Airport. All water from the Mary dunn and Airport Wells are treated to Non-Detect by the Carbon Filters.

The Maher Wells have high PFAS6 concentrations, ranging from 218 to 130 ng/l. PFAS6 in groundwater at the Maher wells is likely due to the nearby upgradient sources at the Municipal Airport; BCFTA, potential secondary redistributed PFAS along an extended flow path from the WPCF and septic system on the WSD service. The percentage of PFOS ranges from 30% to 43% in the Maher wells. However, the highest percentage of the 6:2 FTS and other Perfluoroalkyl Carboxylates is detected in groundwater from ME-1 that is closest and most downgradient well to the Airport which made exclusive use of the Telomerization-AFFF. Treatment for the Maher Wells to remove PFAS began in September 2020.

The Hyannis Port Wellfield consisting of the Straightway, Simmons Pond and Hyannisport wells have lower PFAS concentrations than the Maher wells. The wells in the Hyannis Port Wellfield have PFAS6 concentrations ranging from 116 to 57 ng/l, with the highest being the Simmons Pond Well and Straightway 2 Well. The HyannisPort Wells are located downgradient form the WPCF and unsewered development. PFAS from the primary sources of groundwater contamination at the BCFTA and Airport that impacted supply wells has subsequently been transported by the water system and redistributed by the WPCF and Hyannis area septic systems as secondary sources.

The WSD wellfields now all have carbon treatment to remove PFAS, so the drinking water has no detectable PFAS. PFAS will have a long legacy because PFAS, known as "forever compounds" can last for decades in the soil and groundwater (Weber, et al, 2017) and the need for continued treatment is certain.

An average Total PFAS concentration of nearly 200 ng/l defines highly contaminated Tier 1 Ponds in the Hyannis Area. The Tier 2 Ponds on the outskirts of Hyannis to the northwest and northeast of the WPFC have Total PFAS concnetrations of 28 ng/l. Tier 3 ponds remote to Hyannis have an average Total PFAS concentration of 13 ng/l. Average PFAS6 concentrations for the Tier 1, 2, and 3 Ponds is 109 ng/l, 16 ng/l and 5 ng/l respectively. There is a relation between a pond's PFAS concentration and the distance from the WPCF (Figure 8). An average T-PFAS background concentration of 5 ng/l identifies ponds with on-site septic sources sources of PFAS in their watershed. Ponds with an average PFAS6 above 10 are likely to have sources associated with the primary PFAS point sources of the BFTA and Airport and the redistributed secondary sources.

The Tier 1 Hyannis area ponds; St. Francis Pond, Fawcetts Pond, Aunt Bettys Pond, Bens Pond, Dunns Pond, and the Hyannis and Yarmouth Creeks that are in close proximity and downgradient of the WPCF and dense septic systems are significantly impacted with high concentrations of Total PFAS ranging from 252 ng/l to 138 ng/l with PFAS6 ranging from 159ng/l to 71 ng/l. The Teir 1 Hyannis area ponds average Total PFAS is 200 ng/l. The high PFOS detections range from 75 to 29 ng/l. The source of PFAS in the Tier 1 Ponds is secondary PFAS from the WPCF and unsewered areas served by the WSD.

A second tier of ponds; Shallow Pond, Fresh Hole Pond, Indy Pond-West, Gooseberry, Wequaquet, Hathaways and Long Pond have Total PFAS concentrations ranging from 51ng/l to 2.8 ng/l with detected PFAS6 concentrations ranging from 30ng/l to 11ng/l. Detected PFOS in the Tier 2 Group range 11 to 2 ng/l. The presence of PFOS in the Tier 2 ponds indicates a secondary PFAS source from septic systems and potentially the WPCF.

A third tier of ponds tested in remote areas away from Hyannis including Spruce, Garrets, Joshua, Eagle, Shubaels, and Mystic have low Total PFAS concentrations ranging from 29ng/l to 3 ng/l with PFAS6 ranging from 6.9 ng/l to Non-Detect. The general absence of PFOS in the Tier 3 Barnstable Ponds with higher percentages of PFCAs is an indication of domestic septic sources.

Mystic Pond is an outlier of the Tier 3 group with a detection of PFOS at 13.9 ng/l. The moderate concentration of PFOS in Mystic Lake is an outlier. A potential source may be from the use of legacy AFFF at the Municipal Airfield since the Pond is immediately downgradient of the Airfield.

Shubaels Pond in Marstons Mills with only high density septic systems as a source has a low PFAS concentration of 4.99 ng/l (comprised of 50% of PFOA without any PFOS) supports the

finding that the Hyannis Ponds, with substantial PFOS are impacted by primary AFFF sources redistributed through the WPCF and septic systems.

Spruce Pond with sparse development and an electric right of way in its assumed watershed, has neither PFOS or PFOA and its PFAS concentration of 29.2 ng/l is totally PFBA

Identifying other potential primary sources in the Hyannis area may prove difficult due to the pervasive presence of PFAS from primary sources stemming from the BCFTA andMunicipal Airport, and secondary redistributed PFAS contamination through the WPCF and Hyannis area septic systems.

Areas with high levels of PFAS concentrations in surface water are coincident with high concentrations of PFAS in groundwater and therefore should be considered less favorable for the development of future well sites given the costs to treat PFAS contamination to non-detect levels. Taking into account the behavior of contamination plumes from multiple sources, several future well sites can be ruled out. For example, two of the most convenient potential future well sites located within Hyannis, thus requiring the shortest transmission mains, have a high degree of risk because of the presence of PFAS detected in groundwater from redistributed sources, including septic systems and the WPCF.

Recommendations

1. Coordinate with the BFD to have wells analyzed for a more inclusive compound list 537 Method.

2. Coordinate the evaluation of PFAS groundwater sampling programs, including the former BCFTA, Municipal Airport, WSD New Source Exploration Program, Barnstable Fire District, Hyannis Wildlife Management Area (USGS 2019) and other potential investigators.

3. Research if historic samples from the WPCF were analyzed for PFAS compounds.

4. Establish a PFAS sampling program for the WPFC and its downgradient monitoring wells and consider additional monitoring locations to determine the distribution of legacy PFAS in the effluent groundwater plume.

5. Sample additional surface waters in potential water exploration areas.

6. Evaluate the interactions of PFAS sources and water supply withdrawals through groundwater modeling and particle tracking.

7. Incorporate planning of potential new wastewater discharge areas into water supply consideration.

References

Liu, J., Avendaño, S. M. 2013., Microbial degradation of polyfluoroalkyl chemicals in the environment: A review., Env. Int. 61, 98–114

Briggs MA, Tokranov AK, Hull RB, LeBlanc DR, Haynes AB, Lane JW, 2017. Hillslope groundwater discharges provide localized stream ecosystem buffers from regional per- and polyfluoroalkyl substances contamination. Hydrological Processes. 2020;34:2281–2291. https://doi.org/10.1002/hyp.13752 2017

Cambareri, T. C. and Michaud S.M., 2009. Final Prolonged Pumping Test Report for Well Site BFD No. 5., Cape Cod Commission.

Cambareri, T.C., 2010. Draft Town-Wide Zone II Study for the Town of Barnstable, MA., Cape Cod Commission.

Cambareri, T. C., 2015.Immediate Response Action Plan Barnstable County Fire and Rescue Training Academy RTN:4-26179, Cape Cod Commission, Barnstable MA,

Carlson, C.S., Masterson, J.P., Walter, D.A., and Barbaro, J.R., 2017, Development of simulated groundwater-contributing areas to selected streams, ponds, coastal water bodies, and production wells in the Plymouth-Carver region and Cape Cod, Massachusetts: U.S. Geological Survey Data Series 1074, 17 p., https://doi.org/10.3133/ds1074.

CDM-Smith May 2020, Effluent Discharge Study, Barnstable, MA., May 2020.

Horsley-Witten, 2019 IRA Modification Plan Barnstable Municipal Airport RTN 4- 26347, Sandwich, MA.

Horsely-Witten, 2021 Fianl Phase II Comprehensive Site Assessment of the Barnstable Municipal Airport RTN-4-26347.

Interstate Technology Regulatory Council, 2020. https://pfas-1.itrcweb.org/

Leblanc, D.R. McCobb and Barbaro., 2019., Simulated Water-Table and Pond-Level Responses to Proposed Public Water-Supply Withdrawals in the Hyannis Ponds Wildlife Management Area, Barnstable, Massachusetts, USGS, Scientific Investigations Report 2019-5121

MA-DEP, 2020., Documentation for Updated Office of Research and Standards Guidelines (ORSG) for Per- and Polyfluoroalkyl Substances (PFAS) in Drinking Water Ma-DEP, 2020 https://www.mass.gov/doc/massdep-ors-guideline-for-pfas/download

John P. Masterson, Donald A. Walter, and Denis R. Leblanc, 1998. Delineation of Contributing Areas to Selected Public-Supply Wells, Western Cape Cod, Massachusetts Water-Resources Investigations Report 98-4237 , USGS.

Martin Shafer, Mark Olson, Camille Danielson and Kirsten Widmayer., 2019. Evaluation of the Efficacy of the National Atmospheric Deposition Program (NADP) National Trends Network (NTN) for Assessment of PFAS Deposition in Precipitation.http://nadp.slh.wisc.edu/conf/2019/abstract.aspx?abstractID=1922

Preimesberger A.J., 2020., Water Quality Standards Technical Support Document: Human Health Protective Water Quality Criteria for Perfluorooctane Sulfonate (PFOS). Minnesota Water Pollution Control Agency.

B.J. Ruyle., H.M. Pickard, D.R. LeBlanc, A.K. Tokranov, C.P. Thackray, X.C. Hu, C. D. Vecitis, and E.M. Sunderlan, 2021. Isolating the AFFF Signature in Coastal Watersheds Using Oxidizable PFAS Precursors and Unexplained Organofluorine., *Environ. Sci. Technol.* 2021, 55, 6, 3686–3695

Schaider, L., Rudel, R., Dunagan, M.A., Ackerman, J., Perovich, L., Brody, J., 2010. Emerging Contaminates in Cape Cod Drinking Water. Silent Spring Institute. Newton, MA

Schaider, L.A., Rudel, R.A., Ackerman, J.M., Dunagan, S.C., Brody, J.B., 2014. Pharmaceuticals, perfluorosurfactants, and other organic wastewater compounds in public drinking water wells in a shallow sand and gravel aquifer. Sci. Total Environ. 2014, 468–469, 384–393.

Schaider, L.A., et al., 2015. Septic systems as sources of organic wastewater compounds in domestic drinking water wells in a shallow sand and gravel aquifer, Sci Total Environ. http://dx.doi.org/10.1016/j.scitotenv.2015.12.081

Walter, D.A., 2008. Use of Numerical Models to Simulate Transport of Sewage-Derived Nitrate in a Coastal Aquifer, Central and Western Cape Cod, Massachusetts: U.S. Geological Survey Scientific Investigations Report 2007–5259, 41 p.

Weber, Andrea K., Barber, L.M., LeBlanc, D.R., Sunderland E.M. and Chad D. Vecitis 2017. Geochemical and Hydrologic Factors Controlling Subsurface Transport of Poly- and Perfluoroalkyl Substances, Cape Cod, Massachusetts, Environ. Sci. Technol. 2017, 51, 8, 4269–4279 https://doi.org/10.1021/acs.est.6b05573

Weston and Sampson, 2020 Barnstable New Source Exploration Study, Phase 3. Reading, MA.

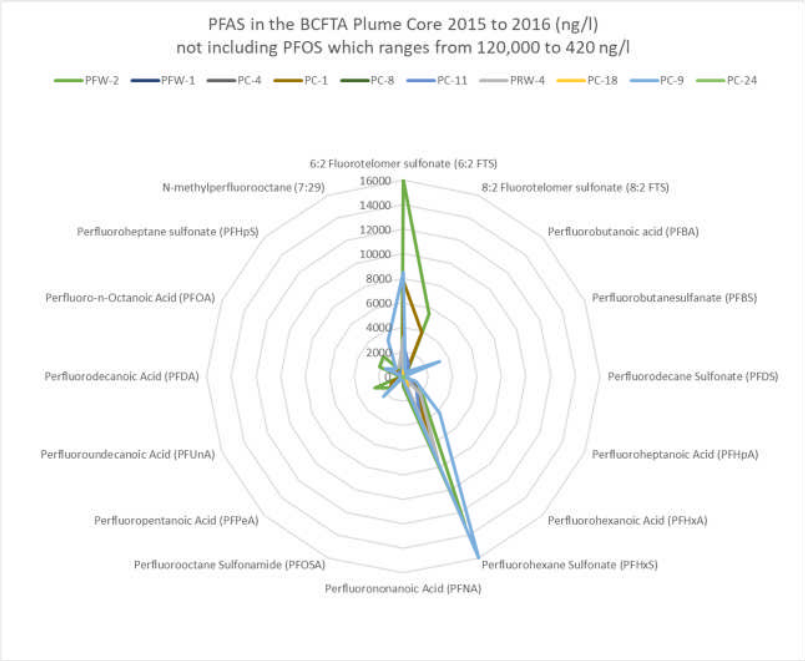
Wang, Z., et al., 2015., Neutral Poly/Per-Fluoroalkyl Substances in Air from the Atlantic to the Southern Ocean and in Antarctic Snow. Environmental Science & Technology 49(13)

Technical Appendix A– Comparative Chemical Composition of PFAS in Ponds and Wells

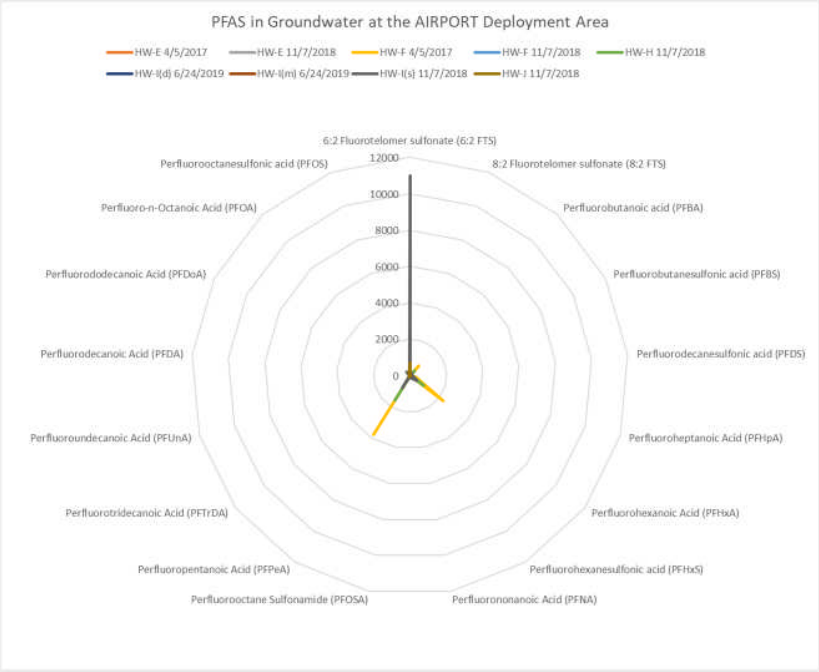
The detection of a broad compound list through the A2-537 Isotope method was used to evaluate the relative abundance of PFAS compounds to see if one set of detections has a different chemical signature than the other. The PFAS results were compiled and graphed as a series of Radar plots. The Radar Plots show the relative concentrations of the individual detected PFAS compounds as listed at the vertexes. The successive circles denote concentration in ng/l from the highest detected on the outside to zero in the center. The plots show each pond, well, creek and how much of each PFAS component is present. The total of the individual components is equal to the groups shown on the previous Table of Results.

The chemical Composition of PFAS in the BCFTA Plume in 2017 is shown (not including PFOS which at 120,000 ng/l would dominate the graph.) The chemical composition of PFAS in the Airport Deployment Area is shown, including PFOS which occurs at a much lower level of 130 ng/l. In general, the 6:2 Telomer is a dominant compound in both sources exceeding 10,000 ng/l. The Sulfonic acids like PFOS and PFHxS dominate the BCFTA whereas it is nearly absent in the Deployment Zone where Carboxylic Acids PFHXA, PFPeA and PFBA are more dominant. These source data are all recent and do not represent what may have been present at earlier times. More work is necessary to compare the other source areas in the Airport.

Barnstable County Fire Training Academy Radar Plot



Municipal Airport Deployment Area Radar Plot



Supply Well Radar Plots

The Radar Plots show the relative concentrations of the individual detected PFAS compounds as listed at the vertexes. The successive circles denote concentration in ng/l from the highest detected on the outside to zero in the center. The Radar Plots of the BFD Wells are based on only the Sum of Six compounds. The Plots are described in the extended captions. The Airport and Mary Dunn Wells have PFOS and PFHxS with Higher PFPeA, PFHxA and 6:2 FTS in the Airport Well.

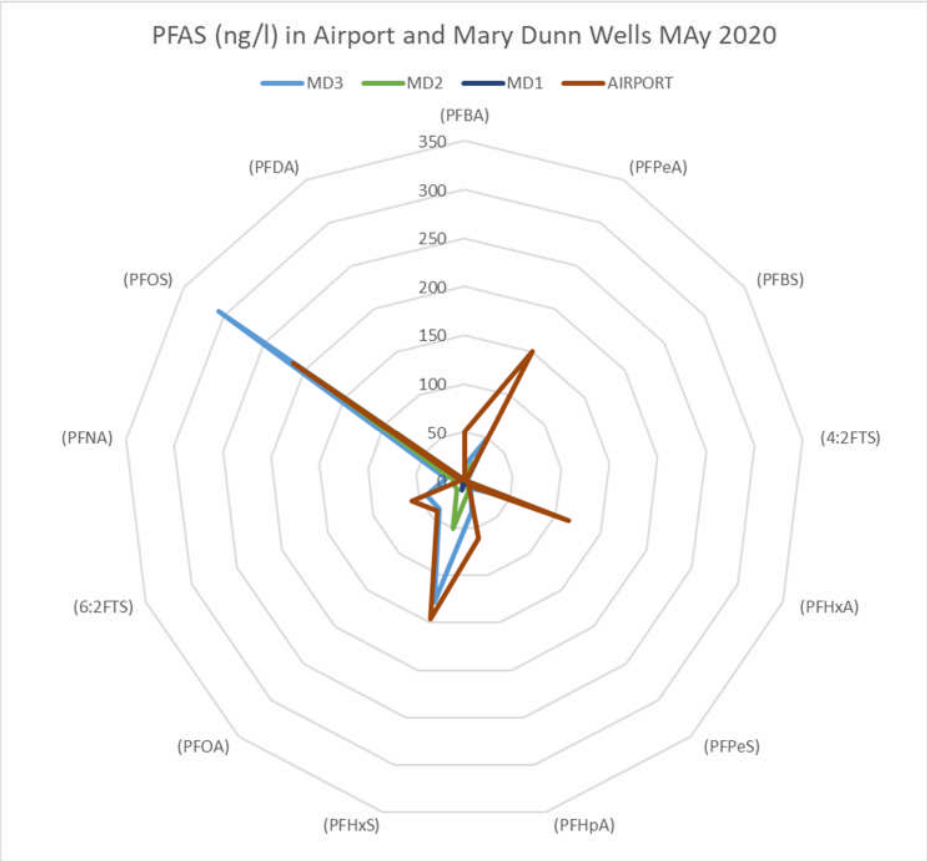


Figure 13 Radar Plot of Airport and Mary Dunn Wells

PFOS occurs at the highest concentration at MD3 at 307 ng/l followed by PFHxS and PFPeA and PFHxA at 150 to 100 ng/l, lower concentrations of 6:2 FTS, PFOA and PFBA are all less than 50 ng/l.

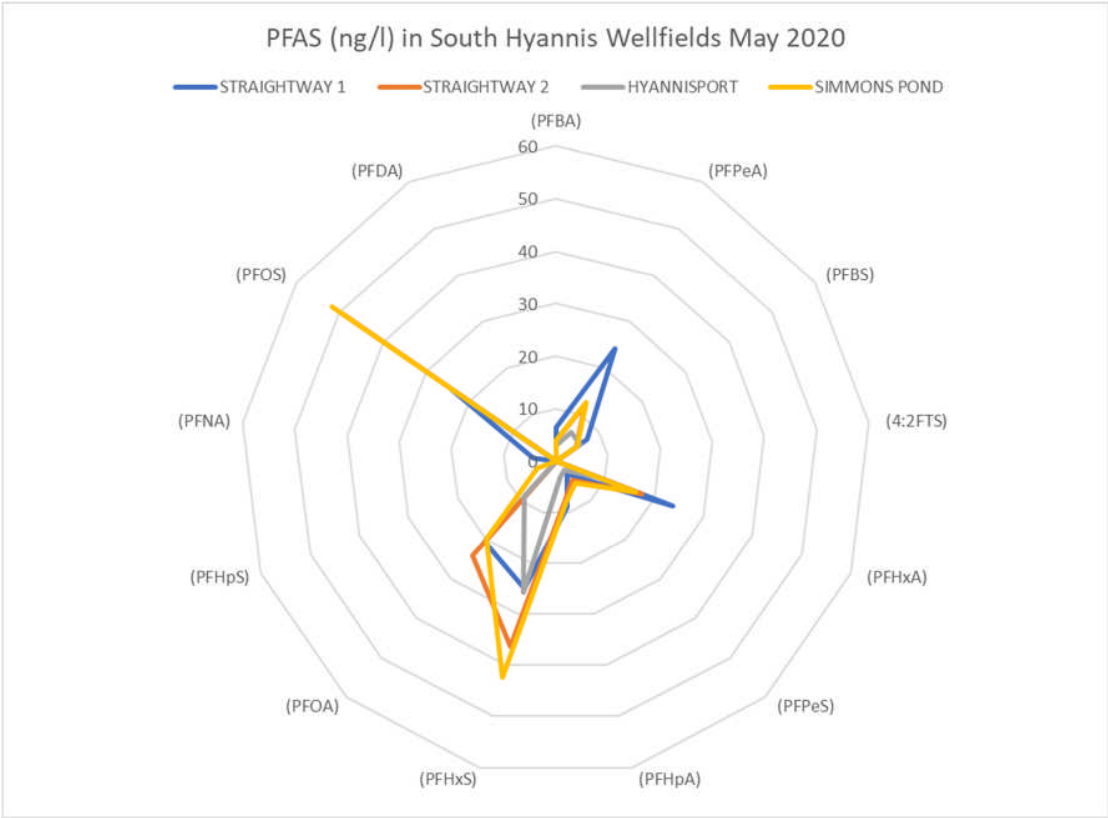


Figure 14 Radar Plot of PFAS in the Hyannis Port Wellfield Wells

The Radar Plot of PFAS in the Hyannis Port Wellfield has similar pattern of components to the Mary Dunn and Airport Wells but the concentrations all are less than 51 ng/l. PFOS concentration is less dominating than the Mary Dunn and Airport Wells indicating some alteration or breakdown from its 8-carbon chain to 7 and 6 carbon chain compounds. Both the Sulfonic and Carboxylic Acid compounds are present.

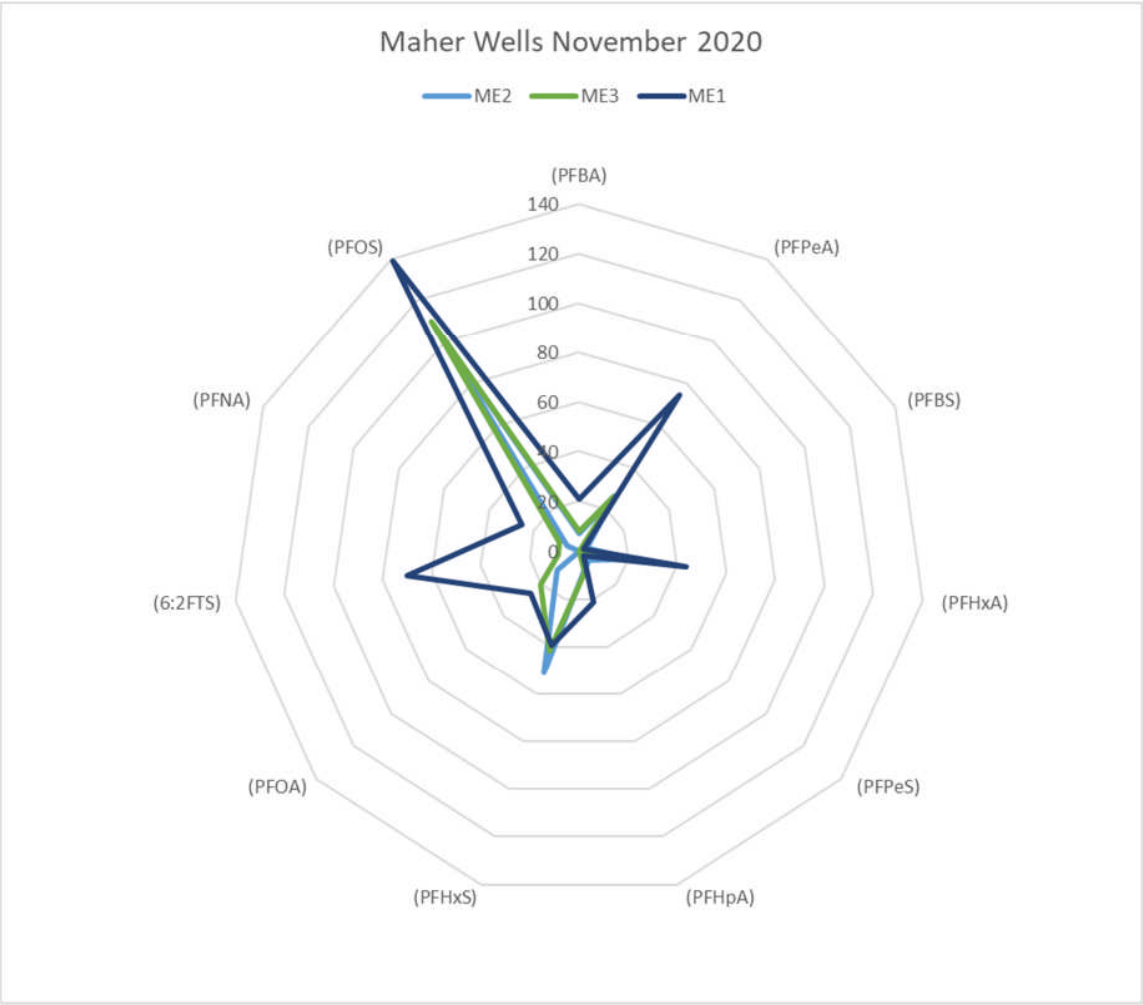


Figure 15 Radar Plot of PFAS in Maher Wells

The Maher Wells have higher PFAS concentrations than the Hyannis Port Wellfield. PFOS is at 110 ng/l in Maher 1 and PFHxS at 68 ng/l in Maher 2 followed by Carboxylic Acids PFHpA, PFOA and PFDA. The chemical composition is more complex because of the multiple sources and the multiple depths of the wells. The Maher wells are placed along a line that is perpendicular to groundwater flow. This means groundwater flow to ME-2 on the east end is different from ME1 on the west end. The percentage of PFOS ranges from 30% to 43% in the Maher wells (Table 4). However, the highest percentages of the 6:2 FTS and other Perfluoroalkyl Carboxylates (PFPeA, PFHxA and PFHpA) is detected in groundwater from ME1 that is closest and most downgradient well to the Airport. The PFAS assessment of the Airport indicates a higher percentage of the PFCAs. The ME1 well PFAS composition is distinctly different than the others.

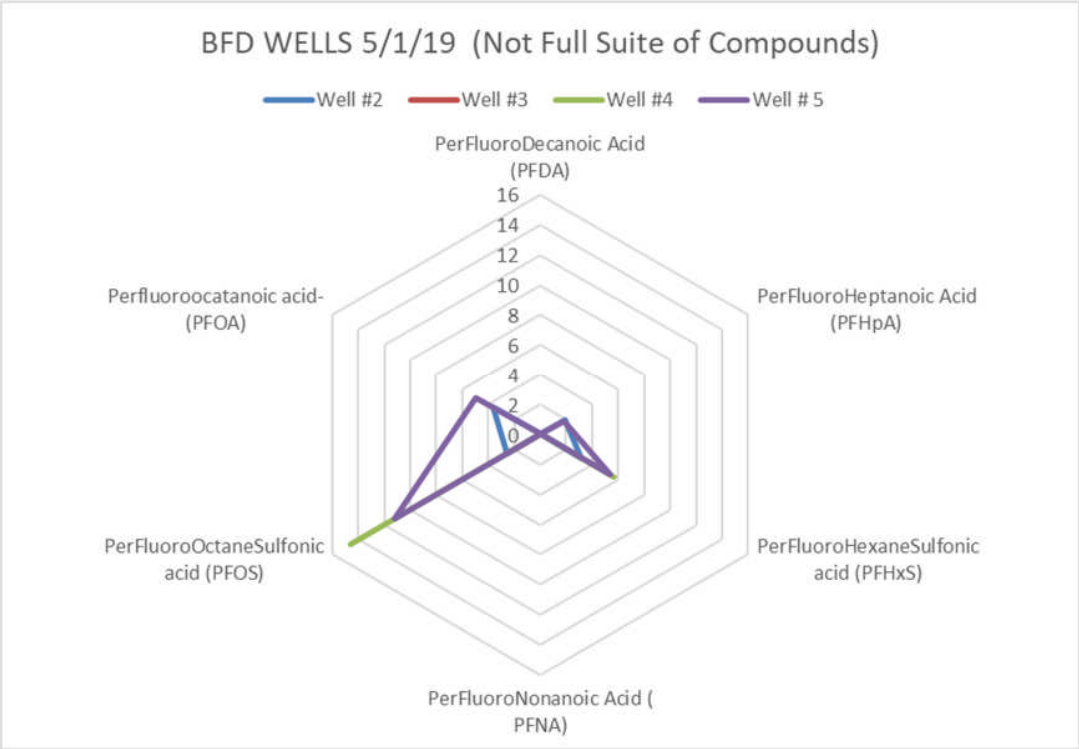


Figure 16 Radar Plot of PFAS in the BFD Wells

These results are from May 2019. The BFD Wells have the least amount of PFAS. PFOS in BFD4 and BFD5 are 15 ng/l and 11 ng/l respectively. PFHxS and PFOA are at 6 and 4.6 ng/l in BFD5. BFD Well #2 and #3 are lower than Wells #5 and #4. PFOS is occurs with 3 other PFAS compounds, PFOA, PFHxS and PFHpA. Additional sampling should consider an expanded 537 Method.

Ponds Radar Plots

The Radar Plots show the relative concentrations of the individual detected PFAS compounds. The successive circles denote concentration in ng/l from the highest detected on the outside to zero in the center.

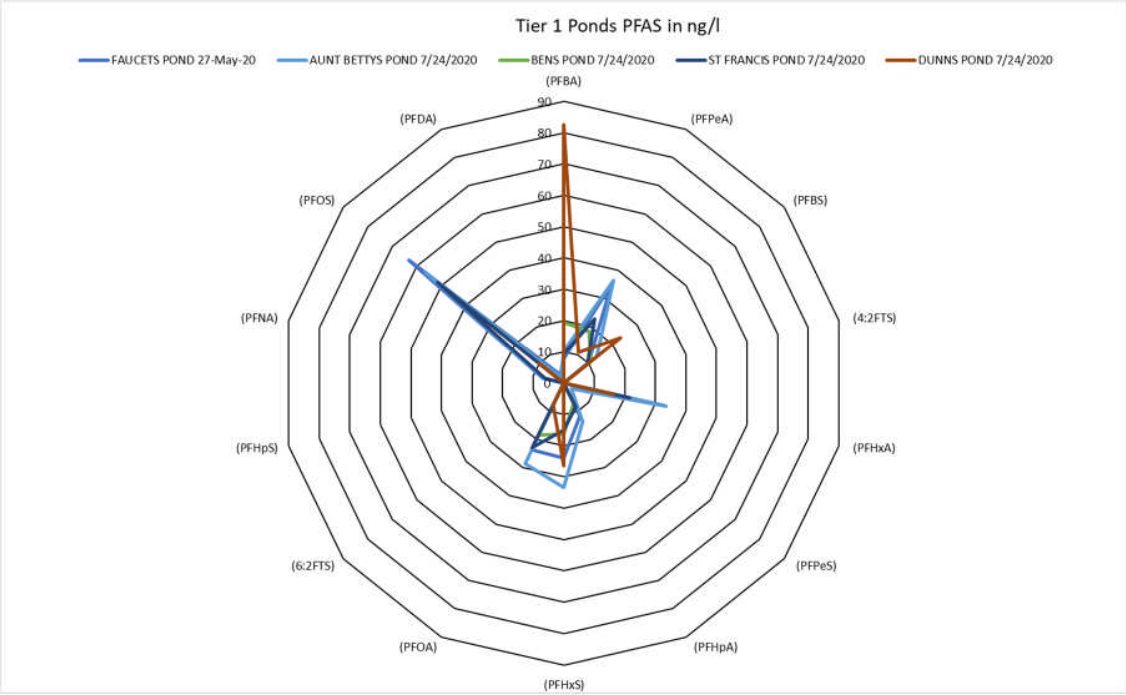


Figure 17 Radar Plot of PFAS in Tier 1 Barnstable Ponds

The pattern of detected PFAS compounds in Hyannis Ponds is similar to the pattern observed in the Wells. The high PFAS concentrations is also consistent with the secondary and tertiary sources in Hyannis. Compounds include PFOS, PFBA, PFPeA, PFHxS, PFHxA, and PFOA, and minor amounts of PFHpS, PFDA, PFPeS, and PFNA.

Figure 18 Radar Plot of PFAS in Tier 2 Barnstable Ponds

The pattern of and compounds of PFAS detected in the Barnstable Ponds is similar but the concentrations are markedly lower. Shallow Pond has the highest concentration of PFOS and PFHxS.

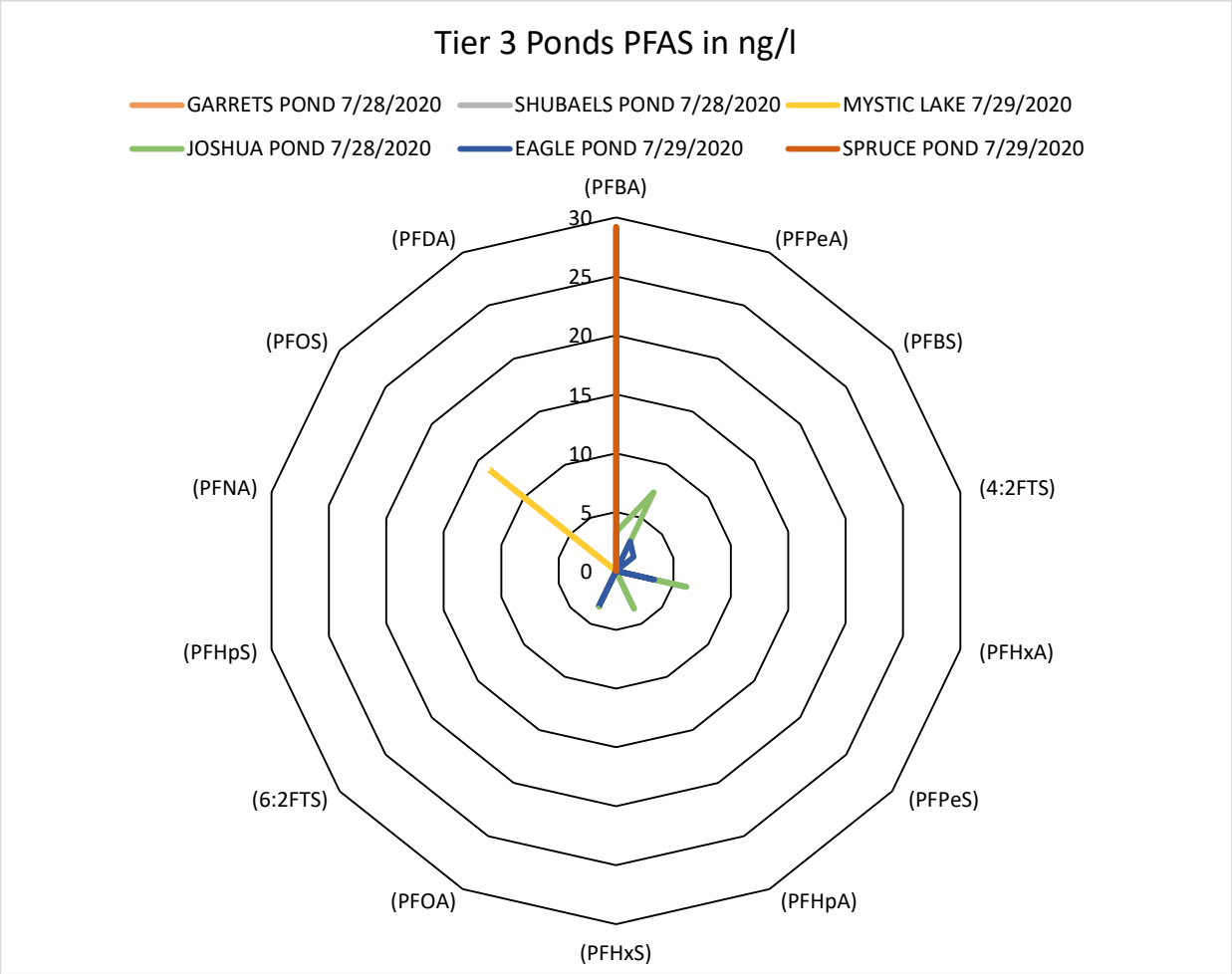


Figure 19 Radar Plot of PFAS in Tier 3 Ponds

The Tier 3 Ponds have relatively lower PFAS concentrations of PFCAs except of Spruce at 29.2 ng/l PFBA and Mystic Lake with PFOS at 13.9

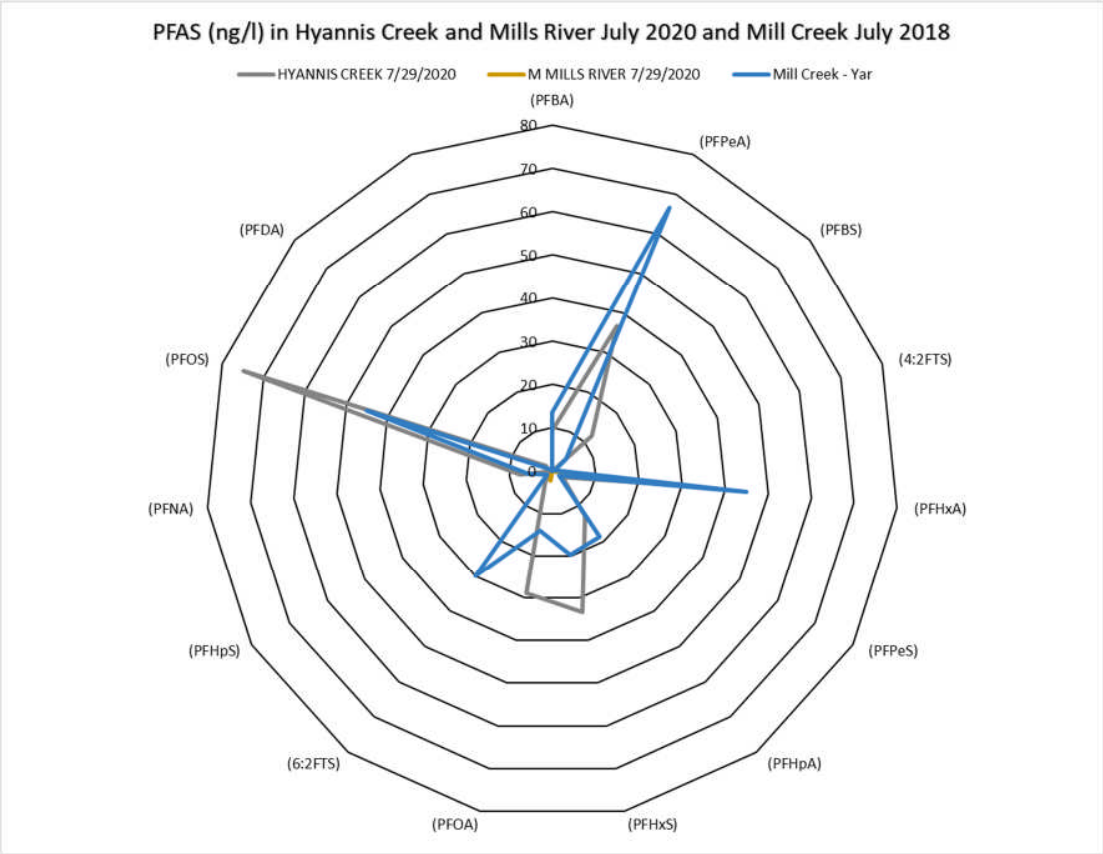


Figure 20 Radar Plot of PFAS in Hyannis Creek, Mill Creek and Marstons Mills River

The pattern and composition of the high concentrations of PFAS in Hyannis Creek and Mill Creek are similar to the Ponds and Wells in Hyannis except for 6:2 FTS and PFHxA in Mill Creek. PFAS concentrations are very low in the Marstons Mills River.