PFAS IN MASSACHUSETTS BACKGROUND SOILS

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Executive Summary

Woodard & Curran conducted a study to evaluate the concentrations of per- and polyfluoroalkyl substances (PFAS) in Massachusetts background soils. Identification of "background" concentrations of contaminants is important to determine whether a regulated release to the environment has occurred and to characterize the nature, extent, and associated risks for release-related constituents. The Massachusetts Contingency Plan (MCP; 310 Code of Massachusetts Regulations [CMR] 40.0000) defines background as "those levels of oil and hazardous material that would exist in the absence of the disposal site of concern" and includes constituents of both naturally occurring and anthropogenic origins. It is essential to understand background levels in order to distinguish MCP-regulated releases that warrant response actions from those that may be considered exempt under the MCP. This concept of background is especially relevant to PFAS, since regulatory limits for PFAS in soil and groundwater are among the most stringent ever promulgated in Massachusetts (as well as other states throughout the nation), even though background levels of PFAS in soil and groundwater are currently not established in Massachusetts.

This study sought to evaluate background concentrations of PFAS in surface soils from locations across Massachusetts, in undeveloped conservation lands that were not in proximity to known PFAS releases or other potential sources, with the goal of understanding how these concentrations compare with state-mandated reportable concentrations and cleanup standards. The study included collection of 100 surface soil samples (0 to 6 inches below ground surface) from 25 undeveloped conservation areas across Massachusetts for analysis of 36 PFAS. The results of this study indicate the following:

» Nine PFAS are present at measurable concentrations in surface soil across all regions of the state.

» One or more PFAS analytes were detected in 88 of the 100 samples.

» PFAS were detected at all 25 conservation areas that were sampled.

» Perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) were detected at the highest frequencies and at the overall highest concentrations.

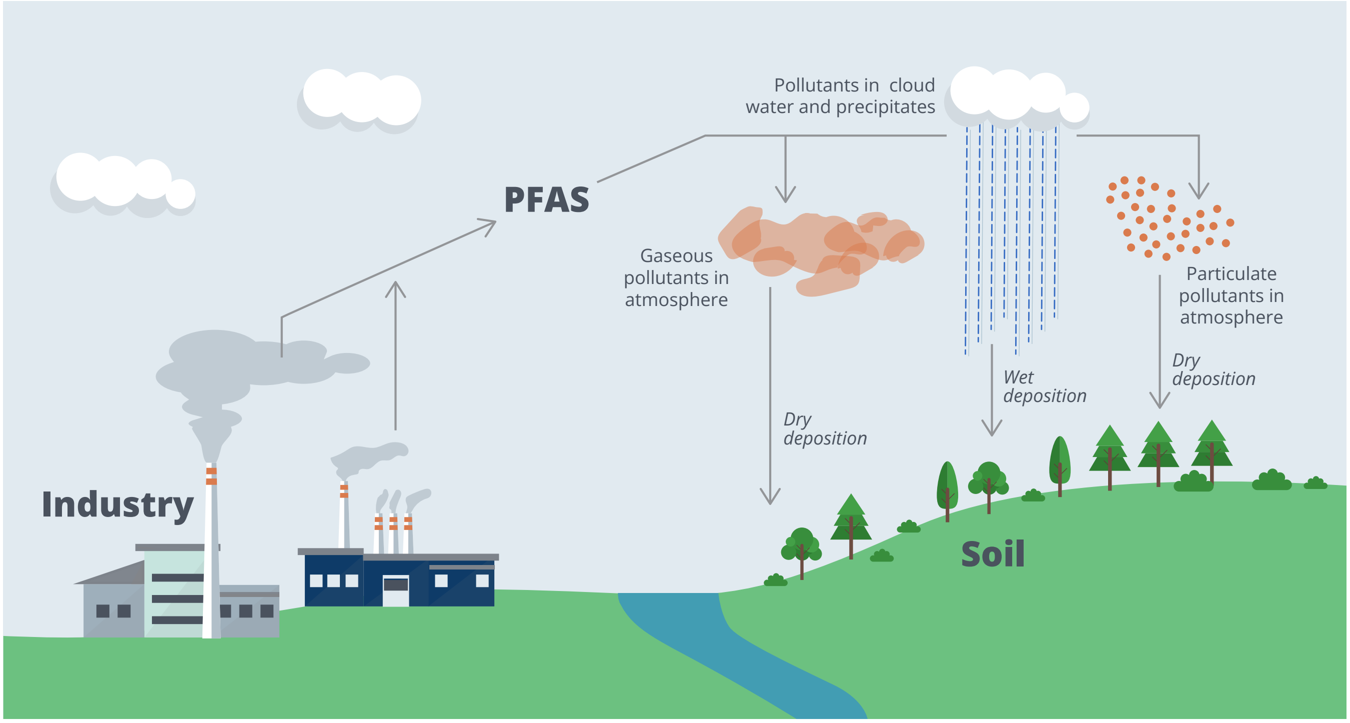
» Concentrations of several PFAS exceeded the MCP soil remediation standards (soil standards) at 21 of the 25 conservation areas that were sampled.

The findings generated from this study show that PFAS (and PFOS and PFOA in particular) are ubiquitous in surface soil in undeveloped open spaces across Massachusetts, in areas that are considered pristine or otherwise unimpacted by known or suspected sources of contamination. Massachusetts is not unique with respect to PFAS detections in soil. The concentrations of PFOS and PFOA found in this Massachusetts study were similar to those found in other studies conducted within New England (Vermont, Maine, and New Hampshire). These findings suggest that atmospheric deposition, either via dry and/or wet depositional processes, likely plays a key role in both the localized and widespread distribution of PFAS in both the atmosphere and the ground. Based on these data, Massachusetts-specific PFAS soil background levels are proposed that could be applied at MCP disposal sites and considered when standards are revisited.

Introduction

Per- and polyfluoroalkyl substances (PFAS) have been documented in air, soil, sediment, water, and biota across the globe, even in undeveloped "pristine" areas as remote as the Arctic. There are various ways PFAS can enter the environment. PFAS may enter the environment through direct land application, such as use of aqueous film forming foam (AFFF) for firefighting, disposal of PFAS-containing materials in landfills, or application of PFAS-impacted biosolids. PFAS may also enter the environment by diffuse atmospheric emissions and subsequent dry (particulate) or wet deposition (rainfall and snow) *(Figure 1)*. PFAS released from the diffuse pollutant emissions sources potentially can account for dispersed PFAS contamination even in areas far removed from known sources.

Figure 1: Primary Migration Pathways for PFAS in Background Areas



The Massachusetts Contingency Plan (MCP; 310 Code of Massachusetts Regulations [CMR] 40.0000) defines background as "...those levels of oil and hazardous material that would exist in the absence of the disposal site of concern..." and includes constituents of both naturally occurring and anthropogenic origins. Woodard & Curran conducted this study with the primary objective of characterizing the types and concentrations of PFAS in surface soils in undeveloped areas of Massachusetts that were not expected to be significantly impacted by PFAS point sources, and thus represented true background locations.

Broad-scale studies of background levels in PFAS in soil are limited. Brusseau et al. (2020) assimilated soil PFAS data from over 30,000 samples collected from over 2,500 sites across the world, including background sites, primary-source sites (such as fire-training areas and manufacturing plants), and secondary-source sites (such as biosolids applications and irrigation water use). Their review reported a median concentration of 2.7 micrograms per kilogram (µg/kg; or parts per billion) for both perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) in soil from "background" sites, with maximum concentrations over 100 μg/kg for both constituents. Brusseau also reported PFAS concentrations often were observed to decrease with soil depth. Mattias et al. (2022) conducted a nationwide study of 28 individual PFAS in soils from 27 sites across Sweden and demonstrated the country-wide presence of PFOS and 15 other PFAS analytes; PFOS was detected at the highest frequency and with a median concentration of 0.39 μg/kg.

There are currently three state-wide published soil PFAS background studies in New England, including Vermont (Zhu et al., 2019), Maine (Sanborn, Head, and Associates [SHA], 2022), and New Hampshire (Santangelo, 2022). To date, there have been no published state-wide background studies for PFAS in Massachusetts soils. While Massachusetts is relatively small in land area (10,565 square miles), the state varies significantly in topography, degree of development/urbanization, land and groundwater usage, and the types of known and potential sources of PFAS in the environment. Accordingly, Woodard & Curran conducted this background study to quantify the typical background levels of PFAS in soils across Massachusetts by selecting locations in undeveloped conservation lands that were not in proximity to known PFAS releases or potential source locations (such as airports, chrome plating facilities, coatings manufacturers, fire stations, landfills, etc.), and with the goal of understanding regional differences in the types and concentrations of PFAS within the state, as well as among other regional studies.

The concept of background is especially relevant to the assessment and remediation of PFAS at contaminated sites, because the regulatory limits for PFAS in soil and groundwater are among the most stringent ever promulgated throughout the nation. In particular, the MCP soil remediation standards (soil standards) for PFAS set to be protective of leaching to the underlying groundwater are often below 1 μg/kg. With regard to the assessment and cleanup of contaminated sites, therefore, it is critical to understand local background concentrations of PFAS to determine whether a regulated contaminant release to the environment has occurred, to characterize the nature and extent of the release, and to estimate the potential exposures and health risks to release-related chemical constituents.

Results from this study help to broaden our understanding of the levels and distribution of PFAS in Massachusetts soils and inform the establishment and/or calibration of MCP soil standards, which must take background into consideration pursuant to MCP regulations (310 CMR 40.0984(1)). These data also broaden the larger understanding of the ubiquitous presence of PFAS across our environment and point toward the need for additional study, particularly with regard to the potential for PFAS in soil to leach to groundwater. This is especially relevant in light of the extremely low drinking water advisory concentrations and existing or proposed groundwater and drinking water quality standards for PFAS.

Materials and Methods

Field Study Design

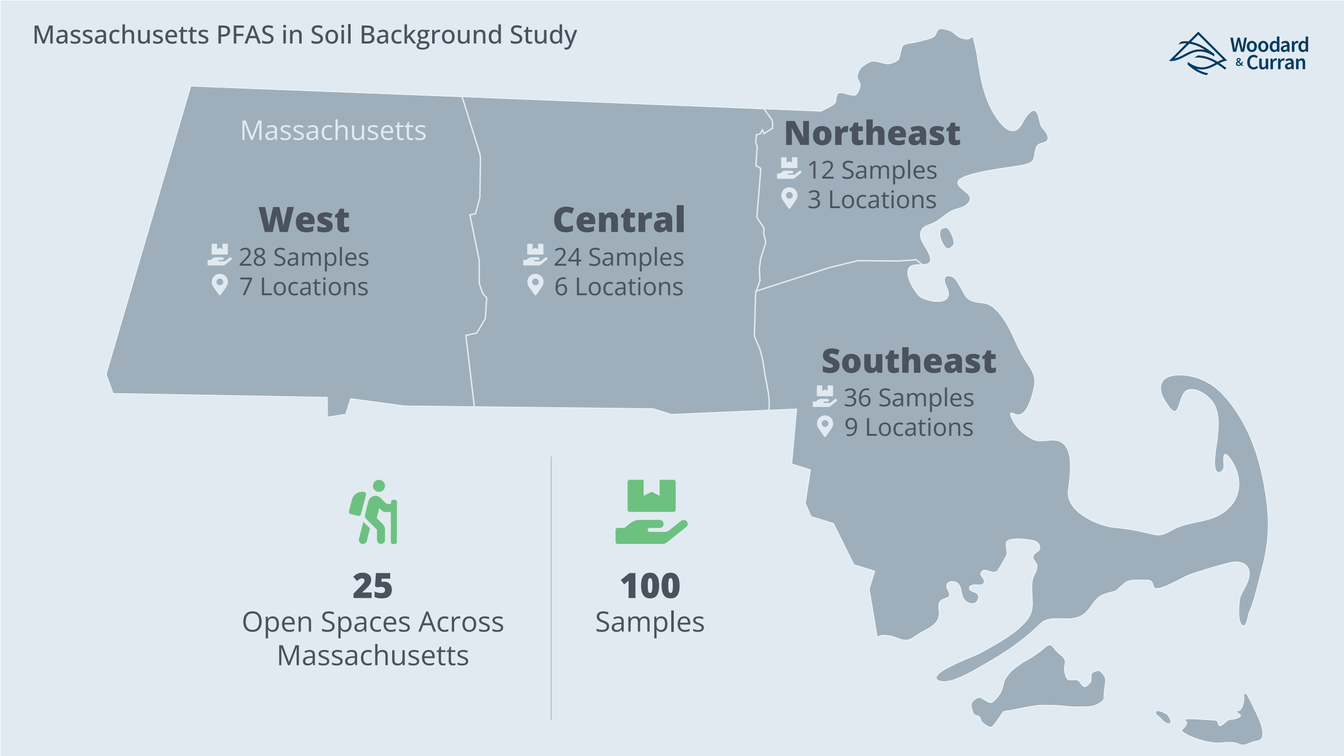
The primary objective in this study was to characterize the types and concentrations of PFAS in soils in background areas—areas of Massachusetts that were undeveloped, did not have a known history of PFAS use, and were not expected to be significantly impacted by potential off-property PFAS point sources. The following steps were taken to achieve this objective:

1. Conservation and recreational lands were targeted as the primary sampling sites;
2. The Massachusetts Geographical Information System (MassGIS) was used to identify areas of open space across the state, which included publicly- and privately-owned, undeveloped or minimally developed, parks, woodlands, and other similar types of conservation areas; and
3. Access was then requested and granted by the anonymous owners of multiple open-space properties to sample on their lands.

Subsequently, the selected properties for sample collection were required to meet the following criteria:

1. Geographical distribution across the entire state and within each of the four state regions: northeast, southeast, central, and west *(Figure 2)*;
2. No current or recent development, and no suspected historical PFAS sources on the property;
3. Not located next to or near properties with known hazardous waste sites;
4. Not located adjacent to commercial or industrial facilities, airports, landfills, fire stations, military installations, ranges or training areas, or other suspected (potential) sources of contamination; and
5. Were publicly accessible via hiking trails.

Figure 2: Summary of Properties and Soil Samples within Four Massachusetts Regions



Twenty-five individual properties were identified across Massachusetts that met these criteria. In general, these properties largely consisted of mature, mixed evergreen and hardwood forest with some maintained meadows. At the property owner's request, both the owner and the location of these properties are not identified. The number of properties per region was roughly weighted by the area of each region: nine in the southeast, seven in the west, six in the central, and three in the northeast *(see Figure 2)*.

Woodard & Curran collected four soil samples across each of the 25 properties, for a total of 100 unique sample locations. All samples were collected from the upper six inches of the ground surface from upland areas, located at least several feet laterally away from trails, paths, walkways, and pavement. Leaves, twigs, roots, and other detritus were first removed from each soil sampling location. Using a stainless-steel hand trowel, the sampler removed soil from 0 to 6 inches below ground surface and transferred it to a stainless-steel bowl for mixing. Approximately 16 ounces of soil were collected at each sample location. The soil was then transferred to laboratory-supplied glass jars and placed on wet ice in coolers until samples were delivered to the analytical laboratory. Sampling tools were cleaned between each sample location using brushes and water. One equipment blank and three field blanks (using laboratory-supplied PFAS-free water) were collected to confirm that no cross-contamination from equipment or surroundings occurred.

Need for Double-Blind Study

While the lack of exact geospatial information is unusual for environmental studies, a double-blind study design was necessary to protect the property owner from potential regulatory obligations. The MCP cleanup regulations specify soil Reportable Concentrations (RCs) for six PFAS: perfluorodecanoic acid (PFDA), perfluoroheptanoic acid (PFHpA), perfluorohexanesulfonic acid

(PFHxS), perfluorononanoic acid (PFNA), PFOS, and PFOA. If soil concentrations of these PFAS are found in excess of the applicable RCs, the property owner is obligated to notify the Massachusetts Department of Environmental Protection (MassDEP), who may then identify the presence of these compounds as a "release" regulated under the Massachusetts General Law Chapter 21E and MCP cleanup program, regardless of the original source of contamination.

Because of this, and in order to avoid potential regulatory repercussions for the property owners, Woodard & Curran designed the sampling program as a double-blind study where the exact location of each sample result was not known by either Woodard & Curran or the laboratory. The region of the state from where the sample was obtained was documented, as well as the soil and habitat type for each sample, and the four samples from within each conservation area were identified as a group; however, no other geospatial information was collected for the samples.

The process for sample identification was as follows:

1. At least two properties were sampled during each sampling day.
2. The sampler collected one sample from each of four locations at each property, identifying samples by the region (NE for northeast, SE for southeast, C for central, or W for west), habitat type (Forest [FT] or Field [FD]), and soil type (sand [SD], silt [ST], or loam [LM]).
3. Each of the four samples from a property was labeled A through D, and the four samples were kept together in bags or in separate coolers as a group, but a specific property name or other identifier was not assigned to the group. As an example, the sample identification of SE-1A-FT-SD indicates that the sample was obtained from a property in the southeast region (SE), the first sample ("A"), from a forested habitat (FT), and that the soils were best characterized as sand (SD).
4. The sampler transferred the samples to a second individual ("handler"), who then assigned numbered sample identifiers (IDs) to each group of samples collected at each property. Other than the region of the state, the handler did not know from which parks the individual groups of samples were collected on a particular day, and the sampler did not know which ID was assigned to which group of samples they collected. The number "1" in the above example (SE-1A-FT-SD) is the arbitrary number assigned to the property by the handler.
5. Samples were sent on wet ice under chain of custody procedures to Alpha Analytical Laboratories of Mansfield, Massachusetts. To avoid association of specific properties with field duplicates, which would otherwise require additional sample volume collection in the field, extra volume of soil was collected at each location and the laboratory randomly selected samples to perform laboratory duplicate analysis.
6. In summary, the study evaluated a total of 111 samples, which included 100 primary samples from the 25 properties, two field blanks, one equipment blank, and eight laboratory duplicates.

Chemical Analysis

Table 1 summarizes the target PFAS analyte list, which included 36 PFAS analytes. Samples were also analyzed for total organic carbon (TOC) and percent solids. Methods are described in the following pages.

Table 1: Target PFAS Analyte List

Analyte	CASN
11-Chloroeicosafluoro-3-Oxaundecane-1-Sulfonic Acid (11Cl-PF3OUdS)	763051-92-9
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	39108-34-4
1H,1H,2H,2H-Perfluorododecanesulfonic Acid (10:2FTS)	120226-60-0
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	757124-72-4
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	27619-97-2
2,3,3,3-Tetrafluoro-2-1,1,2,2,3,3,3-Heptafluoropropoxy]-Propanoic acid (HFPO-DA)	13252-13-6
4,8-Dioxa-3h-Perfluorononanoic Acid (ADONA)	919005-14-4
9-Chlorohexadecafluoro-3-Oxanone-1-Sulfonic Acid (9Cl-PF3ONS)	756426-58-1
N-Ethyl Perfluorooctane Sulfonamide (NEtFOSA)	4151-50-2
N-Ethyl Perfluorooctanesulfonamido Ethanol (NEtFOSE)	1691-99-2
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	2991-50-6
N-Methyl Perfluorooctane Sulfonamide (NMeFOSA)	31506-32-8
N-Methyl Perfluorooctanesulfonamido Ethanol (NMeFOSE)	24448-09-7
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	2355-31-9
Perfluorobutanesulfonic Acid (PFBS)	375-73-5
Perfluorobutanoic Acid (PFBA)	375-22-4
Perfluorodecanesulfonic Acid (PFDS)	335-77-3
Perfluorodecanoic Acid (PFDA)	335-76-2
Perfluorododecane Sulfonic Acid (PFDoDS)	79780-39-5
Perfluorododecanoic Acid (PFDoA)	307-55-1
Perfluoroheptanesulfonic Acid (PFHpS)	375-92-8
Perfluoroheptanoic Acid (PFHpA)	375-85-9
Perfluorohexadecanoic Acid (PFHxDA)	67905-19-5
Perfluorohexanesulfonic Acid (PFHxS)	355-46-4
Perfluorohexanoic Acid (PFHxA)	307-24-4
Perfluorononanesulfonic Acid (PFNS)	68259-12-1
Perfluorononanoic Acid (PFNA)	375-95-1
Perfluorooctadecanoic Acid (PFODA)	16517-11-6
Perfluorooctanesulfonamide (FOSA)	754-91-6
Perfluorooctanesulfonic Acid (PFOS)	1763-23-1
Perfluorooctanoic Acid (PFOA)	335-67-1
Perfluoropentanesulfonic Acid (PFPeS)	2706-91-4
Perfluoropentanoic Acid (PFPeA)	2706-90-3
Perfluorotetradecanoic Acid (PFTA)	376-06-7
Perfluorotridecanoic Acid (PFTrDA)	72629-94-8
Perfluoroundecanoic Acid (PFUnA)	2058-94-8

PFAS Analysis

For this study, a modified, user-defined liquid chromatography (LC) tandem mass spectrometry (MS) procedure (LC/MS/MS) with solid phase extraction (SPE) was used. This procedure utilized the weak anion exchange (WAX) SPE cartridge and incorporated the use of extracted internal standards (EIS) as part of the isotopic dilution method calibration and sample quantification technique. The target compound list consisted of 31 PFAS compounds, and a total of 19 ^{13}C–enriched and six ^{2}H-enriched compounds were utilized as EIS.

Sample Preparation: A representative sample aliquot was homogenized, and approximately 2 to 4 grams of homogenized soil were weighed into a 50 milliliter (mL) polypropylene centrifuge tube. The samples were fortified with EIS and vortexed with methanol. The samples were then sonicated for 30 minutes and allowed to stand overnight. The sample extracts were then centrifuged, and the supernatant removed for cleanup. An aliquot of the sample extract was then added to the properly prepared WAX SPE cartridge and slowly eluted. Once the entire sample had passed through the cartridge, the sample collection vials were rinsed with methanol, which was then drawn through the cartridge as well. The extract was then concentrated with nitrogen in a heated water bath, fortified with non-EIS, and adjusted to a 1-mL volume with 80:20% (vol/vol) methanol: water.

Extract Analysis Utilizing LC/MS/MS: The extracts were analyzed by LC/MS/MS. A 3-microliter extract injection was made into the LC, which is equipped with a C18 column that is interfaced to the MS/MS. The analytes are separated by LC and identified by comparing the LC retention times, monitored transition ions, and acquired mass spectra to the retention times and reference spectra for calibration standards acquired under identical LC/MS/MS conditions. The target analytes were then quantified in accordance with the method Standard Operating Procedures.

Total Organic Carbon

The samples were analyzed for TOC in accordance with U.S. Environmental Protection Agency (USEPA) Method 9060 using an elemental analyzer operated in combustion mode. An aliquot of solid sample was dried, homogenized, weighed into a tin capsule, pre-treated with hydrochloric acid, and heated to 75°C to liberate the inorganic carbon to CO_2 prior to analysis. The sample was oxidized in a pure oxygen environment, introduced into a furnace by a 60-slot autosampler, then combusted. The oxygen carrier gas was combined with the carbon content of the combusted sample to form carbon dioxide (CO_2). A thermal conductivity detector then measured the CO_2. The amount of CO_2 derived from a sample is directly proportional to the concentration of organic carbon material in the sample.

Data Usability Analysis

New Environmental Horizons (NEH) of Arlington, Massachusetts conducted a USEPA Level 4 data validation on several laboratory reports. Woodard & Curran reviewed the remaining laboratory reports for the detected PFAS analytes for major quality control issues. The results for any analytes that had less than 10% laboratory surrogate recoveries were rejected *(flagged with an 'R' in Appendix A)*. Where a sample analysis was rerun due to recovery or other issues, the results for analytes with a higher recovery were used as the representative concentration for that sample. Results for samples with low recoveries below laboratory acceptance criteria but greater than

10% are biased low but were considered representative and usable for purposes of calculating summary statistics and deriving conclusions from the dataset.

The results of the data validation review process indicated that the vast majority of PFAS results were identified as usable for characterization of background conditions. Analytes with instances of one or more rejected results included PFHxA (7 samples), PFHpA (6 samples), PFPeA (5 samples), PFBA (4 samples), PFOA (3 samples), and PFNA (1 sample).

Statistics

The USEPA statistical software program ProUCL (Version 5.2) was used to calculate summary statistics, conduct data distribution and outlier tests, and generate upper tolerance limits (UTLs). Concentrations are reported in units of micrograms per kilogram (µg/kg) dry weight (or parts per billion). Data were also evaluated for potential correlations between PFAS concentrations and TOC using ProUCL. The Kaplan-Meier method was used in evaluation of censored data (i.e., results reported as not detected above the laboratory reporting limit) in calculating UTLs, correlations, and other statistics.

Where duplicate samples were analyzed, the maximum detected concentration, or the lowest reporting limit if non-detect, was used as the representative concentration for that sample.

ProUCL produces multiple UTLs for various data distributions. The 95% UTLs were selected according to the following hierarchy of criteria:

1. The 95% UTLs from parametric distributions were preferred over non-parametric distributions.
2. Of the parametric distributions, the order preference was as follows: normal > gamma > lognormal.
3. If data distribution was non-parametric, then non-parametric statistics were selected (95% UTL with 95% coverage).

These statistical calculations were used for comparing to current MCP soil standards, as well as to calculate concentrations that could be considered representative of anthropogenic background concentrations of PFAS.

Results

Table 2 presents the frequency of detection, range of detected concentrations, mean concentration, standard deviation, and 95% UTLs for the detected PFAS analytes across all 100 samples collected. A tabulated summary of validated analytical laboratory results for all analytes is provided in *Appendix A*.

Table 2: Summary Statistics[2] for Detected PFAS in Massachusetts Background Soil Samples

Analyte	Detection Frequency	No. of Detects/ No. Valid Results	Range of Detected Concentrations (µg/kg)		Median Detected Concentration (µg/kg)	Mean Detected Concentration (µg/kg)	Standard Deviation (µg/kg)	95% Upper Tolerance Limit (µg/kg)
			Minimum	Maximum				
PFOS	86%	86/100	0.328	6.00	1.29	1.379	0.957	3.07
PFOA	68%	66/97	0.293	4.20	0.758	0.990	0.686	2.03
PFNA	36%	36/99	0.293	1.20	0.450	0.517	0.215	0.715
PFDA	16%	16/100	0.329	0.755	0.4065	0.442	0.122	0.458
PFHpA	13%	12/94	0.326	1.53	0.4605	0.595	0.375	0.63
PFBA	8%	8/96	0.78	2.39	0.986	1.215	0.53	1.04
PFUnA	2%	2/100	0.771	0.787	0.779	0.779	0.0113	Not calculated
PFHxA	1%	1/93	3.56	3.56	3.56	3.56	Not calculated	Not calculated
PFPeA	1%	1/95	5.46	5.46	5.46	5.46	Not calculated	Not calculated

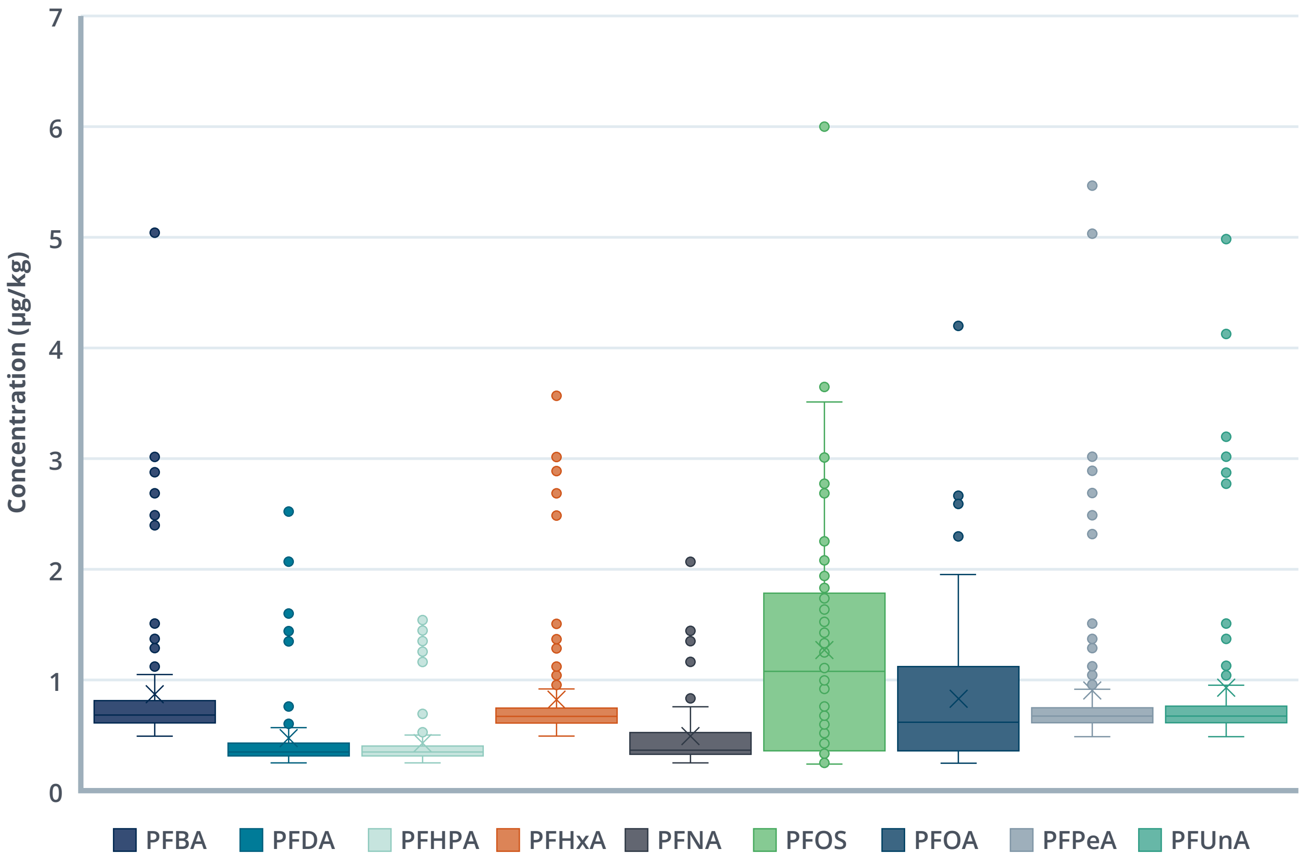
[2] Kaplan-Meier mean and 95% UTL calculated using both detected and non-detected results.

Summary of State-wide Results

One or more PFAS analytes were detected in 88 of the 100 sample locations, and PFAS were detected at every property sampled. PFOS and PFOA were detected at the highest frequencies and at the overall highest concentrations (median concentrations of 1.29 µg/kg for PFOS and 0.758 µg/kg for PFOA). PFNA was detected in 36% of samples; all other PFAS analytes were detected at frequencies lower than 20%. PFPeA and PFHxA were detected only in one sample each, but was detected at the third highest concentration among detected analytes compared to PFOS and PFOA. In general, however, the range of concentrations across each detected PFAS was narrow and typically within a factor of 10.

Figure 3 presents box and whisker plots showing the relative ranges of distribution in concentration for each of the detected PFAS analytes. Of the 36 PFAS analytes, nine (PFOS, PFOA, PFNA, PFDA, PFHpA, PFBA, PFUnA, PFHxA, and PFPeA) were detected in one or more samples *(Figure 4)*.

Figure 3: Box and Whisker Plot for all Detected PFAS Analytes—Statewide

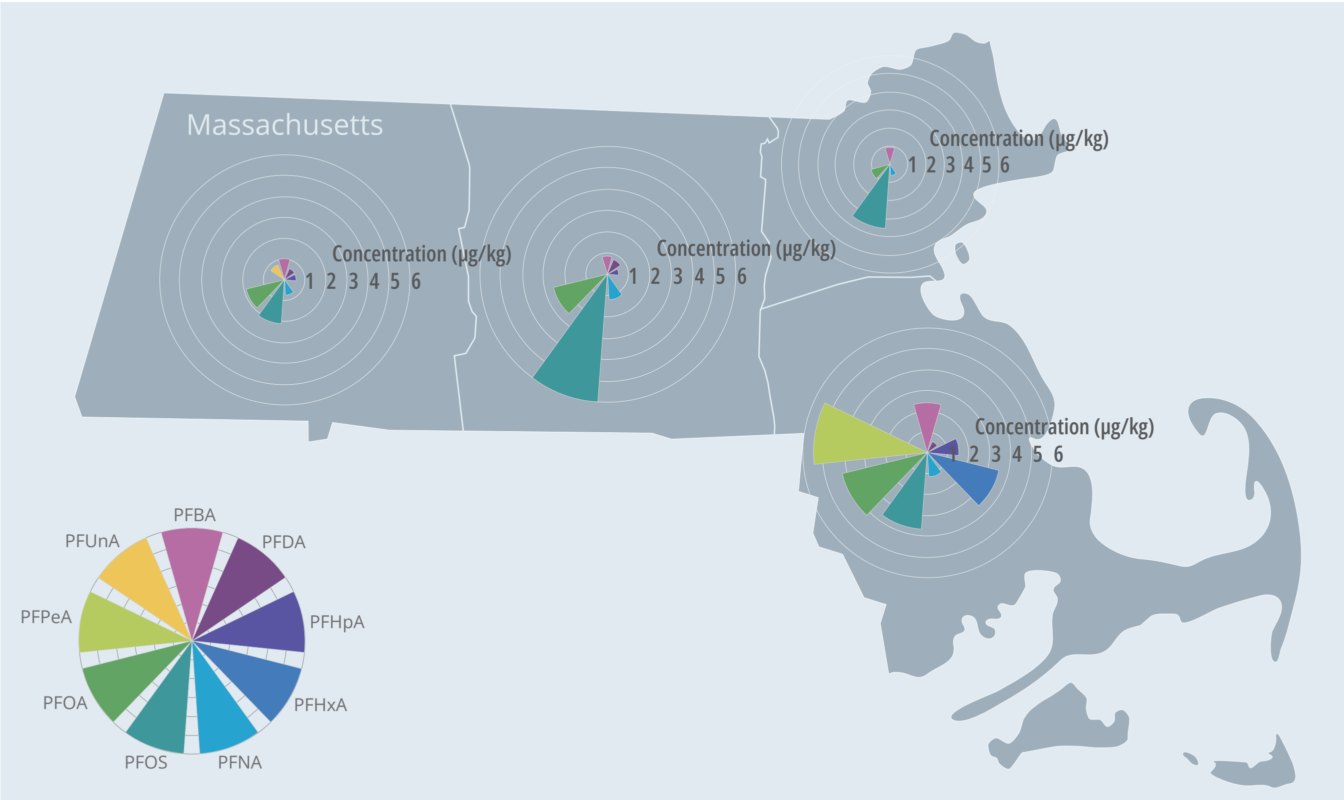


Notes: Non-detect results plotted at reporting limit. The above plot includes a "box" of varying width, with lines on either end called "whiskers". The bottom and top edges of the "box" indicate the first (25th) and third (75th) quartile concentrations, respectively. The median concentration is depicted as the horizontal line within the box between the two quartiles. The 'X' within the box is the mean concentration. The "whiskers" indicate 1.5 times the interquartile range of the concentrations. Points outside of the whiskers are potential statistical outliers.

Regional Differences

Evaluation of results by Massachusetts region indicated slight differences in the detection frequency and magnitude of the various PFAS, although overall, the differences in PFOA and PFOS concentrations across the four regions were marginal. *Figure 4* shows the highest detected concentration among the four regions, with each slice of the pie chart representing one of the nine individual PFAS analytes that was detected.

Figure 4: Types of PFAS and Maximum PFAS Concentrations across Massachusetts Regions



The western and northeast regions generally had the lowest concentrations of PFAS among the four regions. The highest detected PFOA concentration (4.2 µg/kg) was detected in the southeast region, which also had the only detected concentrations of PFHxA and PFPeA. The central region had the highest detected PFOS concentration (6 µg/kg).

Figures 5 and *6* present box and whisker plots comparing the distribution of the results for PFOS and PFOA, respectively, in each of the four state regions. As indicated for both compounds, variability among the four regions is relatively low; the scale of the concentration on the vertical axis in both charts spans only seven parts per billion. Even “outliers” (for example, 6 µg/kg for PFOS in the central region) are only about two to four times the concentration of the next highest PFAS concentration. Statistical comparison of the regional datasets via non-parametric Kruskal-Wallis Analysis of Variance (ANOVA) shows no statistical difference ($p<0.05$) in median PFOS concentrations among the four regions, and a modest although statistically significant difference for PFOA in median concentrations of the central region compared to the other three regions.

Figure 5: Box and Whisker Plots of PFOS Concentrations in Soil in the Four Regions of Massachusetts

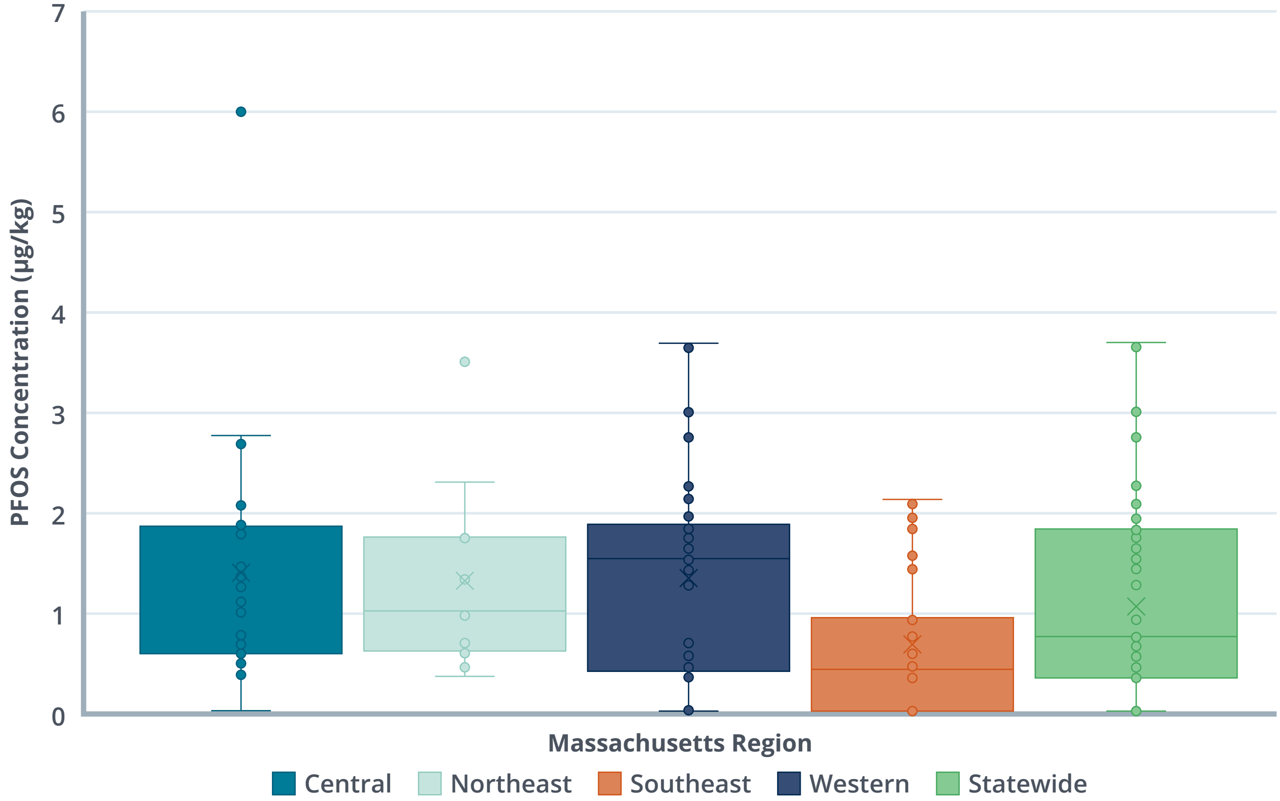
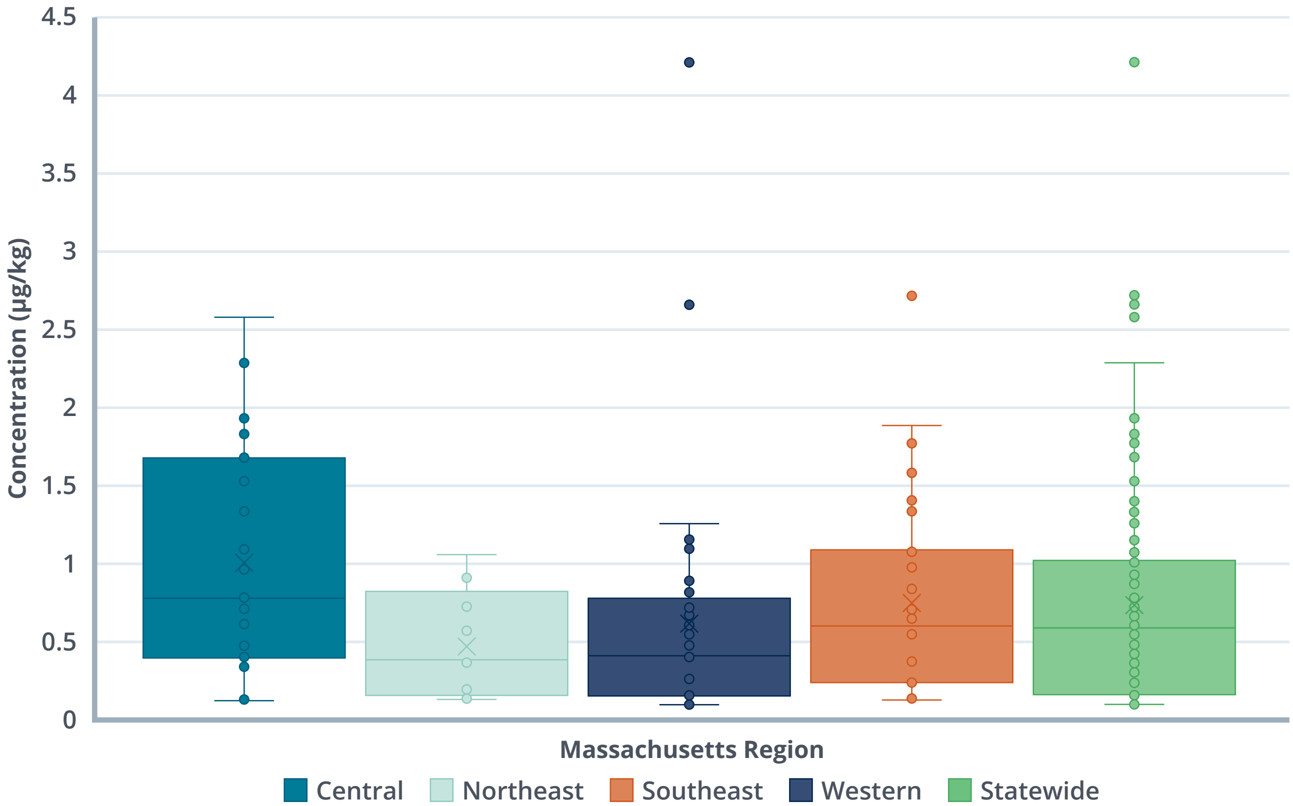


Figure 6: Box and Whisker Plots of PFOA Concentrations in Soil in the Four Regions of Massachusetts



Other Parameters

This study focused on only surficial soils (zero to six inches below the ground surface). Most of the samples were obtained from loamy soils within mature, albeit relatively young, mixed hardwood forests that are characteristic of Massachusetts. Percent solids in samples ranged from 31% to 98%; the average solids content for samples was 69%. Of the 100 locations sampled, 88% were from soils best characterized as loam, consistent with most locations occurring in mature forests. Because of this, it is difficult to draw any conclusions about PFAS concentrations relating to soil type. Likewise, 73% of samples were collected from forest versus field habitats. Because the dataset was biased toward loam samples from forest, Woodard & Curran did not conduct any analyses for relationships between the presence or concentration of individual PFAS with soil type or habitat.

The TOC content in samples ranged from 1% to 29%, with an overall average TOC concentration of 5.7%. In each case, correlation of TOC content with PFOS and PFOA concentration was statistically significant although poor, with R values of 0.55 for PFOS and 0.23 for PFOA (95% confidence).

Discussion

The findings generated from this study show that PFAS—in particular, PFOS and PFOA—are ubiquitous in surface soil in undeveloped open spaces across Massachusetts, in areas that are considered pristine or otherwise unimpacted by known or suspected sources of contamination. As discussed in Section 1, the properties that were the focus of this study were all undeveloped conservation and/or recreational lands that were selected specifically due to the lack of nearby known or suspected PFAS sources. These findings suggest that atmospheric deposition, via either dry or wet depositional processes, likely plays a key role in both the localized and widespread distribution of PFAS in both the atmosphere and the ground. Atmospheric transport and deposition have been implicated in PFAS transport around the globe to remote areas such as the Arctic (e.g., Nash et al., 2011; Kwok et al., 2013).

Comparison to MCP Soil Standards

MassDEP currently regulates six PFAS compounds ("PFAS6"), which include PFOS, PFOA, PFNA, PFDA, PFHpA and PFHxS, and has promulgated soil standards in MCP. For PFAS, the most stringent among the various categories of soil criteria are the Method 1 S1/GW1 standards (310 CMR 40.0985, Table 5). These are soil criteria protective of residential or similar high-intensity exposure scenarios and where the underlying aquifer is used as a current or potential future drinking water source. PFAS concentrations in background samples exceeded these standards but did not exceed any other MCP soil standard that was not based on leaching to a potable aquifer (i.e., S1/GW2; S1/GW3). Simply put, the most stringent PFAS soil standards in Massachusetts (and other states) are those that are based on potential leaching to a potable aquifer; the PFAS soil standards based on direct contact/incidental ingestion exposures are significantly higher, often by orders of magnitude.

Figure 7 indicates the percentage of detected concentrations of the PFAS6 that exceed Method 1 S1/GW1 standards across all Massachusetts samples. Sixty percent of samples in the study exceeded a Method 1 S1/GW1 standard, and 21 of the 25 properties had at least one sample with an exceedance of a Method 1 S1/GW1 standard.

Figure 7: Percent of Detected PFAS6 Concentrations that Exceed MCP Method 1 S1/GW1 Standards

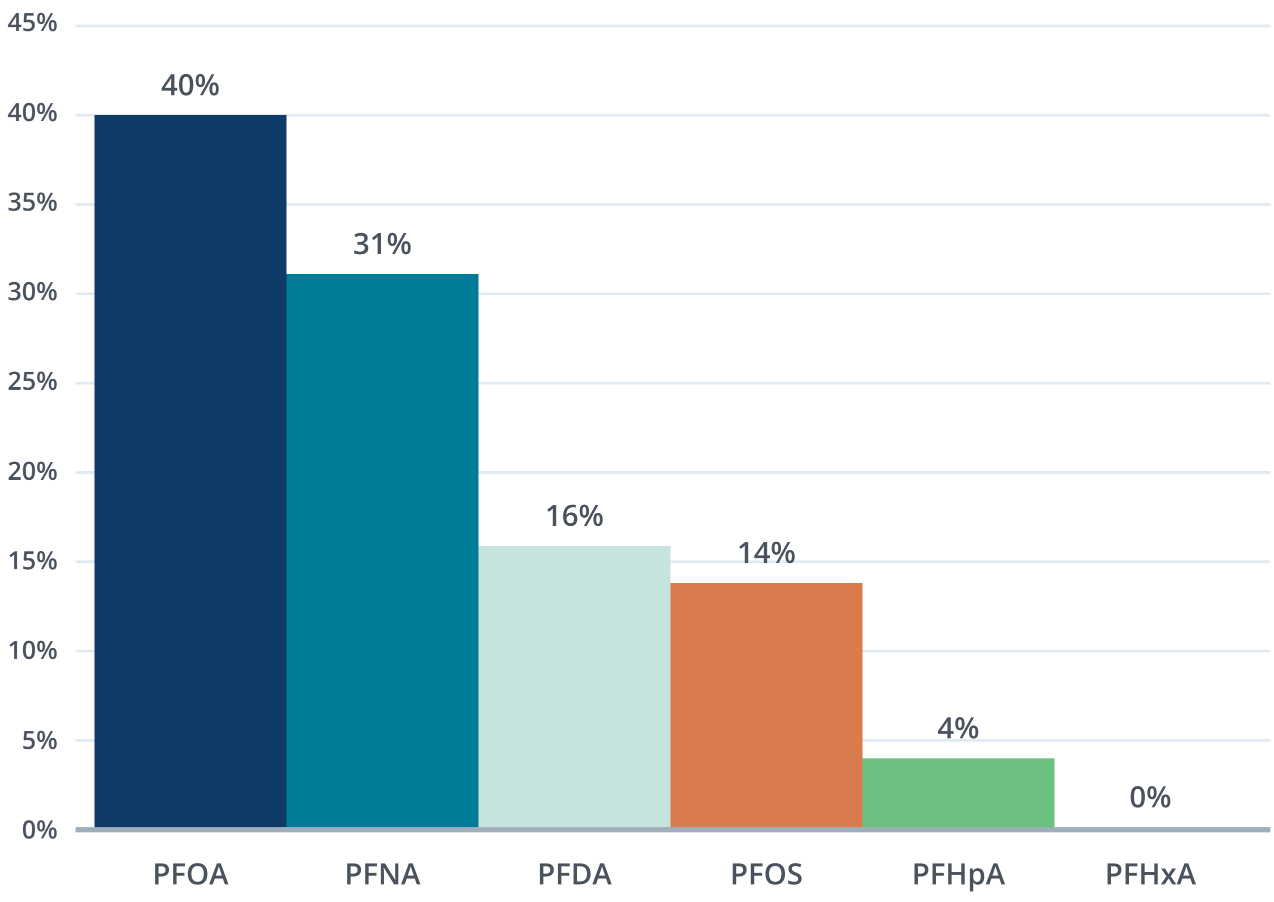
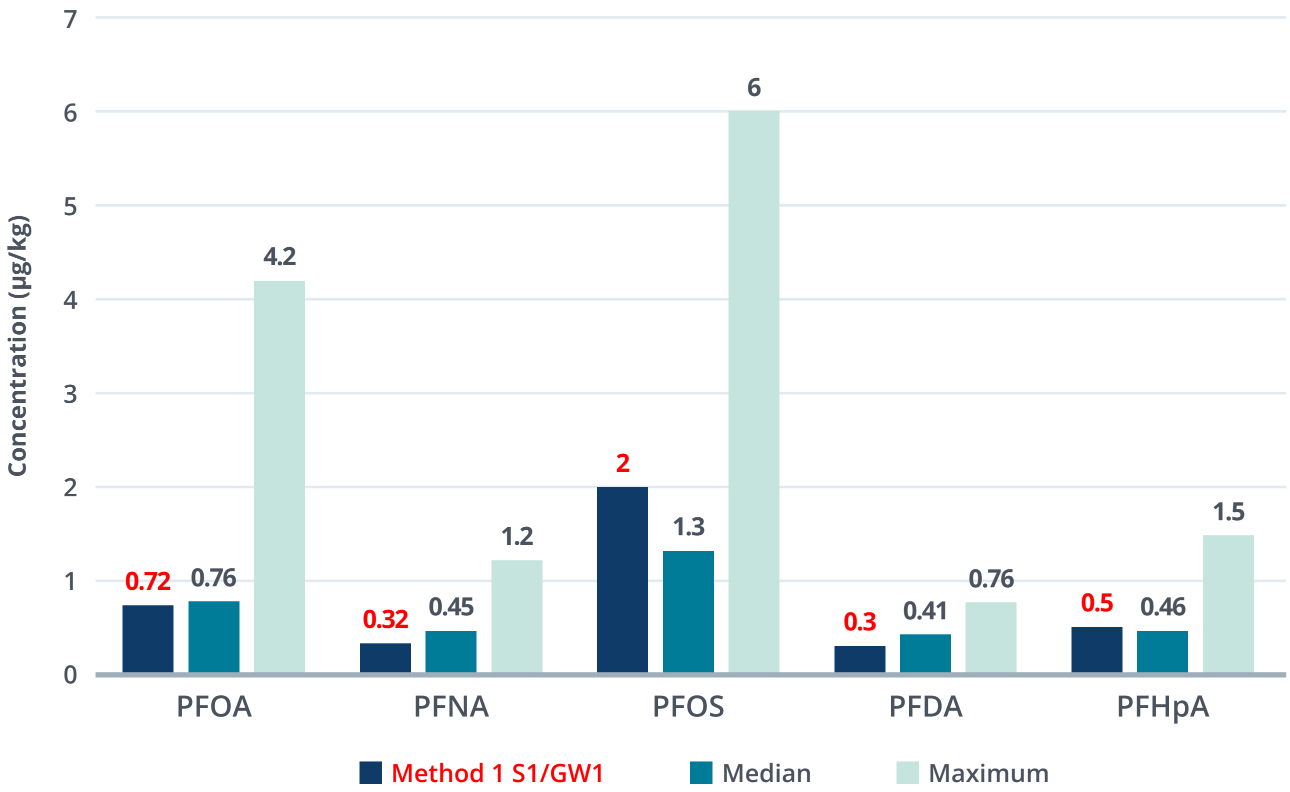


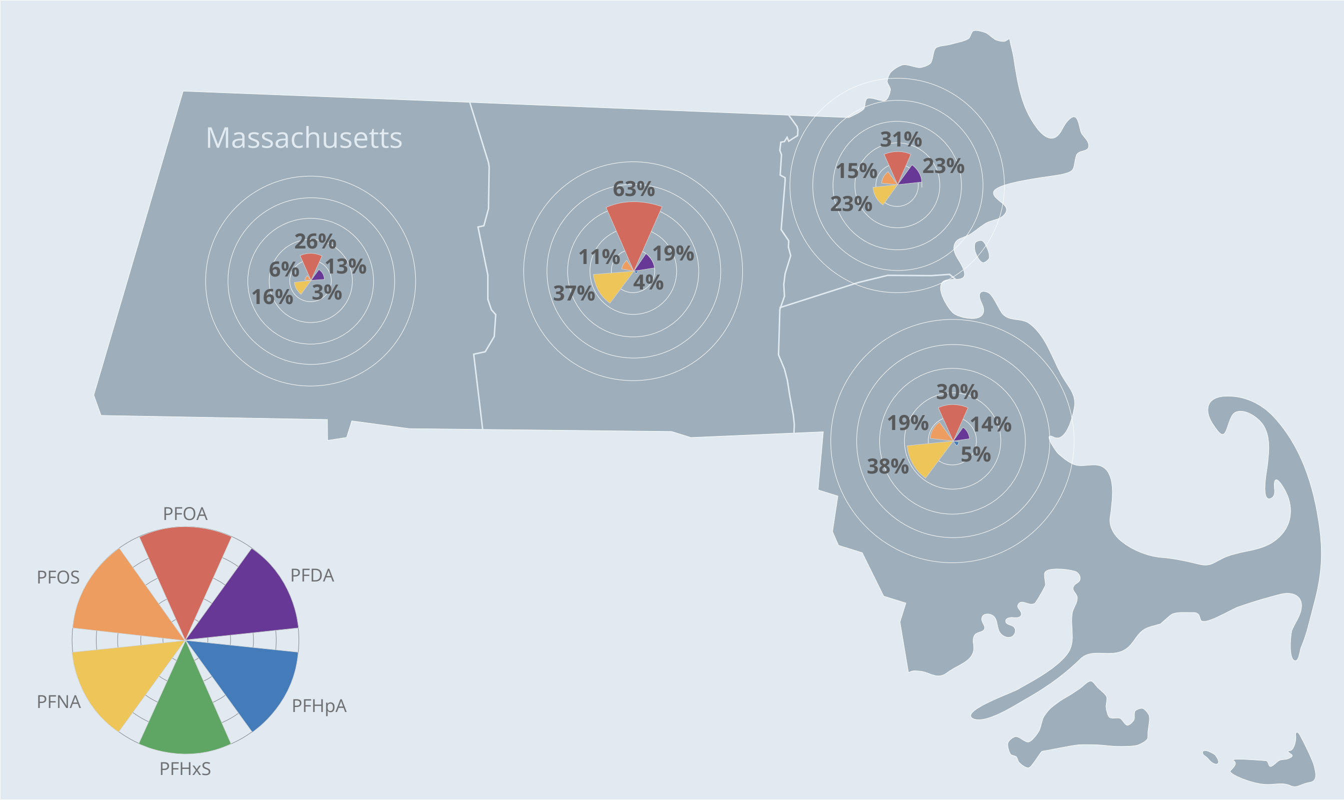
Figure 8 depicts the maximum and median detected concentrations of PFOA, PFNA, PFOS, PFDA, and PFHpA in soil samples from across the state to MCP Method 1 S1/GW1 standards. The maximum detected concentrations of all five compounds exceeded the standards, while the median concentrations of PFOA, PFNA, and PFDA exceeded the standards.

Figure 8: Comparison of Maximum and Median Detected PFAS Concentrations to MCP Method 1 S1/GW1 Standards



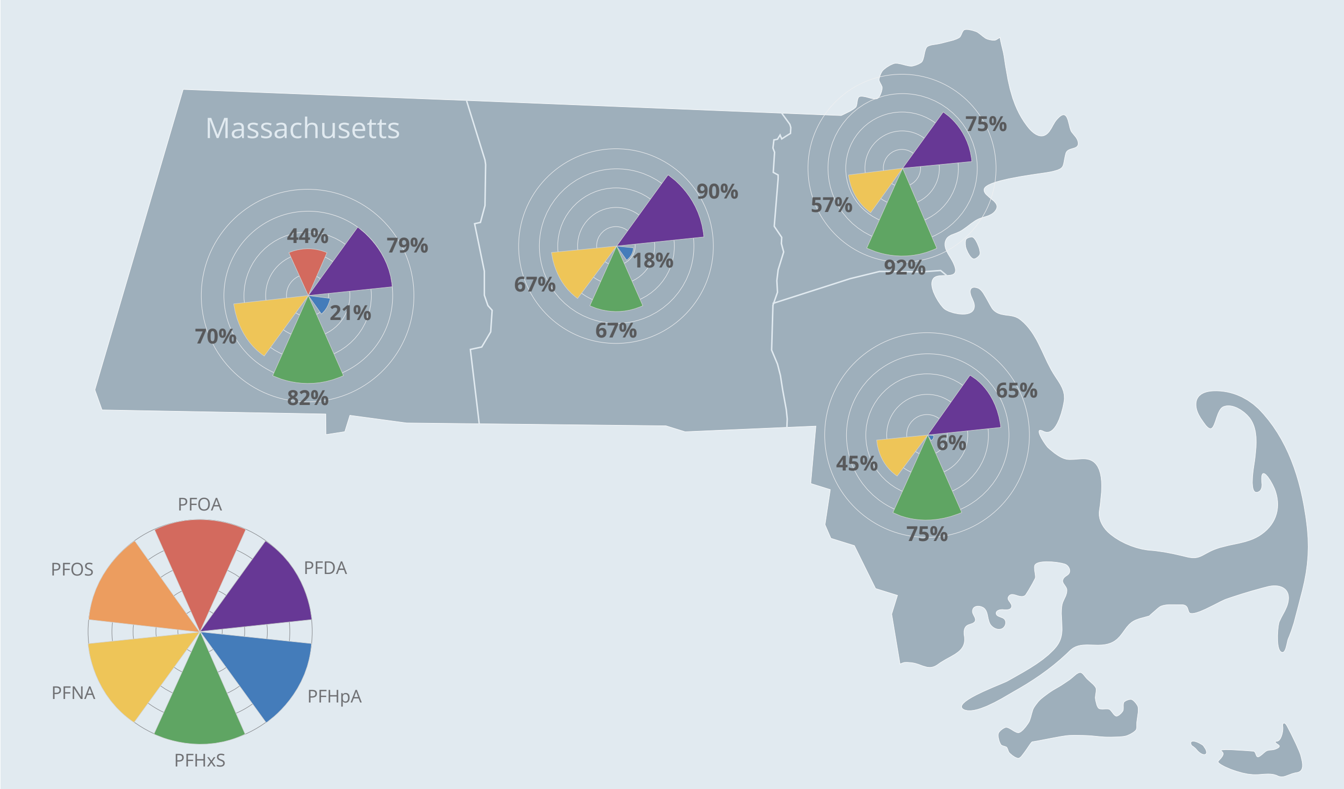
On a regional basis *(Figure 9)*, the central region of the state had the highest percentage of Method 1 S1/GW1 exceedances, with 67% of PFOA concentrations and 41% of PFNA concentrations higher than their standards, although exceedances for these compounds (and other PFAS) occurred in all regions.

Figure 9: Percentage of Soil Samples by Region with PFAS6 Concentrations Greater than MCP Method 1 S1/GW1 Standards



It is important to note that even the reporting limits for non-detect results exceeded Method 1 S1/GW1 standards in numerous samples for all PFAS6 compounds except for PFOS. *Figure 10* depicts the percentage of reporting limits that exceeded MCP criteria for the PFAS6 analytes. As discussed, PFHxS was not detected in any Massachusetts sample; however, the majority of samples had reporting limits above the Method 1 S1/GW1 standard of 0.3 μg/kg for this analyte. Overall, the results from this study highlight the need for further consideration of the technical feasibility of achieving an appropriate level of analytical sensitivity when setting PFAS soil criteria.

Figure 10: Percentage of PFAS6 Laboratory Reporting Limits that Exceed MCP Method 1 S1/GW1 Standards



Considering that the sampled properties represent uncontaminated background areas of the state, these findings are significant with respect to characterizing the nature and extent of PFAS impacts at actual contaminated sites, even those with a known PFAS source, given that there is an underlying background contribution of PFAS from non-point sources. These results highlight the need to include an evaluation of background as an essential component of PFAS site investigation.

MassDEP derives MCP soil standards considering:

1. Human health risk-based concentrations based on direct-contact exposure routes (dermal contact, incidental ingestion);
2. Leaching potential to underlying groundwater; and
3. Feasibility of achievement, which includes achievable reporting limits as well as background concentrations, when available.

When the calculated risk-based and/or leaching-based concentrations are lower than background concentrations, the criteria are set at the background concentration. An example of this is the Method 1 S1/GW1 criterion for arsenic of 20 parts per million, which is based on the 90^{th} percentile arsenic concentration (rounded to one significant figure) from a Massachusetts study (MassDEP, 1995).

A Massachusetts-specific background dataset for PFAS was not available when MassDEP derived the Method 1 soil standards for PFAS6. MassDEP instead relied on 90th percentile concentrations from the Vermont background study (Zhu et al., 2019). The results from the Woodard & Curran study show that Massachusetts background concentrations of the PFAS6 are higher than those of Vermont, thus highlighting the need to update the Method 1 standards to reflect actual Massachusetts-specific PFAS background concentrations.

Lastly, it is important to note that none of the detected concentrations in this study exceeded MCP standards for non-potable aquifers, indicating that the concentrations of PFAS in Massachusetts background soils do not pose either an unacceptable human health risk as a result of direct contact with soils or an ecological risk associated with leaching to groundwater and subsequent migration to a surface water body.

Study Limitations and Direction for Future Research

The objective of this study was to characterize the types and concentrations of PFAS in soil in background areas of Massachusetts. While some of these background locations were in more densely developed portions of the state, they were all located within rural or suburban areas. The background PFAS soil profile could potentially look different in soils from urban areas, based on land uses and depending on the known/unknown PFAS point sources and other factors in these areas. For example, another previous PFAS background study differentiated between urban and non-urban soils and found that PFDA and PFOS had overall higher concentrations in urban vs. non-urban areas (SHA, 2022). Data from additional broad geographic studies would be useful in better understanding how PFAS background varies regionally and from land use differences.

This study also focused on only surficial soils up to six inches below the ground surface. Most of the samples were obtained from loamy soils within mature, albeit relatively young, mixed hardwood forests that are characteristic of Massachusetts. It is expected, based on the likely age of such forests (grown over former farmland within the past century) and the leaf litter that is annually deposited, that this depth interval is representative of the past several decades; however, it is unknown how deep PFAS contamination in soils extends due to historical deposition, soil turnover by organisms, erosion, or leaching via precipitation. Additionally, our study composited soil from across the six-inch interval; it is possible that there may be stratification of PFAS concentrations and composition even within that shallow interval. Studies that include soil profiling in combination with depositional studies (such as radiodating) will allow for more informed conclusions to be made regarding stratification and deposition.

Soil characteristics may potentially influence the nature and concentration of PFAS at a particular location. While we collected qualitative information on soil type and location, and quantitative data for soil organic carbon content, our study was unable to determine any association between these types of factors and PFAS concentration. Many studies have shown PFAS sorption to soil is correlated with TOC (e.g., Milinovic et al. 2015) and with pH and cation composition (e.g., Pereira et al., 2018). Further understanding of these associations will be critical for assessing fate and transport of PFAS in the soil column.

Lastly, the Method 1 S1/GW1 standards are based on the assumption that a contaminant in soil may leach to an underlying aquifer that is or may be used as a potable water supply. One of the largest current data gaps surrounding PFAS environmental issues is that of leaching potential—what factors affect the migration of PFAS in soil into underlying aquifers? Given the widespread number of Method 1 S1/GW1 exceedances observed in background areas of Massachusetts, one would expect to see widespread PFAS groundwater contamination at levels exceeding drinking water criteria. Potable water monitoring data collected by MassDEP in the Private Wells PFAS Sampling Program in 2021–2022 across many municipalities within Massachusetts, however, did not find this to be the case. Our review of the PFAS private well data posted by MassDEP indicated that, of 1,669 samples, PFAS6 constituents were detected in 27% of wells, and at levels above the GW-1 standard of 20 ng/L in only about 6% of wells across the state. This lack of widespread groundwater exceedances does not mirror the widespread Method 1 S1/GW1 soil criteria exceedances (58%) observed in our study. The association between soil PFAS concentrations and aquifer PFAS concentrations is a key area for which few data are available. Further research on this topic is needed to better understand the fate and transport of PFAS through the soil column and to develop or refine fate and transport models that more accurately estimate leachability potential.

Conclusions

The primary objective of our study was to determine concentrations of PFAS in soils within areas of Massachusetts representative of background with respect to Massachusetts General Laws Chapter 21E and the MCP. Findings from this study show that PFAS are present in soil in undeveloped areas at detectable concentrations across the state. While concentrations are variable both within specific undeveloped areas as well as state-wide, the overall concentration spread is relatively small. Given the lack of known or suspected PFAS sources at or proximal to the properties (all conservation land), it was concluded that PFAS were most likely deposited via atmospheric deposition from non-specific sources such as atmospheric emissions. These findings were similar to those of other state studies that showed widespread, low-level PFAS contamination across New England.

Particularly problematic was that many of the detected PFAS concentrations in these undeveloped open spaces with no known or probable source of PFAS exceeded Massachusetts leaching-based soil standards applicable to protection of potable aquifers. This suggests widespread PFAS impacts to potable groundwater (i.e., PFAS levels in groundwater above the GW-1 standard) across the state; however, private well data from across Massachusetts do not show that this is the case, thus highlighting the uncertainty regarding accuracy of models used to evaluate the soil leaching to groundwater pathway. Also problematic is that these study results suggest that for many contaminated sites, state standards may simply be unachievable given the ubiquity of detected PFAS concentrations coupled with standards set at levels at or below background levels, or in some instances below current laboratory analytical testing capabilities for a highly variable matrix such as soil.

Overall, the concentrations of PFAS observed in these open space recreational areas are not expected to pose an unacceptable health risk for the recreational users of these areas or for the plants and wildlife that inhabit these areas. However, the state of both science and regulation is rapidly evolving for PFAS, particularly with respect to human and ecological toxicology, and new information and state and federal guidance and standards may potentially alter such conclusions in the future.

Lastly, this and other regional studies of PFAS in soil highlight the need for characterizing background concentrations in PFAS when undertaking an environmental investigation of a PFAS release, particularly in Massachusetts. Clearly, PFAS are ubiquitous in the environment as a result of many non-specific sources and are capable of long-range transport, such that even areas considered to be pristine may be impacted. Consequently, because PFAS can come to be located at any property by a variety of mechanisms, the investigator needs to be robust in assessing both the nature and extent at a disposal site and background levels of PFAS.

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Station Name	**CAS Number**	**Units**	**MassDEP S1/GW-1**	**MassDEP S1/GW-2**	**MassDEP S1/GW-3**	**CEN-1**	**CEN-1**	**CEN-1**	**CEN-1**	**CEN-2**	**CEN-2**	**CEN-2**	**CEN-2**	**CEN-2**	**CEN-3**	**CEN-3**	**CEN-3**	**CEN-3**	**CEN-3**	**CEN-3**	**CEN-4**
Sample ID						**CEN-1A-ST-FD**	**CEN-1B-LM-FT**	**CEN-1C-LM-FT**	**CEN-1D-LM-FT**	**CEN-2A-LM-FT**	**CEN-2B-LM-FT**	**LD**	**CEN-2C-LM-FT**	**CEN-2D-LM-FT**	**CEN-3A-LM-FD**	**CEN-3B-LM-FT**	**LD**	**LD**	**CEN-3C-LM-FT**	**CEN-3D-LM-FT**	**CEN-4A-LM-FT**
Sample Date						9/17/2021	9/17/2021	9/17/2021	9/17/2021	10/10/2021	10/10/2021	10/25/2021	10/10/2021	10/10/2021	9/17/2021	9/17/2021	9/28/2021	10/1/2021	9/17/2021	9/17/2021	9/17/2021
Primary Sample												CEN-2B-LM-FT					CEN-3B-LM-FT	CEN-3B-LM-FT			
PFAS																					
11-Chloroeicosafluoro-3-Oxaundecane-1-Sulfonic Acid (11Cl-PF	763051-92-9	ug/kg				<1.28	<1.21	<1.39	<1.48	<1.27	<1.4		<1.31	<1.15	<10	<1.35		<1.33	<2.72	<3	<1.34
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	39108-34-4	ug/kg				<0.64	<0.605	<0.697	<0.74	<0.637	<0.703	<0.676	<0.655	<0.576	<5.03	<0.674		<0.667	<1.36	<1.5	<0.67
1H,1H,2H,2H-Perfluorododecanesulfonic Acid (10:2FTS)	120226-60-0	ug/kg				<1.28	<1.21	<1.39	<1.48	<1.27	<1.4	<1.35	<1.31	<1.15	<10	<1.35		<1.33	<2.72	<3	<1.34
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	757124-72-4	ug/kg				<1.28	<1.21	<1.39	<1.48	<1.27	<1.4	<1.35	<1.31	<1.15	<10	<1.35		<1.33	<2.72	<3	<1.34
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	27619-97-2	ug/kg				<0.64	<0.605	<0.697	<0.74	<0.637	<0.703	<0.676	<0.655	<0.576	<5.03	<0.674		<0.667	<1.36	<1.5	<0.67
2,3,3,3-Tetrafluoro-2-1,1,2,2,3,3,3-Heptafluoropropoxy]-Pro	13252-13-6	ug/kg				<12.8	<12.1	<13.9	<14.8	<12.7	<14	<13.5	<13.1	<11.5	<100	<13.5		<13.3	<27.2	<30	<13.4
4,8-Dioxa-3h-Perfluorononanoic Acid (ADONA)	919005-14-4	ug/kg				<1.28	<1.21	<1.39	<1.48	<1.27	<1.4	<1.35	<1.31	<1.15	<10	<1.35		<1.33	<2.72	<3	<1.34
9-Chlorohexadecafluoro-3-Oxanone-1-Sulfonic Acid (9Cl-PF3ONS	756426-58-1	ug/kg				<1.28	<1.21	<1.39	<1.48	<1.27	<1.4	<1.35	<1.31	<1.15	<10	<1.35		<1.33	<2.72	<3	<1.34
N-Ethyl Perfluorooctane Sulfonamide (NEtFOSA)	4151-50-2	ug/kg				<1.28	<1.21	<1.39	<1.48	<1.27	<1.4	<1.35	<1.31	<1.15	<2.79	<1.35		<1.33	<2.72	<3	<1.34
N-Ethyl Perfluorooctanesulfonamido Ethanol (NEtFOSE)	1691-99-2	ug/kg				<2.56	<2.42	<2.79	<2.96	<2.55	<2.81	<2.7	<2.62	<2.3	<5.58	<2.7		<2.67	<5.45	<6	<2.68
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	2991-50-6	ug/kg				<0.64	<0.605	<0.697	<0.74	<0.637	<0.703	<0.676	<0.655	<0.576	<5.03	<0.674		<0.667	<1.36	<1.5	<0.67
N-Methyl Perfluorooctane Sulfonamide (NMeFOSA)	31506-32-8	ug/kg				<1.28	<1.21	<1.39	<1.48	<1.27	<1.4	<1.35	<1.31	<1.15	<2.79	<1.35		<1.33	<2.72	<3	<1.34
N-Methyl Perfluorooctanesulfonamido Ethanol (NMeFOSE)	24448-09-7	ug/kg				<2.56	<2.42	<2.79	<2.96	<2.55	<2.81	<2.7	<2.62	<2.3	<5.58	<2.7		<2.67	<5.45	<6	<2.68
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	2355-31-9	ug/kg				<0.64	<0.605	<0.697	<0.74	<0.637	<0.703	<0.676	<0.655	<0.576	<5.03	<0.674		<0.667	<1.36	<1.5	<0.67
Perfluorobutanesulfonic Acid (PFBS)	375-73-5	ug/kg				<0.32	<0.303	<0.348	<0.37	<0.318	<0.351	<0.338	<0.328	<0.288	<2.51	<0.337		<0.334	<0.681	<0.75	<0.335
Perfluorobutanoic Acid (PFBA)	375-22-4	ug/kg				<0.64	<0.605	<0.697	<0.74	<0.637	<0.703	<0.676	**0.847**	<0.576	<5.03	<0.674		<0.667	<1.36	<1.5	<0.67
Perfluorodecanesulfonic Acid (PFDS)	335-77-3	ug/kg				<0.64	<0.605	<0.697	<0.74	<0.637	<0.703	<0.676	<0.655	<0.576	<5.03	<0.674		<0.667	<1.36	<1.5	<0.67
Perfluorodecanoic Acid (PFDA)	335-76-2	ug/kg	0.3	300	300	<0.32	<0.303	<0.348	<0.37	**0.369**	<0.351	<0.338	<0.328	<0.288	<2.51	<0.337		<0.334	**0.755**	<0.75	<0.335
Perfluorododecane Sulfonic Acid (PFDoDS)	79780-39-5	ug/kg				<1.28	<1.21	<1.39	<1.48	<1.27	<1.4	<1.35	<1.31	<1.15	<10	<1.35		<1.33	<2.72	<3	<1.34
Perfluorododecanoic Acid (PFDoA)	307-55-1	ug/kg				<0.64	<0.605	<0.697	<0.74	<0.637	<0.703	<0.676	<0.655	<0.576	<5.03	<0.674		<0.667	<1.36	<1.5	<0.67
Perfluoroheptanesulfonic Acid (PFHpS)	375-92-8	ug/kg				<0.64	<0.605	<0.697	<0.74	<0.637	<0.703	<0.676	<0.655	<0.576	<5.03	<0.674		<0.667	<1.36	<1.5	<0.67
Perfluoroheptanoic Acid (PFHpA)	375-85-9	ug/kg	0.5	300	300	<0.32	<0.303	<0.348	<0.37	<0.318	<0.351	<0.338	**0.442**	<0.288	R	<0.337		**0.362**	<0.681	<0.75	<0.335
Perfluorohexadecanoic Acid (PFHxDA)	67905-19-5	ug/kg				<3.2	<3.03	<3.48	<3.7	<13.1	<14.9	<3.38	<13.5	<11.5	<6.97	<3.37			<6.81	<28.9	<3.35
Perfluorohexanesulfonic Acid (PFHxS)	355-46-4	ug/kg	0.3	300	300	<0.32	<0.303	<0.348	<0.37	<0.318	<0.351	<0.338	<0.328	<0.288	<2.51	<0.337		<0.334	<0.681	<0.75	<0.335
Perfluorohexanoic Acid (PFHxA)	307-24-4	ug/kg				<0.64	<0.605	<0.697	<0.74	<0.637	<0.703	<0.676	<0.655	<0.576	R	<0.674		<0.667	<1.36	<1.5	<0.67
Perfluorononanesulfonic Acid (PFNS)	68259-12-1	ug/kg				<1.28	<1.21	<1.39	<1.48	<1.27	<1.4	<1.35	<1.31	<1.15	<10	<1.35		<1.33	<2.72	<3	<1.34
Perfluorononanoic Acid (PFNA)	375-95-1	ug/kg	0.32	300	300	<0.32	<0.303	<0.348	<0.37	**0.437**	<0.351	<0.338	**0.51**	**0.409**	**0.75**	**0.494**		**0.525**	**1.2**	<0.75	<0.335
Perfluorooctadecanoic Acid (PFODA)	16517-11-6	ug/kg				<3.2	<3.03	<3.48	<3.7	<13.1	<14.9	<3.38	<13.5	<11.5	<6.97	<3.37			<6.81	<28.9	<3.35
Perfluorooctanesulfonamide (FOSA)	754-91-6	ug/kg				<0.64	<0.605	<0.697	<0.74	<0.637	<0.703	<0.676	<0.655	<0.576	<1.39	<0.674		<0.667	<1.36	<1.5	<0.67
Perfluorooctanesulfonic Acid (PFOS)	1763-23-1	ug/kg	2	300	300	**0.368**	**1.38**	**0.574**	**0.733**	**1.51**	**0.507**	**0.55**	**2.76**	**1.35**	**2.68**	**1.04**		**0.991**	**6**	<0.75	**0.667**
Perfluorooctanoic Acid (PFOA)	335-67-1	ug/kg	0.72	300	300	<0.32	<0.303	**0.732**	**0.754**	**0.494**	**0.364**	**0.42**	**1.72**	**0.632**	R	**1.12**		**1.35**	**2.58**	**0.8**	**0.981**
Perfluoropentanesulfonic Acid (PFPeS)	2706-91-4	ug/kg				<1.28	<1.21	<1.39	<1.48	<1.27	<1.4	<1.35	<1.31	<1.15	<10	<1.35		<1.33	<2.72	<3	<1.34
Perfluoropentanoic Acid (PFPeA)	2706-90-3	ug/kg				<0.64	<0.605	<0.697	<0.74	<0.637	<0.703	<0.676	<0.655	<0.576	<5.03	<0.674		<0.667	<1.36	<1.5	<0.67
Perfluorotetradecanoic Acid (PFTA)	376-06-7	ug/kg				<0.64	<0.605	<0.697	<0.74	<2.63	<0.703	<0.676	<2.71	<0.576	<1.39	<0.674		<0.667	<1.36	<1.5	<0.67
Perfluorotridecanoic Acid (PFTrDA)	72629-94-8	ug/kg				<0.64	<0.605	<0.697	<0.74	<2.63	<0.703	<0.676	<2.71	<0.576	<1.39	<0.674		<0.667	<1.36	<1.5	<0.67
Perfluoroundecanoic Acid (PFUnA)	2058-94-8	ug/kg				<0.64	<0.605	<0.697	<0.74	<0.637	<0.703	<0.676	<0.655	<0.576	<5.03	<0.674		<0.667	<1.36	<1.5	<0.67
Other																					
Total Organic Carbon	7440-44-0	%				**1.57**	**3.11**	**2.78**	**4.11**	**4.63**	**5.11**		**8.9**	**3.66**	**18.9**	**3.9**	**4.48**		**22.5**	**17.7**	**6.15**
Total Solids	NONE	%				**68.1**	**79.6**	**64.8**	**59.8**	**73.9**	**67.1**	**74.3**	**69.7**	**80.7**	**34.3**	**72.4**	**72.8**		**33.6**	**30.6**	**65.2**

Notes:
ug/kg = micrograms per kilogram; % = percent
< (value) = not detected at laboratory reporting limit
R = Percent surrogate recovery less than 10%; result rejected.
Red font - sample results modified based on data validation.
Shaded = exceeds MassDEP soil standard
All soil samples were collected from 0-6 inches below ground surface
Sample identification:
CEN-central; NE- northeast; SE - southeast; WT - west
FT-forest; FD-field; SD-sand; ST-silt; LM-loam
LD = laboratory duplicate

APPENDIX A
PFAS SOIL ANALYTICAL RESULTS
WOODARD & CURRAN
PFAS IN MASSACHUSETTS SOILS
BACKGROUND STUDY

Station Name	CAS Number	CEN-4	CEN-4	CEN-4	CEN-5	CEN-5	CEN-5	CEN-5
Sample ID		CEN-4B-LM-FT	CEN-4C-LM-FT	CEN-4D-LM-FT	CEN-5A-LM-FD	CEN-5B-LM-FD	CEN-5C-LM-FT	CEN-5D-LM-FD
Sample Date		9/17/2021	9/17/2021	9/17/2021	9/17/2021	9/17/2021	9/17/2021	9/17/2021
Primary Sample								
PFAS								
11-Chloroeicosafluoro-3-Oxaundecane-1-Sulfonic Acid (11Cl-PF	763051-92-9	<1.88	<1.26	<1.75	<1.26	<2.06	<1.18	<1.31
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	39108-34-4	<0.942	<0.628	<0.877	<0.631	<1.03	<0.589	<0.654
1H,1H,2H,2H-Perfluorododecanesulfonic Acid (10:2FTS)	120226-60-0	<1.88	<1.26	<1.75	<1.26	<2.06	<1.18	<1.31
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	757124-72-4	<1.88	<1.26	<1.75	<1.26	<2.06	<1.18	<1.31
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	27619-97-2	<0.942	<0.628	<0.877	<0.631	<1.03	<0.589	<0.654
2,3,3,3-Tetrafluoro-2-1,1,2,2,3,3,3-Heptafluoropropoxy]-Pro	13252-13-6	<18.8	<12.6	<17.5	<12.6	<20.6	<11.8	<13.1
4,8-Dioxa-3h-Perfluorononanoic Acid (ADONA)	919005-14-4	<1.88	<1.26	<1.75	<1.26	<2.06	<1.18	<1.31
9-Chlorohexadecafluoro-3-Oxanone-1-Sulfonic Acid (9Cl-PF3ONS	756426-58-1	<1.88	<1.26	<1.75	<1.26	<2.06	<1.18	<1.31
N-Ethyl Perfluorooctane Sulfonamide (NEtFOSA)	4151-50-2	<1.88	<1.26	<1.75	<1.26	<2.06	<1.18	<1.31
N-Ethyl Perfluorooctanesulfonamido Ethanol (NEtFOSE)	1691-99-2	<3.77	<2.51	<3.51	<2.52	<4.12	<2.36	<2.62
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	2991-50-6	<0.942	<0.628	<0.877	<0.631	<1.03	<0.589	<0.654
N-Methyl Perfluorooctane Sulfonamide (NMeFOSA)	31506-32-8	<1.88	<1.26	<1.75	<1.26	<2.06	<1.18	<1.31
N-Methyl Perfluorooctanesulfonamido Ethanol (NMeFOSE)	24448-09-7	<3.77	<2.51	<3.51	<2.52	<4.12	<2.36	<2.62
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	2355-31-9	<0.942	<0.628	<0.877	<0.631	<1.03	<0.589	<2.26
Perfluorobutanesulfonic Acid (PFBS)	375-73-5	<0.471	<0.314	<0.438	<0.315	<0.515	<0.294	<0.327
Perfluorobutanoic Acid (PFBA)	375-22-4	<0.942	<0.628	<0.877	<0.631	<1.03	<0.589	<0.654
Perfluorodecanesulfonic Acid (PFDS)	335-77-3	<0.942	<0.628	<0.877	<0.631	<1.03	<0.589	<0.654
Perfluorodecanoic Acid (PFDA)	335-76-2	<0.471	<0.314	<0.438	<0.315	<0.515	<0.294	<0.327
Perfluorododecane Sulfonic Acid (PFDoDS)	79780-39-5	<1.88	<1.26	<1.75	<1.26	<2.06	<1.18	<1.31
Perfluorododecanoic Acid (PFDoA)	307-55-1	<0.942	<0.628	<0.877	<0.631	<1.03	<0.589	<0.654
Perfluoroheptanesulfonic Acid (PFHpS)	375-92-8	<0.942	<0.628	<0.877	<0.631	<1.03	<0.589	<0.654
Perfluoroheptanoic Acid (PFHpA)	375-85-9	**0.489**	<0.314	**0.479**	<0.315	**0.548**	**0.405**	<0.327
Perfluorohexadecanoic Acid (PFHxDA)	67905-19-5	<4.71	<11.8	<4.38	<3.15	<5.15	<2.94	<3.27
Perfluorohexanesulfonic Acid (PFHxS)	355-46-4	<0.471	<0.314	<0.438	<0.315	<0.515	<0.294	<0.327
Perfluorohexanoic Acid (PFHxA)	307-24-4	<0.942	<0.628	<0.877	<0.631	<1.03	<0.589	<0.654
Perfluorononanesulfonic Acid (PFNS)	68259-12-1	<1.88	<1.26	<1.75	<1.26	<2.06	<1.18	<1.31
Perfluorononanoic Acid (PFNA)	375-95-1	<0.471	<0.314	**0.466**	<0.315	<0.515	**0.333**	<0.327
Perfluorooctadecanoic Acid (PFODA)	16517-11-6	<4.71	<11.8	<4.38	<3.15	<5.15	<2.94	<3.27
Perfluorooctanesulfonamide (FOSA)	754-91-6	<0.942	<0.628	<0.877	<0.631	<1.03	<0.589	<0.654
Perfluorooctanesulfonic Acid (PFOS)	1763-23-1	**1.1**	**0.757**	**1.86**	**0.524**	**1.11**	**1.44**	**0.474**
Perfluorooctanoic Acid (PFOA)	335-67-1	**1.94**	**1.02**	**1.84**	**0.748**	**2.29**	**1.72**	**1.11**
Perfluoropentanesulfonic Acid (PFPeS)	2706-91-4	<1.88	<1.26	<1.75	<1.26	<2.06	<1.18	<1.31
Perfluoropentanoic Acid (PFPeA)	2706-90-3	<0.942	<0.628	<0.877	<0.631	<1.03	<0.589	<0.654
Perfluorotetradecanoic Acid (PFTA)	376-06-7	<0.942	<0.628	<0.877	<0.631	<1.03	<0.589	<0.654
Perfluorotridecanoic Acid (PFTrDA)	72629-94-8	<0.942	<0.628	<0.877	<0.631	<1.03	<0.589	<0.654
Perfluoroundecanoic Acid (PFUnA)	2058-94-8	<0.942	<0.628	<0.877	<0.631	<1.03	<0.589	<0.654
Other								
Total Organic Carbon	7440-44-0	**5.59**	**4.4**	**10.1**	**3.49**	**3.98**	**3.85**	**3.42**
Total Solids	NONE	**49.6**	**73.6**	**55.5**	**71.4**	**47.7**	**74.3**	**73.1**

Station Name	CEN-6	CEN-6	CEN-6	CEN-6	CEN-6	NE-1	NE-1	NE-1	NE-1	NE-1	NE-2	NE-2
Sample ID	CEN-6A-LM-FT	LD	CEN-6B-LM-FT	CEN-6C-LM-FT	CEN-6D-LM-FT	NE-1A-FT-LM	NE-1B-FT-LM	NE-1C-FD-LM	NE-1D-FD-LM	LD	NE-2A-FD-LM	NE-2B-FT-LM
Sample Date	10/10/2021	10/25/2021	10/10/2021	10/10/2021	10/10/2021	9/16/2021	9/16/2021	9/16/2021	9/16/2021	9/29/2021	9/16/2021	9/16/2021
Primary Sample		CEN-6A-LM-FT								NE-1D-FD-LM		
PFAS												
11-Chloroeicosafluoro-3-Oxaundecane-1-Sulfonic Acid (11Cl-PF	<1.31	<1.22	<1.27	<1.29	<6.02	<1.2	<1.61	<1.35	<1.45	<1.39	<1.2	<1.18
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	<0.653	<0.613	<0.634	<0.647	<3.01	<0.598	<0.806	<0.674	<0.727	<0.695	<0.599	<0.588
1H,1H,2H,2H-Perfluorododecanesulfonic Acid (10:2FTS)	<1.31	<1.22	<1.27	<1.29	<6.02	<1.2	<1.61	<1.35	<1.45	<1.39	<1.2	<1.18
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	<1.31	<1.22	<1.27	<1.29	<6.02	<1.2	<1.61	<1.35	<1.45	<1.39	<1.2	<1.18
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	<0.653	<0.613	<0.634	<0.647	<3.01	<0.598	<0.806	<0.674	<0.727	<0.695	<0.599	<0.588
2,3,3,3-Tetrafluoro-2-1,1,2,2,3,3,3-Heptafluoropropoxy]-Pro	<13.1	<12.2	<12.7	<12.9	<60.2	<12	<16.1	<13.5	<14.5	<13.9	<12	<11.8
4,8-Dioxa-3h-Perfluorononanoic Acid (ADONA)	<1.31	<1.22	<1.27	<1.29	<6.02	<1.2	<1.61	<1.35	<1.45	<1.39	<1.2	<1.18
9-Chlorohexadecafluoro-3-Oxanone-1-Sulfonic Acid (9Cl-PF3ONS	<1.31	<1.22	<1.27	<1.29	<6.02	<1.2	<1.61	<1.35	<1.45	<1.39	<1.2	<1.18
N-Ethyl Perfluorooctane Sulfonamide (NEtFOSA)	<1.31	<1.22	<1.27	<1.29	<1.5	<1.2	<1.61	<1.35	<1.45	<1.39	<1.2	<1.18
N-Ethyl Perfluorooctanesulfonamido Ethanol (NEtFOSE)	<2.61	<2.45	<2.54	<2.59	<3	<2.39	<3.23	<2.7	<2.91	<2.78	<2.4	<2.35
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	<0.653	<0.613	<0.634	<0.647	<3.01	<0.598	<0.806	<0.674	<0.727	<0.695	<0.599	<0.588
N-Methyl Perfluorooctane Sulfonamide (NMeFOSA)	<1.31	<1.22	<1.27	<1.29	<1.5	<1.2	<1.61	<1.35	<1.45	<1.39	<1.2	<1.18
N-Methyl Perfluorooctanesulfonamido Ethanol (NMeFOSE)	<2.61	<2.45	<2.54	<2.59	<3	<2.39	<3.23	<2.7	<2.91	<2.78	<2.4	<2.35
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	<0.653	<0.613	<0.634	<0.647	<3.01	<0.598	<0.806	<0.674	<0.727	<0.695	<0.599	<0.588
Perfluorobutanesulfonic Acid (PFBS)	<0.327	<0.306	<0.317	<0.324	<1.5	<0.299	<0.403	<0.337	<0.364	<0.348	<0.299	<0.294
Perfluorobutanoic Acid (PFBA)	<0.653	<0.613	<0.634	<0.647	<3.01	<0.598	<0.806	**0.952**	<0.727	<0.695	<0.599	<0.588
Perfluorodecanesulfonic Acid (PFDS)	<0.653	<0.613	<0.634	<0.647	<3.01	<0.598	<0.806	<0.674	<0.727	<0.695	<0.599	<0.588
Perfluorodecanoic Acid (PFDA)	**0.332**	**0.355**	<0.317	**0.329**	<1.5	<0.299	**0.424**	**0.476**	<0.364	<0.348	**0.332**	<0.294
Perfluorododecane Sulfonic Acid (PFDoDS)	<1.31	<1.22	<1.27	<1.29	<6.02	<1.2	<1.61	<1.35	<1.45	<1.39	<1.2	<1.18
Perfluorododecanoic Acid (PFDoA)	<0.653	<0.613	<0.634	<0.647	<3.01	<0.598	<0.806	<0.674	<0.727	<0.695	<0.599	<0.588
Perfluoroheptanesulfonic Acid (PFHpS)	<0.653	<0.613	<0.634	<0.647	<3.01	<0.598	<0.806	<0.674	<0.727	<0.695	<0.599	<0.588
Perfluoroheptanoic Acid (PFHpA)	<0.327	<0.306	<0.317	<0.324	<1.5	<0.299	<0.403	<0.337	<0.364	<0.348	<0.299	<0.294
Perfluorohexadecanoic Acid (PFHxDA)	<3.27	<3.06	<12.4	<12.1	<15	<2.99	<4.03	<3.37	<3.64	<3.48	<2.99	<2.94
Perfluorohexanesulfonic Acid (PFHxS)	<0.327	<0.306	<0.317	<0.324	<1.5	<0.299	<0.403	<0.337	<0.364	<0.348	<0.299	<0.294
Perfluorohexanoic Acid (PFHxA)	<0.653	<0.613	<0.634	<0.647	<3.01	<0.598	<0.806	<0.674	<0.727	<0.695	<0.599	<0.588
Perfluorononanesulfonic Acid (PFNS)	<1.31	<1.22	<1.27	<1.29	<6.02	<1.2	<1.61	<1.35	<1.45	<1.39	<1.2	<1.18
Perfluorononanoic Acid (PFNA)	<0.327	<0.306	**0.386**	<0.324	<1.5	<0.299	**0.598**	**0.504**	<0.364	<0.348	<0.299	<0.294
Perfluorooctadecanoic Acid (PFODA)	<3.27	<3.06	<12.4	<12.1	<15	<2.99	<4.03	<3.37	<3.64	<3.48	<2.99	<2.94
Perfluorooctanesulfonamide (FOSA)	<0.653	<0.613	<0.634	<0.647	<0.751	<0.598	<0.806	<0.674	<0.727	<0.695	<0.599	<0.588
Perfluorooctanesulfonic Acid (PFOS)	**1.85**	**1.89**	**1.24**	**1.77**	**1.69**	**0.68**	**3.5**	**2.3**	**1.77**	**1.73**	**1.32**	**0.354**
Perfluorooctanoic Acid (PFOA)	<0.327	<0.306	**0.728**	<0.324	**1.54**	<0.299	**1.07**	**0.743**	<0.364	<0.348	**0.426**	**0.381**
Perfluoropentanesulfonic Acid (PFPeS)	<1.31	<1.22	<1.27	<1.29	<6.02	<1.2	<1.61	<1.35	<1.45	<1.39	<1.2	<1.18
Perfluoropentanoic Acid (PFPeA)	<0.653	<0.613	<0.634	<0.647	<3.01	<0.598	<0.806	<0.674	<0.727	<0.695	<0.599	<0.588
Perfluorotetradecanoic Acid (PFTA)	<0.653	<0.613	<2.48	<0.647	<3.01	<0.598	<0.806	<0.674	<0.727	<0.695	<0.599	<0.588
Perfluorotridecanoic Acid (PFTrDA)	<0.653	<0.613	<2.48	<0.647	<3.01	<0.598	<0.806	<0.674	<0.727	<0.695	<0.599	<0.588
Perfluoroundecanoic Acid (PFUnA)	<0.653	<0.613	<0.634	<0.647	<3.01	<0.598	<0.806	<0.674	<0.727	<0.695	<0.599	<0.588
Other												
Total Organic Carbon	**15.9**		**3.15**	**5.33**	**7.9**	**4.25**	**2.96**	**3.58**	**8.69**	**7.03**	**5.16**	**2.53**
Total Solids	**72.2**		**72.7**	**75.2**	**65.1**	**74.2**	**58.9**	**70.6**	**66.6**		**76.6**	**74.3**

Notes:
ug/kg = micrograms per kilogram; % = percent
< (value) = not detected at laboratory reporting limit
R = Percent surrogate recovery less than 10%; result rejected.
Red font - sample results modified based on data validation.
Shaded = exceeds MassDEP soil standard
All soil samples were collected from 0-6 inches below ground surface
Sample identification:
CEN-central; NE- northeast; SE - southeast; WT - west
FT-forest; FD-field; SD-sand; ST-silt; LM-loam
LD = laboratory duplicate

APPENDIX A
PFAS SOIL ANALYTICAL RESULTS
WOODARD & CURRAN
PFAS IN MASSACHUSETTS SOILS
BACKGROUND STUDY

Station Name	CAS Number	NE-2	NE-2	NE-3	NE-3	NE-3	NE-3	SE-1	SE-1	SE-1	SE-1	SE-1	SE-2	SE-2	SE-2	SE-2	SE-3	SE-3	SE-3	SE-3
Sample ID		NE-2C-FD-LM	NE-2D-FT-LM	NE-3A-FT-LM	NE-3B-FT-LM	NE-3C-FT-LM	NE-3D-FT-LM	SE-1A-FT-SD	LD	SE-1B-FT-SD	SE-1C-FT-SD	SE-1D-FT-LM	SE-2A-LM-FD	SE-2B-LM-FT	SE-2C-LM-FD	SE-2D-LM-FD	SE-3A-LM-FT	SE-3B-LM-FT	SE-3C-LM-FT	LD
Sample Date		9/16/2021	9/16/2021	9/16/2021	9/16/2021	9/16/2021	9/16/2021	10/16/2021	10/25/2021	10/16/2021	10/16/2021	10/16/2021	10/16/2021	10/16/2021	10/16/2021	10/16/2021	10/10/2021	10/10/2021	10/10/2021	10/28/2021
Primary Sample									SE-1A-FT-SD											SE-3C-LM-FT
PFAS																				
11-Chloroeicosafluoro-3-Oxaundecane-1-Sulfonic Acid (11Cl-PF	763051-92-9	<1.74	<1.59	<1.34	<1.13	<1.28	<1.27	<0.953		<1.64	<1.05	<1.06	<1.12	<1.5	<1.32	<1.32	<1.43	<1.33	<1.34	
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	39108-34-4	<0.872	<0.796	<0.672	<0.564	<0.641	<0.635	<0.477		<0.821	<0.526	<0.53	<0.563	<0.75	<0.659	<0.658	<0.715	<0.667	<0.671	
1H,1H,2H,2H-Perfluorododecanesulfonic Acid (10:2FTS)	120226-60-0	<1.74	<1.59	<1.34	<1.13	<1.28	<1.27	<0.953		<1.64	<1.05	<1.06	<1.12	<1.5	<1.32	<1.32	<1.43	<1.33	<1.34	
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	757124-72-4	<1.74	<1.59	<1.34	<1.13	<1.28	<1.27	<0.953		<1.64	<1.05	<1.06	<1.12	<1.5	<1.32	<1.32	<1.43	<1.33	<1.34	
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	27619-97-2	<0.872	<0.796	<0.672	<0.564	<0.641	<0.635	<0.477		<0.821	<0.526	<0.53	<0.563	<0.75	<0.659	<0.658	<0.715	<0.667	<0.671	
2,3,3,3-Tetrafluoro-2-1,1,2,2,3,3,3-Heptafluoropropoxy]-Pro	13252-13-6	<17.4	<15.9	<13.4	<11.3	<12.8	<12.7	<9.53		<16.4	<10.5	<10.6	<11.2	<15	<13.2	<13.2	<14.3	<13.3	<13.4	
4,8-Dioxa-3h-Perfluorononanoic Acid (ADONA)	919005-14-4	<1.74	<1.59	<1.34	<1.13	<1.28	<1.27	<0.953		<1.64	<1.05	<1.06	<1.12	<1.5	<1.32	<1.32	<1.43	<1.33	<1.34	
9-Chlorohexadecafluoro-3-Oxanone-1-Sulfonic Acid (9Cl-PF3ONS	756426-58-1	<1.74	<1.59	<1.34	<1.13	<1.28	<1.27	<0.953		<1.64	<1.05	<1.06	<1.12	<1.5	<1.32	<1.32	<1.43	<1.33	<1.34	
N-Ethyl Perfluorooctane Sulfonamide (NEtFOSA)	4151-50-2	<1.74	<1.59	<1.34	<1.13	<1.28	<1.27	<0.953		<1.64	<1.05	<1.06	<1.12	<1.5	<1.32	<1.32	<1.43	<1.33	<1.34	
N-Ethyl Perfluorooctanesulfonamido Ethanol (NEtFOSE)	1691-99-2	<3.49	<3.18	<2.69	<2.26	<2.56	<2.54	<1.91		<3.28	<2.1	<2.12	<2.25	<3	<2.64	<2.63	<2.86	<2.67	<2.68	
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	2991-50-6	<0.872	<0.796	<0.672	<0.564	<0.641	<0.635	<0.477		<0.821	<0.526	<0.53	<0.563	<0.75	<0.659	<0.658	<0.715	<0.667	<0.671	
N-Methyl Perfluorooctane Sulfonamide (NMeFOSA)	31506-32-8	<1.74	<1.59	<1.34	<1.13	<1.28	<1.27	<0.953		<1.64	<1.05	<1.06	<1.12	<1.5	<1.32	<1.32	<1.43	<1.33	<1.34	
N-Methyl Perfluorooctanesulfonamido Ethanol (NMeFOSE)	24448-09-7	<3.49	<3.18	<2.69	<2.26	<2.56	<2.54	<1.91		<3.28	<2.1	<2.12	<2.25	<3	<2.64	<2.63	<2.86	<2.67	<2.68	
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	2355-31-9	<0.872	<0.796	<0.672	<0.564	<0.641	<0.635	<0.477		<0.821	<0.526	<0.53	<0.563	<0.75	<0.659	<0.658	<0.715	<0.667	<0.671	
Perfluorobutanesulfonic Acid (PFBS)	375-73-5	<0.436	<0.398	<0.336	<0.282	<0.321	<0.318	<0.238		<0.411	<0.263	<0.265	<0.281	<0.375	<0.33	<0.329	<0.358	<0.333	<0.336	
Perfluorobutanoic Acid (PFBA)	375-22-4	<0.872	<0.796	<0.672	<0.564	<0.641	<0.635	<0.477		<0.821	<0.526	<0.53	<0.563	<0.75	**1.28**	<0.658	<0.715	<0.667	<0.671	
Perfluorodecanesulfonic Acid (PFDS)	335-77-3	<0.872	<0.796	<0.672	<0.564	<0.641	<0.635	<0.477		<0.821	<0.526	<0.53	<0.563	<0.75	<0.659	<0.658	<0.715	<0.667	<0.671	
Perfluorodecanoic Acid (PFDA)	335-76-2	<0.436	<0.398	<0.336	<0.282	<0.321	<0.318	<0.238		<0.411	<0.263	<0.265	**0.342**	<0.375	**0.437**	<0.329	<0.358	<0.333	<0.336	
Perfluorododecane Sulfonic Acid (PFDoDS)	79780-39-5	<1.74	<1.59	<1.34	<1.13	<1.28	<1.27	<0.953		<1.64	<1.05	<1.06	<1.12	<1.5	<1.32	<1.32	<1.43	<1.33	<1.34	
Perfluorododecanoic Acid (PFDoA)	307-55-1	<0.872	<0.796	<0.672	<0.564	<0.641	<0.635	<0.477		<0.821	<0.526	<0.53	<0.563	<0.75	<0.659	<0.658	<0.715	<0.667	<0.671	
Perfluoroheptanesulfonic Acid (PFHpS)	375-92-8	<0.872	<0.796	<0.672	<0.564	<0.641	<0.635	<0.477		<0.821	<0.526	<0.53	<0.563	<0.75	<0.659	<0.658	<0.715	<0.667	<0.671	
Perfluoroheptanoic Acid (PFHpA)	375-85-9	<0.436	<0.398	<0.336	<0.282	<0.321	<0.318	<0.238		<0.411	<0.263	<0.265	<0.281	<0.375	<0.33	<0.329	<0.358	<0.333	<0.336	
Perfluorohexadecanoic Acid (PFHxDA)	67905-19-5	<4.36	<3.98	<3.36	<2.82	<3.21	<3.18	<2.38		<4.11	<2.63	<2.65	<2.81	<16	<12.6	<12.6	<14.3	<12.9	<13	
Perfluorohexanesulfonic Acid (PFHxS)	355-46-4	<0.436	<0.398	<0.336	<0.282	<0.321	<0.318	<0.238		<0.411	<0.263	<0.265	<0.281	<0.375	<0.33	<0.329	<0.358	<0.333	<0.336	
Perfluorohexanoic Acid (PFHxA)	307-24-4	<0.872	<0.796	<0.672	<0.564	<0.641	<0.635	<0.477		<0.821	<0.526	<0.53	<0.563	<0.75	<0.659	<0.658	<0.715	<0.667	<0.671	
Perfluorononanesulfonic Acid (PFNS)	68259-12-1	<1.74	<1.59	<1.34	<1.13	<1.28	<1.27	<0.953		<1.64	<1.05	<1.06	<1.12	<1.5	<1.32	<1.32	<1.43	<1.33	<1.34	
Perfluorononanoic Acid (PFNA)	375-95-1	<0.436	<0.398	**0.377**	**0.3**	<0.321	<0.318	<0.238		<0.411	<0.263	<0.265	<0.281	**0.408**	**0.54**	**0.579**	<0.358	**0.403**	**0.548**	
Perfluorooctadecanoic Acid (PFODA)	16517-11-6	<4.36	<3.98	<3.36	<2.82	<3.21	<3.18	<2.38		<4.11	<2.63	<2.65	<2.81	<16	<12.6	<12.6	<14.3	<12.9	<13	
Perfluorooctanesulfonamide (FOSA)	754-91-6	<0.872	<0.796	<0.672	<0.564	<0.641	<0.635	<0.477		<0.821	<0.526	<0.53	<0.563	<0.75	<0.659	<0.658	<0.715	<0.667	<0.671	
Perfluorooctanesulfonic Acid (PFOS)	1763-23-1	**0.572**	**1.73**	**0.96**	**0.64**	**0.439**	**0.988**	<0.238		<0.411	<0.263	**1.63**	**1.77**	**2.25**	**2.81**	**3.69**	**1.73**	**1.48**	**1.85**	
Perfluorooctanoic Acid (PFOA)	335-67-1	<0.436	**0.926**	**0.59**	**0.94**	<0.321	**0.404**	<0.238		<0.411	<0.263	**0.446**	**0.31**	**0.64**	**0.739**	**1.11**	**0.567**	<0.333	**0.904**	
Perfluoropentanesulfonic Acid (PFPeS)	2706-91-4	<1.74	<1.59	<1.34	<1.13	<1.28	<1.27	<0.953		<1.64	<1.05	<1.06	<1.12	<1.5	<1.32	<1.32	<1.43	<1.33	<1.34	
Perfluoropentanoic Acid (PFPeA)	2706-90-3	<0.872	<0.796	<0.672	<0.564	<0.641	<0.635	<0.477		<0.821	<0.526	<0.53	<0.563	<0.75	<0.659	<0.658	<0.715	<0.667	<0.671	
Perfluorotetradecanoic Acid (PFTA)	376-06-7	<0.872	<0.796	<0.672	<0.564	<0.641	<0.635	<0.477		<0.821	<0.526	<0.53	<0.563	<0.75	<0.659	<0.658	<0.715	<0.667	<0.671	
Perfluorotridecanoic Acid (PFTrDA)	72629-94-8	<0.872	<0.796	<0.672	<0.564	<0.641	<0.635	<0.477		<0.821	<0.526	<0.53	<0.563	<0.75	<0.659	<0.658	<0.715	<0.667	<0.671	
Perfluoroundecanoic Acid (PFUnA)	2058-94-8	<0.872	<0.796	<0.672	<0.564	<0.641	<0.635	<0.477		<0.821	<0.526	<0.53	<0.563	<0.75	<0.659	<0.658	<0.715	<0.667	<0.671	
Other																				
Total Organic Carbon	7440-44-0	**2.78**	**4.92**	**2.78**	**6.01**	**1.76**	**5.32**	**3.11**		**5.37**	**1.04**	**5.14**	**4.91**	**9.51**	**10.1**	**5.42**	**3.04**	**14.8**	**11.4**	**14.2**
Total Solids	NONE	**51.4**	**58.7**	**73.3**	**80.2**	**72.2**	**72.4**	**92**	**91.3**	**53.4**	**90.9**	**88.7**	**78.8**	**62.6**	**67.4**	**70.3**	**66.6**	**69.6**	**70.1**	

Notes:
ug/kg = micrograms per kilogram; % = percent
< (value) = not detected at laboratory reporting limit
R = Percent surrogate recovery less than 10%; result rejected.
Red font - sample results modified based on data validation.
Shaded = exceeds MassDEP soil standard
All soil samples were collected from 0-6 inches below ground surface
Sample identification:
CEN-central; NE- northeast; SE - southeast; WT - west
FT-forest; FD-field; SD-sand; ST-silt; LM-loam
LD = laboratory duplicate

APPENDIX A
PFAS SOIL ANALYTICAL RESULTS
WOODARD & CURRAN
PFAS IN MASSACHUSETTS SOILS
BACKGROUND STUDY

Station Name	CAS Number	SE-3	SE-4	SE-4	SE-4	SE-4	SE-5	SE-5	SE-5	SE-5	SE-6	SE-6	SE-6	SE-6	SE-7	SE-7	SE-7	SE-7	SE-7	SE-8
Sample ID		**SE-3D-LM-FT**	**SE-4A-LM-FT**	**SE-4B-LM-FT**	**SE-4C-LM-FT**	**SE-4D-LM-FT**	**SE-5A-LM-FT**	**SE-5B-LM-FT**	**SE-5C-LM-FT**	**SE-5D-LM-FT**	**SE-6A-LM-FT**	**SE-6B-LM-FT**	**SE-6C-LM-FT**	**SE-6D-LM-FD**	**SE-7A-LM-FD**	**SE-7B-LM-FT**	**SE-7C-LM-FT**	**SE-7D-LM-FT**	**LD**	**SE-8A-FT-LM**
Sample Date		10/10/2021	10/10/2021	10/10/2021	10/10/2021	10/10/2021	10/10/2021	10/10/2021	10/10/2021	10/10/2021	10/10/2021	10/10/2021	10/10/2021	10/10/2021	10/16/2021	10/16/2021	10/16/2021	10/16/2021	10/27/2021	10/16/2021
Primary Sample																			SE-7D-LM-FT	
PFAS																				
11-Chloroeicosafluoro-3-Oxaundecane-1-Sulfonic Acid (11Cl-PF	763051-92-9	<1.23	<1.1	<1.5	<1.31	<1.13	<2.57	<1.26	<1.26	<0.97	<1.42	<1.81	<1.4	<1.12	<1.43	<2.22	<1.22	<1.48		<1.03
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	39108-34-4	<0.617	<0.55	<0.752	<0.656	<0.564	<1.28	<0.628	<0.633	<0.485	<0.709	<0.905	<0.701	<0.559	<0.713	<1.11	<0.61	<0.738		<0.516
1H,1H,2H,2H-Perfluorododecanesulfonic Acid (10:2FTS)	120226-60-0	<1.23	<1.1	<1.5	<1.31	<1.13	<9.97	<1.26	<1.26	<0.97	<1.42	<1.81	<5.4	<1.12	<1.43	<2.22	<1.22	<1.48		<1.03
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	757124-72-4	<1.23	<1.1	<1.5	<1.31	<1.13	<2.57	<1.26	<1.26	<0.97	<1.42	<1.81	<1.4	<1.12	<1.43	<2.22	<1.22	<1.48		<1.03
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	27619-97-2	<0.617	<0.55	<0.752	<0.656	<0.564	<1.28	<0.628	<0.633	<0.485	<0.709	<0.905	<0.701	<0.559	<0.713	<1.11	<0.61	<0.738		<0.516
2,3,3,3-Tetrafluoro-2-1,1,2,2,3,3,3-Heptafluoropropoxy]-Pro	13252-13-6	<12.3	<11	<15	<13.1	<11.3	<25.7	<12.6	<12.6	<9.7	<14.2	<18.1	<14	<11.2	<14.3	<22.2	<12.2	<57.5	<59.2	<10.3
4,8-Dioxa-3h-Perfluorononanoic Acid (ADONA)	919005-14-4	<1.23	<1.1	<1.5	<1.31	<1.13	<2.57	<1.26	<1.26	<0.97	<1.42	<1.81	<1.4	<1.12	<1.43	<2.22	<1.22	<1.48		<1.03
9-Chlorohexadecafluoro-3-Oxanone-1-Sulfonic Acid (9Cl-PF3ONS	756426-58-1	<1.23	<1.1	<1.5	<1.31	<1.13	<2.57	<1.26	<1.26	<0.97	<1.42	<1.81	<1.4	<1.12	<1.43	<2.22	<1.22	<1.48		<1.03
N-Ethyl Perfluorooctane Sulfonamide (NEtFOSA)	4151-50-2	<1.23	<1.1	<1.5	<1.31	<1.13	<2.57	<1.26	<1.26	<0.97	<1.42	<1.81	<1.4	<1.12	<1.43	<2.22	<1.22	<1.48		<1.03
N-Ethyl Perfluorooctanesulfonamido Ethanol (NEtFOSE)	1691-99-2	<2.47	<2.2	<3.01	<2.62	<2.26	<5.14	<2.51	<2.53	<1.94	<2.84	<3.62	<2.8	<2.24	<2.85	<4.44	<2.44	<2.95		<2.07
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	2991-50-6	<0.617	<0.55	<0.752	<0.656	<0.564	<1.28	<0.628	<0.633	<0.485	<0.709	<0.905	<0.701	<0.559	<0.713	<1.11	<0.61	<0.738		<0.516
N-Methyl Perfluorooctane Sulfonamide (NMeFOSA)	31506-32-8	<1.23	<1.1	<1.5	<1.31	<1.13	<2.57	<1.26	<1.26	<0.97	<1.42	<1.81	<1.4	<1.12	<1.43	<2.22	<1.22	<1.48		<1.03
N-Methyl Perfluorooctanesulfonamido Ethanol (NMeFOSE)	24448-09-7	<2.47	<2.2	<3.01	<2.62	<2.26	<5.14	<2.51	<2.53	<1.94	<2.84	<3.62	<2.8	<2.24	<2.85	<4.44	<2.44	<2.95		<2.07
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	2355-31-9	<0.617	<0.55	<0.752	<0.656	<0.564	<1.28	<0.628	<0.633	<0.485	<0.709	<0.905	<0.701	<0.559	<0.713	<1.11	<0.61	<0.738		<0.516
Perfluorobutanesulfonic Acid (PFBS)	375-73-5	<0.309	<0.275	<0.376	<0.328	<0.282	<0.642	<0.314	<0.316	<0.242	<0.354	<0.452	<0.351	<0.28	<0.357	<0.555	<0.305	<0.369		<0.258
Perfluorobutanoic Acid (PFBA)	375-22-4	<0.617	<0.55	**2.39**	<0.656	<0.564	**1.5**	<0.628	<0.633	<0.485	<0.709	<0.905	<0.701	<0.559	<0.713	<1.11	<0.61	<0.738		<0.516
Perfluorodecanesulfonic Acid (PFDS)	335-77-3	<0.617	<0.55	<0.752	<0.656	<0.564	<1.28	<0.628	<0.633	<0.485	<0.709	<0.905	<0.701	<0.559	<0.713	<1.11	<0.61	<0.738		<0.516
Perfluorodecanoic Acid (PFDA)	335-76-2	**0.334**	<0.275	<0.376	<0.328	<0.282	<0.642	<0.314	<0.316	<0.242	**0.413**	<0.452	**0.599**	<0.28	<0.357	<0.555	<0.305	<0.369		<0.258
Perfluorododecane Sulfonic Acid (PFDoDS)	79780-39-5	<1.23	<1.1	<1.5	<1.31	<1.13	<2.57	<1.26	<1.26	<0.97	<1.42	<1.81	<1.4	<1.12	<1.43	<2.22	<1.22	<1.48		<1.03
Perfluorododecanoic Acid (PFDoA)	307-55-1	<0.617	<0.55	<0.752	<0.656	<0.564	<4.98	<0.628	<0.633	<0.485	<0.709	<0.905	<2.7	<0.559	<0.713	<1.11	<0.61	<0.738		<0.516
Perfluoroheptanesulfonic Acid (PFHpS)	375-92-8	<0.617	<0.55	<0.752	<0.656	<0.564	<1.28	<0.628	<0.633	<0.485	<0.709	<0.905	<0.701	<0.559	<0.713	<1.11	<0.61	<0.738		<0.516
Perfluoroheptanoic Acid (PFHpA)	375-85-9	<0.309	<0.275	**1.53**	<0.328	<0.282	**1.21**	<0.314	<0.316	<0.242	<0.354	<0.452	<0.351	<0.28	<0.357	<0.555	<0.305	<1.44	<1.48	<0.258
Perfluorohexadecanoic Acid (PFHxDA)	67905-19-5	<3.09	<12.5	<15.4	<13.4	<11.1		<12.4	<12.7	<10	<14.4	<17.2	<13.5	<11.1	<15.4	<5.55	<12.2	<14.4	<14.8	<2.58
Perfluorohexanesulfonic Acid (PFHxS)	355-46-4	<0.309	<0.275	<0.376	<0.328	<0.282	<0.642	<0.314	<0.316	<0.242	<0.354	<0.452	<0.351	<0.28	<0.357	<0.555	<0.305	<0.369		<0.258
Perfluorohexanoic Acid (PFHxA)	307-24-4	<0.617	<0.55	**3.56**	<0.656	<0.564	<1.28	<0.628	<0.633	<0.485	<0.709	<0.905	<0.701	<0.559	<0.713	<1.11	<0.61	<2.88	<2.96	<0.516
Perfluorononanesulfonic Acid (PFNS)	68259-12-1	<1.23	<1.1	<1.5	<1.31	<1.13	<2.57	<1.26	<1.26	<0.97	<1.42	<1.81	<1.4	<1.12	<1.43	<2.22	<1.22	<1.48		<1.03
Perfluorononanoic Acid (PFNA)	375-95-1	**0.314**	**0.369**	**0.822**	<0.328	**0.39**	**1.16**	**0.338**	<0.316	**0.316**	<0.354	**0.571**	**0.633**	<0.28	<0.357	<0.555	**0.452**	**0.447**		<0.258
Perfluorooctadecanoic Acid (PFODA)	16517-11-6	<3.09	<12.5	<15.4	<13.4	<11.1		<12.4	<12.7	<10	<14.4	<17.2	<13.5	<11.1	<15.4	<5.55	<12.2	<14.4	<14.8	<2.58
Perfluorooctanesulfonamide (FOSA)	754-91-6	<0.617	<0.55	**<0.752**	<0.656	<0.564	<1.28	<0.628	<0.633	<0.485	<0.709	<0.905	<0.701	<0.559	<0.713	<1.11	<0.61	<0.738		<0.516
Perfluorooctanesulfonic Acid (PFOS)	1763-23-1	**2.12**	**1.52**	**3**	**1.42**	**1.68**	**3.64**	**1.26**	**0.547**	**1.85**	**1.86**	**2.74**	**1.82**	**0.338**	**0.687**	**1.87**	**1.53**	**1.95**		**0.429**
Perfluorooctanoic Acid (PFOA)	335-67-1	**0.323**	**0.684**	**2.66**	**1.27**	**0.626**	**4.2**	**1.17**	**0.496**	**1.11**	<0.354	**0.762**	**0.436**	<0.28	<0.357	<0.555	**0.883**	**0.831**		**0.32**
Perfluoropentanesulfonic Acid (PFPeS)	2706-91-4	<1.23	<1.1	<1.5	<1.31	<1.13	<2.57	<1.26	<1.26	<0.97	<1.42	<1.81	<1.4	<1.12	<1.43	<2.22	<1.22	<1.48		<1.03
Perfluoropentanoic Acid (PFPeA)	2706-90-3	<0.617	<0.55	**5.46**	<0.656	<0.564	<1.28	<0.628	<0.633	<0.485	<0.709	<0.905	<0.701	<0.559	<0.713	<1.11	<0.61	<2.88	<2.96	<0.516
Perfluorotetradecanoic Acid (PFTA)	376-06-7	<0.617	<2.51	<3.08	<2.68	<2.23	<4.98	<2.48	<2.55	<2	<0.709	<0.905	<2.7	<0.559	<0.713	<1.11	<2.44	<2.88	<2.96	<0.516
Perfluorotridecanoic Acid (PFTrDA)	72629-94-8	<0.617	<2.51	<3.08	<2.68	<2.23	<4.98	<2.48	<2.55	<2	<0.709	<0.905	<2.7	<0.559	<0.713	<1.11	<2.44	<2.88	<2.96	<0.516
Perfluoroundecanoic Acid (PFUnA)	2058-94-8	<0.617	<0.55	<0.752	<0.656	<0.564	<4.98	<0.628	<0.633	<0.485	<0.709	<0.905	<0.701	<0.559	<0.713	<1.11	<0.61	<0.738		<0.516
Other																				
Total Organic Carbon	7440-44-0	**4.31**	**5.36**	**11.5**	**4.33**	**3.93**	**6.91**	**2.15**	**7.93**	**7.06**	**13.9**	**5.13**	**8.25**	**4.62**	**6.25**	**28.5**	**5.59**	**6.77**		**2.23**
Total Solids	NONE	**73.3**	**79.8**	**64.2**	**70.4**	**78.1**	**34.9**	**75.5**	**76.9**	**98**	**65.6**	**52.5**	**63.8**	**81.8**	**64.9**	**41.7**	**72.4**	**63.2**		**87.2**

Notes:
ug/kg = micrograms per kilogram; % = percent 19.422
< (value) = not detected at laboratory reporting limit
R = Percent surrogate recovery less than 10%; result rejected.
Red font - sample results modified based on data validation.
Shaded = exceeds MassDEP soil standard
All soil samples were collected from 0-6 inches below ground surface
Sample identification:
CEN-central; NE- northeast; SE - southeast; WT - west
FT-forest; FD-field; SD-sand; ST-silt; LM-loam
LD = laboratory duplicate

Station Name	**CAS Number**	**SE-8**	**SE-8**	**SE-8**	**SE-8**	**SE-9**	**SE-9**	**SE-9**	**SE-9**	**SE-9**	**WT-1**	**WT-1**	**WT-1**	**WT-1**	**WT-1**	**WT-2**	**WT-2**	**WT-2**	**WT-2**	**WT-2**
Sample ID		**SE-8B-FT-SD**	**LD**	**SE-8C-FT-SD**	**SE-8D-FT-LM**	**SE-9A-FT-LM**	**LD**	**SE-9B-FT-LM**	**SE-9C-FT-LM**	**SE-9D-FD-SD**	**WT-1A-ST-FD**	**LD**	**WT-1B-ST-FD**	**WT-1C-ST-FD**	**WT-1D-LM-FT**	**WT-2A-LM-FD**	**LD**	**LD**	**WT-2B-LM-FD**	**WT-2C-LM-FT**
Sample Date		10/16/2021	10/27/2021	10/16/2021	10/16/2021	10/16/2021	11/10/2021	10/16/2021	10/16/2021	10/16/2021	10/22/2021	11/4/2021	10/22/2021	10/22/2021	10/22/2021	10/29/2021	11/13/2021	11/15/2021	10/29/2021	10/29/2021
Primary Sample			SE-8B-FT-SD				SE-9A-FT-LM					WT-1A-ST-FD					WT-2A-LM-FD	WT-2A-LM-FD		
PFAS																				
11-Chloroeicosafluoro-3-Oxaundecane-1-Sulfonic Acid (11Cl-PF	763051-92-9	<1.02	<0.979	<1.37	<1.48	<1.22		<1.14	<1.39	<0.978	<1.49	<1.4	<2.07	<1.26	<1.55	<1.17	<1.31		<1.25	<1.41
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	39108-34-4	<0.51	<0.49	<0.686	<0.738	<0.611		<0.571	<0.696	<0.489	<0.745	<0.701	<1.04	<0.63	<0.776	<0.586	<0.656		<0.625	<0.704
1H,1H,2H,2H-Perfluorododecanesulfonic Acid (10:2FTS)	120226-60-0	<1.02	<0.979	<1.37	<1.48	<1.22		<1.14	<1.39	<0.978	<1.49	<1.4	<2.07	<1.26	<1.55	<1.17	<1.31		<1.25	<1.41
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	757124-72-4	<1.02	<0.979	<1.37	<1.48	<1.22		<1.14	<1.39	<0.978	<1.49	<1.4	<2.07	<1.26	<1.55	<1.17	<1.31		<1.25	<1.41
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	27619-97-2	<0.51	<0.49	<0.686	<0.738	<0.611		<0.571	<0.696	<0.489	<0.745	<0.701	<1.04	<0.63	<0.776	<0.586	<0.656		<0.625	<0.704
2,3,3,3-Tetrafluoro-2-1,1,2,2,3,3,3-Heptafluoropropoxy]-Pro	13252-13-6	<10.2	<9.79	<13.7	<14.8	<12.2		<11.4	<13.9	<9.78	<14.9	<14	<20.7	<12.6	<15.5	<11.7	<13.1		<12.5	<14.1
4,8-Dioxa-3h-Perfluorononanoic Acid (ADONA)	919005-14-4	<1.02	<0.979	<1.37	<1.48	<1.22		<1.14	<1.39	<0.978	<1.49	<1.4	<2.07	<1.26	<1.55	<1.17	<1.31		<1.25	<1.41
9-Chlorohexadecafluoro-3-Oxanone-1-Sulfonic Acid (9Cl-PF3ONS	756426-58-1	<1.02	<0.979	<1.37	<1.48	<1.22		<1.14	<1.39	<0.978	<1.49	<1.4	<2.07	<1.26	<1.55	<1.17	<1.31		<1.25	<1.41
N-Ethyl Perfluorooctane Sulfonamide (NEtFOSA)	4151-50-2	<1.02	<0.979	<1.37	<1.48	<1.22		<1.14	<1.39	<0.978	<1.49	<1.4	<2.07	<1.26	<1.55	<1.17			<1.25	<1.41
N-Ethyl Perfluorooctanesulfonamido Ethanol (NEtFOSE)	1691-99-2	<2.04	<1.96	<2.74	<2.95	<2.44		<2.28	<2.78	<1.96	<2.98	<2.8	<4.14	<2.52	<3.1	<2.34			<2.5	<2.81
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	2991-50-6	<0.51	<0.49	<0.686	<0.738	<0.611		<0.571	<0.696	<0.489	<0.745	<0.701	<1.04	<0.63	<0.776	<0.586	<0.656		<0.625	<0.704
N-Methyl Perfluorooctane Sulfonamide (NMeFOSA)	31506-32-8	<1.02	<0.979	<1.37	<1.48	<1.22		<1.14	<1.39	<0.978	<1.49	<1.4	<2.07	<1.26	<1.55	<1.17			<1.25	<1.41
N-Methyl Perfluorooctanesulfonamido Ethanol (NMeFOSE)	24448-09-7	<2.04	<1.96	<2.74	<2.95	<2.44		<2.28	<2.78	<1.96	<2.98	<2.8	<4.14	<2.52	<3.1	<2.34			<2.5	<2.81
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	2355-31-9	<0.51	<0.49	<0.686	<0.738	<0.611		<0.571	<0.696	<0.489	<0.745	<0.701	<1.04	<0.63	<0.776	<0.586	<0.656		<0.625	<0.704
Perfluorobutanesulfonic Acid (PFBS)	375-73-5	<0.255	<0.245	<0.343	<0.369	<0.306		<0.286	<0.348	<0.244	<0.372	<0.35	<0.518	<0.315	<0.388	<0.293	<0.328		<0.313	<0.352
Perfluorobutanoic Acid (PFBA)	375-22-4	<0.51	<0.49	<0.686	<0.738	<0.611		<0.571	<0.696	<0.489	<0.745	<0.701	<1.04	<0.63	<0.776	<0.586	<0.656	NA	<0.625	<0.704
Perfluorodecanesulfonic Acid (PFDS)	335-77-3	<0.51	<0.49	<0.686	<0.738	<0.611		<0.571	<0.696	<0.489	<0.745	<0.701	<1.04	<0.63	<0.776	<0.586	<0.656		<0.625	<0.704
Perfluorodecanoic Acid (PFDA)	335-76-2	<0.255	<0.245	<0.343	<0.369	<0.306		<0.286	<0.348	<0.244	<0.372	<0.35	<0.518	<0.315	<0.388	<0.293	<0.328	NA	<0.313	<0.352
Perfluorododecane Sulfonic Acid (PFDoDS)	79780-39-5	<1.02	<0.979	<1.37	<1.48	<1.22		<1.14	<1.39	<0.978	<1.49	<1.4	<2.07	<1.26	<1.55	<1.17	<1.31		<1.25	<1.41
Perfluorododecanoic Acid (PFDoA)	307-55-1	<0.51	<0.49	<0.686	<0.738	<0.611		<0.571	<0.696	<0.489	<0.745	<0.701	<1.04	<0.63	<0.776	<0.586	<0.656		<0.625	<0.704
Perfluoroheptanesulfonic Acid (PFHpS)	375-92-8	<0.51	<0.49	<0.686	<0.738	<0.611		<0.571	<0.696	<0.489	<0.745	<0.701	<1.04	<0.63	<0.776	<0.586	<0.656		<0.625	<0.704
Perfluoroheptanoic Acid (PFHpA)	375-85-9	<0.255	<0.245	<0.343	<0.369	<0.306		<0.286	<0.348	<0.244	<0.372	<0.35	<0.518	<0.315	<0.388	<0.293	<0.328	NA	<0.313	<0.352
Perfluorohexadecanoic Acid (PFHxDA)	67905-19-5	<2.55	<2.45	<3.43	<3.69	<3.06		<2.86		<9.67	<3.72	<3.5	<5.18	<3.15	<3.88	<2.93	<3.28		<3.13	<3.52
Perfluorohexanesulfonic Acid (PFHxS)	355-46-4	<0.255	<0.245	<0.343	<0.369	<0.306		<0.286	<0.348	<0.244	<0.372	<0.35	<0.518	<0.315	<0.388	<0.293	<0.328		<0.313	<0.352
Perfluorohexanoic Acid (PFHxA)	307-24-4	<0.51	<0.49	<0.686	<0.738	<0.611		<0.571	<0.696	<0.489	<0.745	<0.701	<1.04	<0.63	<0.776	<0.586	<0.656	NA	<0.625	<0.704
Perfluorononanesulfonic Acid (PFNS)	68259-12-1	<1.02	<0.979	<1.37	<1.48	<1.22		<1.14	<1.39	<0.978	<1.49	<1.4	<2.07	<1.26	<1.55	<1.17	<1.31		<1.25	<1.41
Perfluorononanoic Acid (PFNA)	375-95-1	<0.255	<0.245	<0.343	<0.369	<0.306		<0.286	<0.348	<0.244	<0.372	<0.35	<0.518	<0.315	<0.388	<0.293	<0.328	NA	<0.313	<0.352
Perfluorooctadecanoic Acid (PFODA)	16517-11-6	<2.55	<2.45	<3.43	<3.69	<3.06		<2.86		<9.67	<3.72	<3.5	<5.18	<3.15	<3.88	<2.93	<3.28		<3.13	<3.52
Perfluorooctanesulfonamide (FOSA)	754-91-6	<0.51	<0.49	<0.686	<0.738	<0.611		<0.571	<0.696	<0.489	<0.745	<0.701	<1.04	<0.63	<0.776	<0.586			<0.625	<0.704
Perfluorooctanesulfonic Acid (PFOS)	1763-23-1	<0.255	<0.245	**0.408**	<0.369	**0.671**		**0.597**	<0.348	**0.384**	<0.372	<0.35	**0.588**	<0.315	**0.575**	**0.362**	<0.328	NA	<0.313	**0.509**
Perfluorooctanoic Acid (PFOA)	335-67-1	<0.255	<0.245	<0.343	<0.369	**0.425**		<0.286	<0.348	<0.244	<0.372	<0.35	<0.518	<0.315	**1.09**	**0.393**	<0.328	NA	<0.313	**0.614**
Perfluoropentanesulfonic Acid (PFPeS)	2706-91-4	<1.02	<0.979	<1.37	<1.48	<1.22		<1.14	<1.39	<0.978	<1.49	<1.4	<2.07	<1.26	<1.55	<1.17	<1.31		<1.25	<1.41
Perfluoropentanoic Acid (PFPeA)	2706-90-3	<0.51	<0.49	<0.686	<0.738	<0.611		<0.571	<0.696	<0.489	<0.745	<0.701	<1.04	<0.63	<0.776	<0.586	<0.656	NA	<0.625	<0.704
Perfluorotetradecanoic Acid (PFTA)	376-06-7	<0.51	<0.49	<0.686	<0.738	<0.611		<0.571	<2.86	<0.489	<0.745	<0.701	<1.04	<0.63	<0.776	<0.586	<0.656		<0.625	<0.704
Perfluorotridecanoic Acid (PFTrDA)	72629-94-8	<0.51	<0.49	<0.686	<0.738	<0.611		<0.571	<2.86	<0.489	<0.745	<0.701	<1.04	<0.63	<0.776	<0.586	<0.656		<0.625	<0.704
Perfluoroundecanoic Acid (PFUnA)	2058-94-8	<0.51	<0.49	<0.686	<0.738	<0.611		<0.571	<0.696	<0.489	<0.745	<0.701	<1.04	<0.63	<0.776	<0.586	<0.656	NA	<0.625	<0.704
Other																				
Total Organic Carbon	7440-44-0	**1.86**		**1.22**	**6.17**	**3.25**	**3.81**	**2.39**	**1.68**	**1.35**	**1.97**		**4.3**	**2.36**	**5.39**	**2.59**		**2.34**	**2.71**	**2.41**
Total Solids	NONE	**92.4**		**70.6**	**60.8**	**78.1**		**84.8**	**67.8**	**89.9**	**65**		**46**	**71.5**	**60.2**	**75.3**			**70.3**	**65.5**

Notes:
ug/kg = micrograms per kilogram; % = percent
< (value) = not detected at laboratory reporting limit
R = Percent surrogate recovery less than 10%; result rejected.
Red font - sample results modified based on data validation.
Shaded = exceeds MassDEP soil standard
All soil samples were collected from 0-6 inches below ground surface
Sample identification:
CEN-central; NE- northeast; SE - southeast; WT - west
FT-forest; FD-field; SD-sand; ST-silt; LM-loam
LD = laboratory duplicate

Station Name	CAS Number	WT-2	WT-3	WT-3	WT-3	WT-3	WT-4	WT-4	WT-4	WT-4	WT-5	WT-5	WT-5	WT-5	WT-6	WT-6	WT-6	WT-6	WT-6	WT-7
Sample ID		WT-2D-LM-FD	WT-3A-ST-FD	WT-3B-LM-FT	WT-3C-LM-FT	WT-3D-LM-FT	WT-4A-LM-FT	WT-4B-LM-FT	WT-4C-LM-FT	WT-4D-LM-FT	WT-5A-ST-FD	WT-5B-LM-FT	WT-5C-LM-FD	WT-5D-LM-FD	WT-6A-LM-FD	WT-6B-LM-FD	WT-6C-LM-FT	WT-6D-LM-FT	LD	WT-7A-LM-FT
Sample Date		10/29/2021	10/22/2021	10/22/2021	10/22/2021	10/22/2021	10/29/2021	10/29/2021	10/29/2021	10/29/2021	10/29/2021	10/29/2021	10/29/2021	10/29/2021	10/22/2021	10/22/2021	10/22/2021	10/22/2021	11/15/2021	10/22/2021
Primary Sample																			WT-6D-LM-FT	
PFAS																				
11-Chloroeicosafluoro-3-Oxaundecane-1-Sulfonic Acid (11Cl-PF	763051-92-9	<1.28	<1.41	<5.79	<8.24	<6.38	<1.14	<1.15	<1.25	<1.21	<1.08	<1.31	<1.14	<1.34	<1.51	<1.35	<5.74	<1.39		<1.45
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	39108-34-4	<0.641	<0.705	<2.89	<4.12	<3.19	<0.568	<0.575	<0.624	<0.607	<0.543	<0.654	<0.569	<0.671	<0.754	<0.674	<2.87	<0.696		<0.724
1H,1H,2H,2H-Perfluorododecanesulfonic Acid (10:2FTS)	120226-60-0	<1.28	<1.41	<5.79	<8.24	<6.38	<1.14	<1.15	<1.25	<1.21	<1.08	<1.31	<1.14	<1.34	<1.51	<1.35	<5.74	<1.39		<1.45
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	757124-72-4	<1.28	<1.41	<5.79	<8.24	<6.38	<1.14	<1.15	<1.25	<1.21	<1.08	<1.31	<1.14	<1.34	<1.51	<1.35	<5.74	<1.39		<1.45
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	27619-97-2	<0.641	<0.705	<2.89	<4.12	<3.19	<0.568	<0.575	<0.624	<0.607	<0.543	<0.654	<0.569	<0.671	<0.754	<0.674	<2.87	<0.696		<0.724
2,3,3,3-Tetrafluoro-2-1,1,2,2,3,3,3-Heptafluoropropoxy]-Pro	13252-13-6	<12.8	<14.1	<57.9	<82.4		<11.4	<49.6	<53.6	<12.1	<10.8	<13.1	<11.4	<13.4	<15.1	<13.5	<57.4	<13.9		<14.5
4,8-Dioxa-3h-Perfluorononanoic Acid (ADONA)	919005-14-4	<1.28	<1.41	<5.79	<8.24	<6.38	<1.14	<1.15	<1.25	<1.21	<1.08	<1.31	<1.14	<1.34	<1.51	<1.35	<5.74	<1.39		<1.45
9-Chlorohexadecafluoro-3-Oxanone-1-Sulfonic Acid (9Cl-PF3ONS	756426-58-1	<1.28	<1.41	<5.79	<8.24	<6.38	<1.14	<1.15	<1.25	<1.21	<1.08	<1.31	<1.14	<1.34	<1.51	<1.35	<5.74	<1.39		<1.45
N-Ethyl Perfluorooctane Sulfonamide (NEtFOSA)	4151-50-2	<1.28	<1.41	<1.3	<2	<1.45	<1.14	<1.15	<1.25	<1.21	<1.08	<1.31	<1.14	<1.34	<1.51	<1.35	<1.3	<1.39		<1.45
N-Ethyl Perfluorooctanesulfonamido Ethanol (NEtFOSE)	1691-99-2	<2.56	<2.82	<2.61	<3.99	<2.89	<2.27	<2.3	<2.5	<2.43	<2.17	<2.61	<2.28	<2.68	<3.02	<2.7	<2.6	<2.78		<2.9
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	2991-50-6	<0.641	<0.705	<2.89	<4.12	<3.19	<0.568	<0.575	<0.624	<2.39	<0.543	<0.654	<0.569	<0.671	<0.754	<0.674	<2.87	<0.696		<0.724
N-Methyl Perfluorooctane Sulfonamide (NMeFOSA)	31506-32-8	<1.28	<1.41	<1.3	<2	<1.45	<1.14	<1.15	<1.25	<1.21	<1.08	<1.31	<1.14	<1.34	<1.51	<1.35	<1.3	<1.39		<1.45
N-Methyl Perfluorooctanesulfonamido Ethanol (NMeFOSE)	24448-09-7	<2.56	<2.82	<2.61	<3.99	<2.89	<2.27	<2.3	<2.5	<2.43	<2.17	<2.61	<2.28	<2.68	<3.02	<2.7	<2.6	<2.78		<2.9
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	2355-31-9	<0.641	<0.705	<2.89	<4.12	<3.19	<0.568	<0.575	<0.624	<2.39	<0.543	<0.654	<0.569	<0.671	<0.754	<0.674	<2.87	<0.696		<0.724
Perfluorobutanesulfonic Acid (PFBS)	375-73-5	<0.321	<0.352	<1.45	<2.06	<1.59	<0.284	<0.287	<0.312	<0.303	<0.271	<0.327	<0.284	<0.335	<0.377	<0.337	<1.43	<0.348		<0.362
Perfluorobutanoic Acid (PFBA)	375-22-4	<0.641	<0.705	R	R	R	<0.568	<2.48	<2.68	<0.607	<0.543	**0.951**	<0.569	<0.671	<0.754	<0.674	<2.87	**1.02**		**0.78**
Perfluorodecanesulfonic Acid (PFDS)	335-77-3	<0.641	<0.705	<2.89	<4.12	<3.19	<0.568	<0.575	<0.624	<0.607	<0.543	<0.654	<0.569	<0.671	<0.754	<0.674	<2.87	<0.696		<0.724
Perfluorodecanoic Acid (PFDA)	335-76-2	<0.321	<0.352	<1.45	<2.06	<1.59	<0.284	<0.287	<1.34	<0.303	<0.271	**0.548**	<0.284	<0.335	<0.377	<0.337	<1.43	**0.4**		**0.591**
Perfluorododecane Sulfonic Acid (PFDoDS)	79780-39-5	<1.28	<1.41	<5.79	<8.24	<6.38	<1.14	<1.15	<1.25	<1.21	<1.08	<1.31	<1.14	<1.34	<1.51	<1.35	<5.74	<1.39		<1.45
Perfluorododecanoic Acid (PFDoA)	307-55-1	<0.641	<0.705	<2.89	<4.12	<3.19	<0.568	<0.575	<0.624	<0.607	<0.543	<0.654	<0.569	<0.671	<0.754	<0.674	<2.87	<0.696		<0.724
Perfluoroheptanesulfonic Acid (PFHpS)	375-92-8	<0.641	<0.705	<2.89	<4.12	<3.19	<0.568	<0.575	<0.624	<0.607	<0.543	<0.654	<0.569	<0.671	<0.754	<0.674	<2.87	<0.696		<0.724
Perfluoroheptanoic Acid (PFHpA)	375-85-9	<0.321	<0.352	R	R	R	<1.16	<1.24	<1.34	**0.326**	<0.271	<0.327	<0.284	<0.335	<0.377	<0.337	R	**0.557**		**0.44**
Perfluorohexadecanoic Acid (PFHxDA)	67905-19-5	<3.21	<3.52	<14.5	<20.6	<15.9	<2.84	<2.87	<3.12	<3.03	<2.71	<3.27	<2.84	<3.35	<3.77	<3.37	<14.3	<14.9		<3.62
Perfluorohexanesulfonic Acid (PFHxS)	355-46-4	<0.321	<0.352	<1.45	<2.06	<1.59	<0.284	<0.287	<0.312	<0.303	<0.271	<0.327	<0.284	<0.335	<0.377	<0.337	<1.43	<0.348		<0.362
Perfluorohexanoic Acid (PFHxA)	307-24-4	<0.641	<0.705	R	R	R	R	<2.48	<2.68	<0.607	<0.543	<0.654	<0.569	<0.671	<0.754	<0.674	R	<0.696		<0.724
Perfluorononanesulfonic Acid (PFNS)	68259-12-1	<1.28	<1.41	<5.79	<8.24	<6.38	<1.14	<1.15	<1.25	<1.21	<1.08	<1.31	<1.14	<1.34	<1.51	<1.35	<5.74	<1.39		<1.45
Perfluorononanoic Acid (PFNA)	375-95-1	<0.321	<0.352	<1.45	<2.06	R	**0.294**	**0.293**	<1.34	<0.303	<0.271	**0.739**	<0.284	**0.375**	<0.377	<0.337	<1.43	**0.694**		**0.688**
Perfluorooctadecanoic Acid (PFODA)	16517-11-6	<3.21	<3.52	<14.5	<20.6	<15.9	<2.84	<2.87	<3.12	<3.03	<2.71	<3.27	<2.84	<3.35	<3.77	<3.37	<14.3	<14.9		<3.62
Perfluorooctanesulfonamide (FOSA)	754-91-6	<0.641	<0.705	<0.652	<0.998	<0.723	<0.568	<0.575	<0.624	<0.607	<0.543	<0.654	<0.569	<0.671	<0.754	<0.674	<0.649	<0.696		<0.724
Perfluorooctanesulfonic Acid (PFOS)	1763-23-1	**0.387**	<0.352	<1.45	**2.12**	**1.83**	**0.742**	**0.789**	**0.923**	**0.448**	**0.958**	**1.55**	**0.328**	**0.907**	**0.644**	**0.485**	<1.43	**2.07**		**1.93**
Perfluorooctanoic Acid (PFOA)	335-67-1	**0.395**	**0.402**	<1.45	**R**	R	**1.89**	**1.41**	<1.34	**1.35**	**0.293**	**0.565**	<0.284	**0.413**	**0.667**	**0.612**	<1.43	**1.59**		**0.991**
Perfluoropentanesulfonic Acid (PFPeS)	2706-91-4	<1.28	<1.41	<5.79	<8.24	<6.38	<1.14	<1.15	<1.25	<1.21	<1.08	<1.31	<1.14	<1.34	<1.51	<1.35	<5.74	<1.39		<1.45
Perfluoropentanoic Acid (PFPeA)	2706-90-3	<0.641	<0.705	R	R	R	<2.31	<2.48	<2.68	<0.607	<0.543	<0.654	<0.569	<0.671	<0.754	<0.674	R	<0.696		<0.724
Perfluorotetradecanoic Acid (PFTA)	376-06-7	<0.641	<0.705	<2.89	<4.12	<3.19	<0.568	<0.575	<0.624	<0.607	<0.543	<0.654	<0.569	<0.671	<0.754	<0.674	<2.87	<0.696		<0.724
Perfluorotridecanoic Acid (PFTrDA)	72629-94-8	<0.641	<0.705	<2.89	<4.12	<3.19	<0.568	<0.575	<0.624	<0.607	<0.543	<0.654	<0.569	<0.671	<0.754	<0.674	<2.87	<0.696		<0.724
Perfluoroundecanoic Acid (PFUnA)	2058-94-8	<0.641	<0.705	<2.89	<4.12	<3.19	<0.568	<0.575	<0.624	<0.607	<0.543	**0.771**	<0.569	<0.671	<0.754	<0.674	<2.87	<0.696		**0.787**
Other																				
Total Organic Carbon	7440-44-0	**3.07**	**1.85**	**5.49**	**3.84**	**5.93**	**1.42**	**2.69**	**3**	**1.08**	**1.1**	**4.06**	**2.16**	**4.54**	**4.9**	**3.68**	**3.28**	**10.6**	**10.8**	**6.04**
Total Solids	NONE	**70.7**	**65.2**	**67.1**	**47.6**	**60.9**	**80.8**	**76.8**	**72.5**	**78.3**	**82.6**	**68.6**	**77.4**	**69**	**63**	**67.3**	**67.7**	**65.9**		**62.5**

Notes:
ug/kg = micrograms per kilogram; % = percent
< (value) = not detected at laboratory reporting limit
R = Percent surrogate recovery less than 10%; result rejected.
Red font - sample results modified based on data validation.
Shaded = exceeds MassDEP soil standard
All soil samples were collected from 0-6 inches below ground surface
Sample identification:
CEN-central; NE- northeast; SE - southeast; WT - west
FT-forest; FD-field; SD-sand; ST-silt; LM-loam
LD = laboratory duplicate

APPENDIX A
PFAS SOIL ANALYTICAL RESULTS
WOODARD & CURRAN
PFAS IN MASSACHUSETTS SOILS
BACKGROUND STUDY

Station Name	**CAS Number**	**WT-7**	**WT-7**	**WT-7**
Sample ID		**WT-7B-LM-FT**	**WT-7C-LM-FT**	**WT-7D-LM-FT**
Sample Date		10/22/2021	10/22/2021	10/22/2021
Primary Sample				
PFAS				
11-Chloroeicosafluoro-3-Oxaundecane-1-Sulfonic Acid (11Cl-PF	763051-92-9	<5.51	<1.34	<1.31
1H,1H,2H,2H-Perfluorodecanesulfonic Acid (8:2FTS)	39108-34-4	<2.76	<0.67	<0.655
1H,1H,2H,2H-Perfluorododecanesulfonic Acid (10:2FTS)	120226-60-0	<5.51	<1.34	<1.31
1H,1H,2H,2H-Perfluorohexanesulfonic Acid (4:2FTS)	757124-72-4	<5.51	<1.34	<1.31
1H,1H,2H,2H-Perfluorooctanesulfonic Acid (6:2FTS)	27619-97-2	<2.76	<0.67	<0.655
2,3,3,3-Tetrafluoro-2-1,1,2,2,3,3,3-Heptafluoropropoxy]-Pro	13252-13-6	<55.1	<13.4	<13.1
4,8-Dioxa-3h-Perfluorononanoic Acid (ADONA)	919005-14-4	<5.51	<1.34	<1.31
9-Chlorohexadecafluoro-3-Oxanone-1-Sulfonic Acid (9Cl-PF3ONS	756426-58-1	<5.51	<1.34	<1.31
N-Ethyl Perfluorooctane Sulfonamide (NEtFOSA)	4151-50-2	<1.36	<1.34	<1.31
N-Ethyl Perfluorooctanesulfonamido Ethanol (NEtFOSE)	1691-99-2	<2.72	<2.68	<2.62
N-Ethyl Perfluorooctanesulfonamidoacetic Acid (NEtFOSAA)	2991-50-6	<2.76	<0.67	<2.72
N-Methyl Perfluorooctane Sulfonamide (NMeFOSA)	31506-32-8	<1.36	<1.34	<1.31
N-Methyl Perfluorooctanesulfonamido Ethanol (NMeFOSE)	24448-09-7	<2.72	<2.68	<2.62
N-Methyl Perfluorooctanesulfonamidoacetic Acid (NMeFOSAA)	2355-31-9	<2.76	<0.67	<0.655
Perfluorobutanesulfonic Acid (PFBS)	375-73-5	<1.38	<0.335	<0.327
Perfluorobutanoic Acid (PFBA)	375-22-4	R	<0.67	<0.655
Perfluorodecanesulfonic Acid (PFDS)	335-77-3	<2.76	<0.67	<0.655
Perfluorodecanoic Acid (PFDA)	335-76-2	<1.38	**0.375**	<0.327
Perfluorododecane Sulfonic Acid (PFDoDS)	79780-39-5	<5.51	<1.34	<1.31
Perfluorododecanoic Acid (PFDoA)	307-55-1	<2.76	<0.67	<0.655
Perfluoroheptanesulfonic Acid (PFHpS)	375-92-8	<2.76	<0.67	<0.655
Perfluoroheptanoic Acid (PFHpA)	375-85-9	R	<0.335	**0.352**
Perfluorohexadecanoic Acid (PFHxDA)	67905-19-5	<13.8	<3.35	<3.27
Perfluorohexanesulfonic Acid (PFHxS)	355-46-4	<1.38	<0.335	<0.327
Perfluorohexanoic Acid (PFHxA)	307-24-4	R	<0.67	<0.655
Perfluorononanesulfonic Acid (PFNS)	68259-12-1	<5.51	<1.34	<1.31
Perfluorononanoic Acid (PFNA)	375-95-1	<1.38	**0.435**	<0.327
Perfluorooctadecanoic Acid (PFODA)	16517-11-6	<13.8	<3.35	<3.27
Perfluorooctanesulfonamide (FOSA)	754-91-6	<0.679	<0.67	<0.655
Perfluorooctanesulfonic Acid (PFOS)	1763-23-1	<1.38	**1.42**	**0.741**
Perfluorooctanoic Acid (PFOA)	335-67-1	<1.38	**1.1**	**1.78**
Perfluoropentanesulfonic Acid (PFPeS)	2706-91-4	<5.51	<1.34	<1.31
Perfluoropentanoic Acid (PFPeA)	2706-90-3	R	<0.67	<0.655
Perfluorotetradecanoic Acid (PFTA)	376-06-7	<2.76	<0.67	<0.655
Perfluorotridecanoic Acid (PFTrDA)	72629-94-8	<2.76	<0.67	<0.655
Perfluoroundecanoic Acid (PFUnA)	2058-94-8	<2.76	<0.67	<0.655
Other				
Total Organic Carbon	7440-44-0	**7.08**	**7.57**	**4.78**
Total Solids	NONE	**69.8**	**67.7**	**73.4**

Notes:
ug/kg = micrograms per kilogram; % = percent
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