PFAS Background Sampling in CT

ENVE Senior Design Project #3

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Executive Summary (GP)

The Connecticut Department of Energy and Environmental Protection (CT DEEP) is looking to create a profile of shallow soil background concentrations for the emerging contaminant, PFAS or per- and polyfluoroalkyl substances, throughout the state of Connecticut. Background concentrations are necessary for contaminants found naturally in the environment, like Arsenic, to be able to distinguish the natural levels from actual contamination events. While PFAS is a manmade chemical not found in the environment naturally, it has become so widespread due to its mass production since the 1950s. Therefore, background concentrations are essential to understanding the existing levels of PFAS in soils which will allow for detection of actual contamination sources. This will further allow for the development of enforceable regulations against PFAS compounds, once contamination events can be detected in comparison to background concentrations. CT DEEP requested a soil sampling plan that will extend across the state's eight counties for a representative understanding of PFAS levels in Connecticut's shallow soils.

The development of the sampling plan required an analysis of online resources to determine potential PFAS sources in Connecticut. Sampling locations were chosen away from these potential sources to ensure true background concentrations were being observed. ArcGIS Online contains vital information in determining these sources and was utilized to identify the relevant layers to this project. For ease of access and a reduced timeframe, CT DEEP requested that all sampling locations be placed on CT DEEP property.

After evaluation of the online data layers of potential PFAS sources, state forests and parks appeared to be most ideally situated for background sampling due to their distance from potential sources. A total of 16 state forests and state parks across Connecticut's eight counties were selected for soil sampling. A total of 110 soil samples were taken between all properties. Samples were taken at two depths: 0 to 6 inches and 18 to 24 inches to gain an understanding of PFAS concentrations at the direct human exposure level and a slightly deeper profile to observe potential transport, respectively.

Lab results of total PFAS concentrations were compiled into an ArcGIS map in conjunction with the recorded GPS coordinates of each sample to display the varying levels of the contaminant at each sampling site across the state. The maps of total PFAS help identify trends of high or low concentrations in certain areas of the state as well as maximum and minimum concentration levels. This data will ultimately aid Environmental Professionals and policy makers in determining the proper standards to set for PFAS soil contamination to be remediated as well as regulations against industrial entities in terms of PFAS release in wastes.

PFAS soil samples normally cost \$240 to analyze, causing the theoretical price of sample analysis to be \$26,400 for the 110 samples of this study. Collaboration with Complete Environmental Testing Labs (CET Labs) occurred to analyze all soil samples for 18 PFAS compounds at no charge, resulting in an actual sample analysis cost of \$0. The cost to mobilize personnel as well as deliver samples to the lab is estimated to be \$2,000 and the cost to physically collect samples using existing equipment is $15,000. The total cost of this study therefore is $17,000 in comparison to the theoretical value of $43,400.

While this study is one piece of a much larger project, it is the first stepping stone to combatting PFAS in Connecticut. The shallow soil concentration values will increase urgency to address the accelerating issue that PFAS poses to human health and the environment and advance Connecticut's position in contaminant regulation.

1. Introduction (GP, GR)

Per- and polyfluoroalkyl substances (PFAS) are emerging contaminants that have been widely used since the 1950s due to their chemical properties that allow them to withstand extremely high temperatures and repel oil and water. These chemical properties present PFAS as a major concern because they cannot be broken down naturally and travel readily through soil and groundwater. Because they do not easily break down, they can last for long periods of time in the environment such as in water bodies and will bioaccumulate in animals and humans when ingested. PFAS is already present within human and animal blood as well as a variety of food products ("PFAS Explained"). They have been found to pose a risk to human health at very low concentrations which could lead to reproductive and developmental effects, among other issues ("PFAS Explained"). The combined environmental and health effects PFAS poses is enough to require immediate action from all government agencies in order to ensure protection of public health and the environment.

The use of PFAS in industrial manufacturing processes as well as disposal and leaching from landfills has resulted in their widespread distribution throughout the world, posing a difficult challenge to environmental professionals. Each state in the United States is moving forward with their own regulations and task forces to address PFAS and its associated compounds in an effort to contain this persistent contaminant. The state of Connecticut has decided to take action through the establishment of an Interagency PFAS Task Force and PFAS Action Plan.

Part of Connecticut's efforts to understand and combat PFAS involves the obtainment of background samples of PFAS concentrations in both soil and groundwater. Background concentrations are necessary to establish for PFAS as the pollutant is virtually everywhere. Sampling must be completed to obtain concentrations in the least likely areas to be affected by PFAS to be able to compare to actual PFAS contamination events. This requires a large effort from various different teams to collect and analyze a significant amount of samples to reach meaningful results. The purpose of this project is to initiate the workload that will contribute to the overarching goal of establishing PFAS regulations and standards for water and soil.

The following project focuses on shallow soil sampling in distributed areas across Connecticut. Properties and sampling locations within each property will be chosen based on existing data indicating potential PFAS sources. The samples will be analyzed for 18 PFAS compounds of which the results will be compiled into maps illustrating the distribution of different PFAS compound concentrations throughout Connecticut.

1.1 Need for Sampling (JJ)

Federal legislators have been pushing for increased regulations on PFAS, but Congress has not enforced even general laws to govern PFAS pollution. EPA is currently sticking with the 2016 standard of 70 parts per trillion as the maximum concentration level in drinking water. Therefore, many states are trying to control PFAS at the state level rather than following federal legislation. For example, Vermont and Michigan are at the forefront of regulating PFAS and eliminating the health risks associated with PFAS exposure.

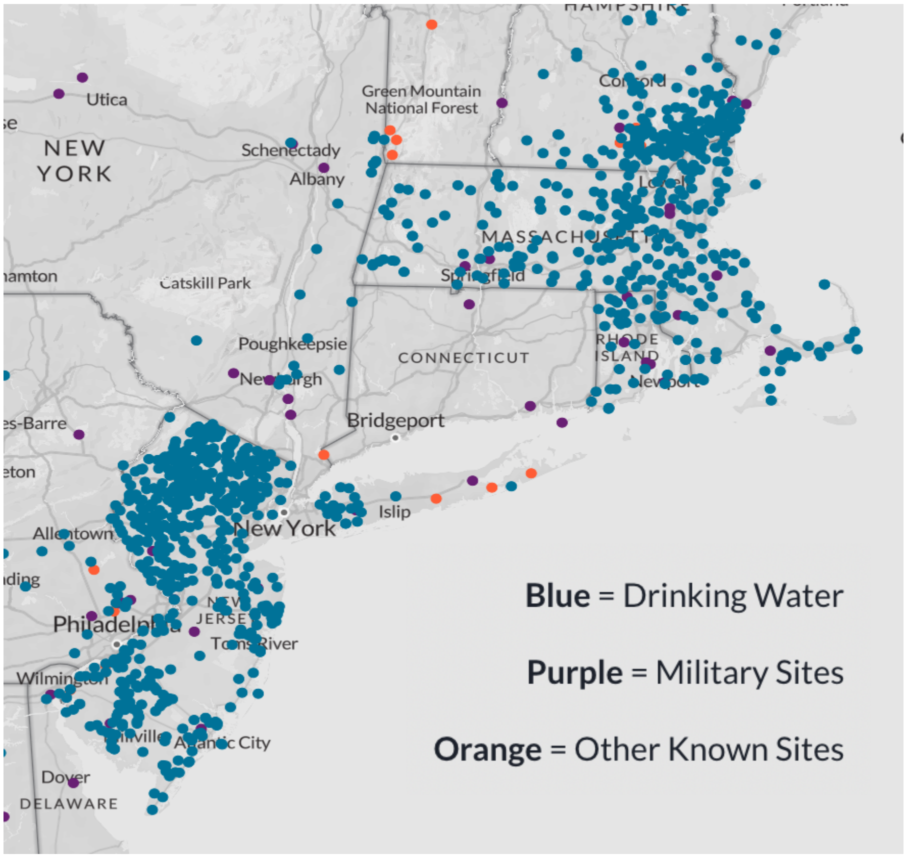


Figure 1. PFAS Contamination Sites in Mid-Atlantic & New England.

1.2 Project Scope (GP)

This project identifies sampling locations in the eight counties of Connecticut that assists with the determination of background concentrations of PFAS throughout the state. Vermont has already sampled and identified PFAS concentrations throughout their state, and this Scope of Work has been inspired by components of Vermont's published study, *PFAS Background in Vermont Shallow Soils*.

Proposed Sampling

Soil is the main focus for sampling with a total of 110 soil samples taken across 16 properties. Samples at each specified location are taken at a depth range of 0 to 6 inches to understand concentrations in comparison to human exposure limits. An additional sample at each specified location was taken at a depth range of 18 to 24 inches to understand how concentrations may differ with depth. The names of properties and number of soil samples at each property are summarized in **Table A1**. A map of the preliminary sampling locations within each property are provided in **Figure A1** at the end of the document. Sampling locations were chosen in an attempt to minimize proximity to potential PFAS sources in Connecticut, of which are shown in **Figure 4**, and biased towards state-owned property for ease of access. Locations were placed nearby accessible roads for further accessibility, specifically for equipment to reach.

Table A2 provides a description of each sampling location within the context of the property, as well as the exact coordinates of each location. These coordinates are the target areas for sampling, however sampling locations were adjusted on site based on observed conditions or unanticipated accessibility issues. The final coordinates of each sample taken were recorded with a GPS device and are shown in **Figure A2**.

Materials

- Approved PFAS sampling materials: low-density polyethylene like Ziploc bags or LDPE tubing, materials made of high-density polyethylene (HDPE), polypropylene, silicone, acetate, stainless steel, glass
    - Prohibited from using: PTFE, PVDF, PCTFE, ETFE, FEP (found in these brands: Teflon and Hostaflon, Kynar, Neoflon, and Tefzel)
- Sample containers made from either HDPE or polypropylene (PFAS free), provided by CET
- Large bore sampler driven with a slide hammer
    - 2 ft acetate liners for soil collection
- GPS device
- Decontamination materials
    - DI water provided by CET or Poland Spring
    - Polyethylene or Polyvinyl chloride brush
- PPE
    - PFAS free gloves
    - Non-water resistant clothing
    - Protective boots (ASTM)

Analysis

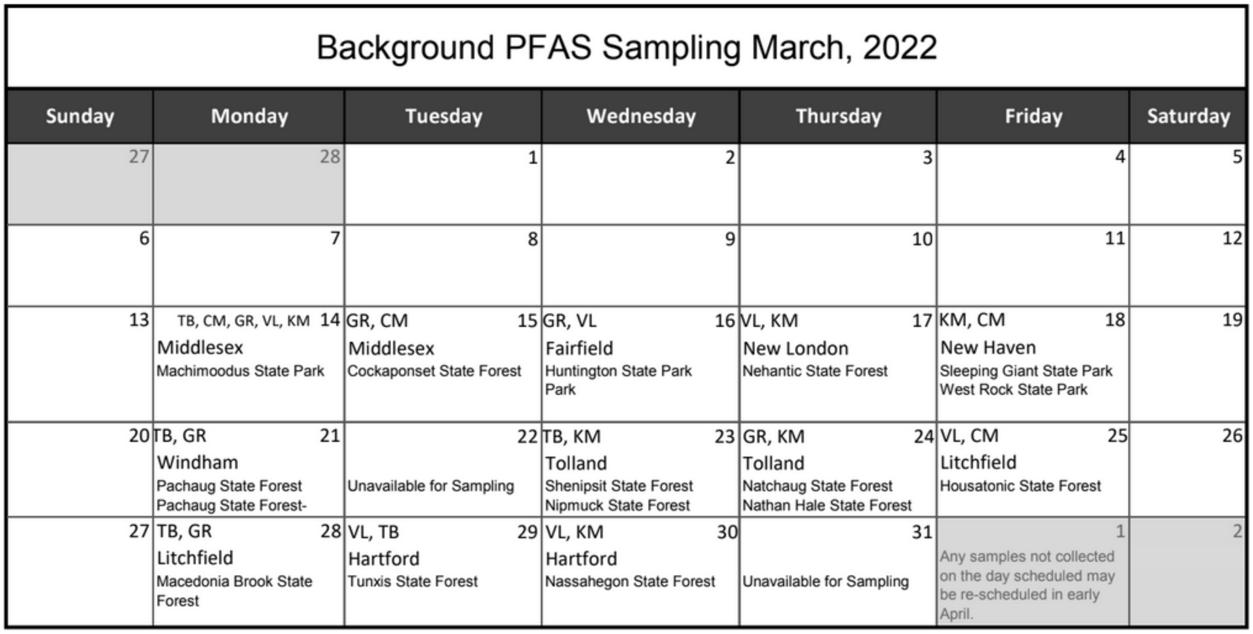
The soil samples were put on ice after collection and taken to the lab (CET Labs) either immediately or at the end of the week to be analyzed for 18 PFAS compounds over the weekend. Testing was performed using EPA-method-8327, with a standard deviation of 2 ppt. Equipment blanks were also analyzed and results received prior to the start of field work to ensure no cross contamination ensues from equipment.

Reporting

The UConn Senior Design team has completed a report that details location identification, sampling techniques, and lab analytics, summarizes data received, and analyzes the soil sample results, indicating any trends in PFAS concentrations across the state or within counties, as well as between different PFAS compounds. A figure has been generated to show the range of PFAS concentrations across the state, included in this report. This report will be provided to CT DEEP for their review.

Schedule

The following figure represents the sampling schedule set for the last three weeks of March and the respective properties sampled each day.



Background PFAS Sampling March, 2022

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
27	28	1	2	3	4	5
6	7	8	9	10	11	12
13	TB, CM, GR, VL, KM 14 Middlesex Machimoodus State Park	GR, CM 15 Middlesex Cockaponset State Forest	GR, VL 16 Fairfield Huntington State Park Park	VL, KM 17 New London Nehantic State Forest	KM, CM 18 New Haven Sleeping Giant State Park West Rock State Park	19
20	TB, GR 21 Windham Pachaug State Forest Pachaug State Forest-	22 Unavailable for Sampling	TB, KM 23 Tolland Shenipsit State Forest Nipmuck State Forest	GR, KM 24 Tolland Natchaug State Forest Nathan Hale State Forest	VL, CM 25 Litchfield Housatonic State Forest	26
27	TB, GR 28 Litchfield Macedonia Brook State Forest	VL, TB 29 Hartford Tunxis State Forest	VL, KM 30 Hartford Nassahegon State Forest	31 Unavailable for Sampling	1 Any samples not collected on the day scheduled may be re-scheduled in early April.	2

Figure 2. Schedule including locations and personnel for PFAS sampling plan execution.

1.3 Health Effects of PFAS

1.3.1 PFAS Background (TM, GP)

This project is motivated by the toxic impacts of PFAS. To properly understand the project, one must understand why PFAS chemicals are of concern. PFAS have been studied very little and the information about their risk to the environment and humans has been heavily biased by the producers of these compounds. This conflict of interests between large corporations and environmental wellness has stunted development of PFAS research. It is essential to know what levels of PFAS are harmful to life in order to make better educated decisions moving forward. This useful information can potentially influence regulations and cleanup efforts, along with larger dedication of funding for research and remediation.

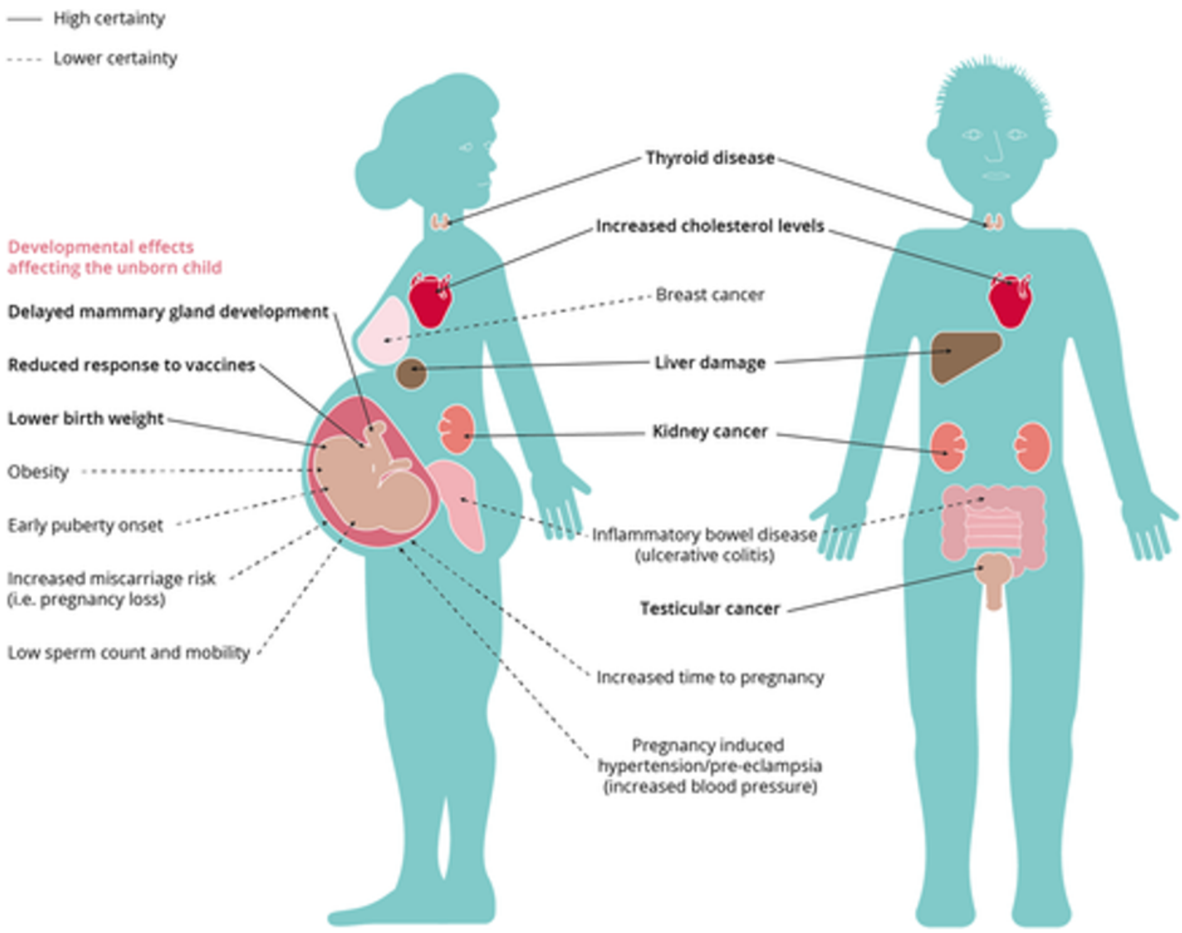
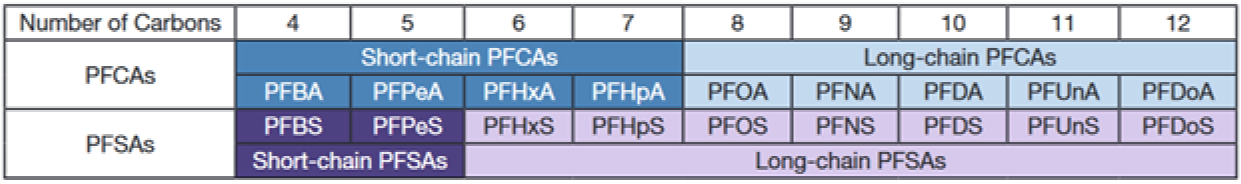


Figure 3. Visual chart of possible health effects to the female and male human body resulting from PFAS contamination. (Fenton, 2020)

The scope of the PFAS contamination is quite large. PFAS were first used commercially in 1949. There is a current estimate of about 5,000 man-made chemicals that contain PFAS that are widely used in many products today. The corporations that use these chemicals do not legally have to disclose their use due to their ability to claim this information as confidential. The scale of the problem is truly unknown. While there are standards for two PFAS chemicals, PFOA and PFOS and their production has been stopped in the US, these two chemicals are only a small portion of the large set of PFAS compounds. For example, in fire fighting foam consisting of aqueous film-forming foam (AFFF) there are many others present. “In addition to PFOA and PFOS, 57 classes of PFAS have been identified in AFFF and/or AFFF-contaminated groundwater, containing over 240 individual compounds, many of which are poorly characterized in terms of toxicity and environmental fate and transport. Surveillance for PFAS is difficult because of the large number of compounds, many of which lack analytical standards” (Cordner, 2019). This information is very useful because it means the contamination is more complex than previously anticipated, many more chemicals are possibly present in the polluted areas and we will have a hard time testing for them. The chemicals can travel rapidly through groundwater and air so the most accurate background concentrations will most likely be found in the state’s forests, away from human contamination. Luckily, CT DEEP owns a substantial amount of forest land, so this provides good sampling sites. Connecticut does not have many public records of the sources of PFAS contamination compiled. For reference, a national database from an October 4th, 2021 update (Figure 2) only shows 3 potential sources in CT; all of which are from firefighting foam on military bases (a very small portion of the overall sources) (Figure 2).

Sources of PFAS range from “fire-fighting foams…nonstick products, food packaging and waterproof and stain repellent fabrics,” which can be attributed to fire service stations, landfills, industrial properties, and sewage treatment plants (Mueller & Yingling, 2020). It can be expected that landfills will contribute to gaseous PFAS emissions as well as aqueous PFAS releases through leachate; these releases are supposed to be monitored more carefully in modern landfills that tend to have leachate and gas collection, however older landfills are expected to produce these types of PFAS contamination. C-F bonds replace C-H bonds in PFAS compounds, causing them to have both high thermal and chemical stability, resulting in resistance to physical and chemical destruction (Mueller & Yingling, 2020). Two of the most researched PFAS compounds, perfluorooctanoate (PFOA) and perfluorooctane sulfonate (PFOS), with an established Lifetime Health Advisory (LHA) of 70 ng/L in drinking water have been phased out by most manufacturers throughout the world, after they were discovered to have damaging health effects on humans (Mueller & Yingling, 2020). However, a new generation of PFAS compounds with shorter carbon chains, that are potentially just as dangerous, are being used as alternatives. Two large categories of these shorter-chained compounds can be grouped as perfluorocarboxylates (PFCAs) and perfluorosulfonates (PFSAs) and are the subject of many current studies.



Number of Carbons	4	5	6	7	8	9	10	11	12
PFCAs	Short-chain PFCAs				Long-chain PFCAs				
	PFBA	PFPeA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA
PFSAs	PFBS	PFPeS	PFHxS	PFHpS	PFOS	PFNS	PFDS	PFUnS	PFDoS
	Short-chain PFSAs		Long-chain PFSAs						

Table 1. Classification of short-chain and long-chain PFCAs and PFSAs (Mueller & Yingling, 2020).

Table 1 details the number of carbons that indicate whether a PFCA or PFSA is considered long-chained or short-chained. It is interesting to note that PFCAs require more carbons to be considered long-chained in comparison to PFSAs, and both PFOA and PFOS contain the same number of carbon atoms.

The range of PFAS compounds is vast, and not all of them can be accounted for. It is important to focus on the most prevalent ones and anticipate their subsequent compounds or degradation products in order to maintain an understanding of the contaminants present in the environment.

1.3.2 Health Effects of PFAS (TM)

One of the major intake pathways for PFAS exposure is through diet. The widespread contamination of the environment by industries has led to PFAS in a large amount of the groundwater. Since the half life of PFAS are very long, they tend to bioaccumulate in plants as they uptake this contaminated water. These plants then transfer the toxins up the food chain to humans and other animals, contaminating milk and meat even further before human consumption. Breast milk is another large source for young children, who had the largest exposure of any age group (ages 1-2 years) (Juliane, 2020). PFAS are an unescapable toxin, they work their way up the food chain and bioaccumulate in all forms of life. The scope of the remediation challenge is huge since they are such a diverse species. This shows how important it is to establish background concentrations to assess how bad the contamination problem is in the state of Connecticut.

The health effects of PFAS in humans have been minimally studied. Only a few out of the thousands of PFAS chemicals have been evaluated for health impacts. It is very likely that there are many other risks from these toxins that we do not yet understand. "Epidemiological studies have revealed associations between exposure to specific PFAS and a variety of health effects, including altered immune and thyroid function, liver disease, lipid and insulin dysregulation, kidney disease, adverse reproductive and developmental outcomes, and cancer. Concordance with experimental animal data exists for many of these effects" (Fenton, 2020). Figure 3 also shows some other health effects. We know that there are many risks already, and that the pollution is widespread. The half lives of PFAS are extremely long so they do not degrade quickly, compounding the problem. The large scale of the pollution has "led to measurable PFAS in the blood of nearly the entire population in developed countries" (Fenton, 2020). Even remote villages that do not have access to the outside world and eat nothing but local foods are testing positive for PFAS. The problem is enormous and needs to be addressed quickly because it will only get worse as more and more of these chemicals continue to be manufactured and used every day.

The scale of PFAS contamination is so vast that we cannot yet properly understand the problem. However, we do know that the problem is very large and serious. The pollution is extremely widespread between water and air transportation along with the long half life associated with PFAS. Finding a proper and accurate sampling site will require traveling as far into the forest as possible to isolate the effects of industrialization. This is an ideal situation for this project since the team has been directed to primarily find sampling sites located on CT DEEP owned land, such as the state forests. The state forest land is probably some of the best land to sample for contamination since it was only cleared and farmed before the era of PFAS for the most part. The health risks are severe even with small doses even though large companies that produce PFAS argue differently. More resources need to be dedicated to the PFAS contamination issue to determine exactly what other health effects are present from toxicity of these industrial compounds. The current research suggests that these chemicals are even more powerful than currently proven.

2. Analysis

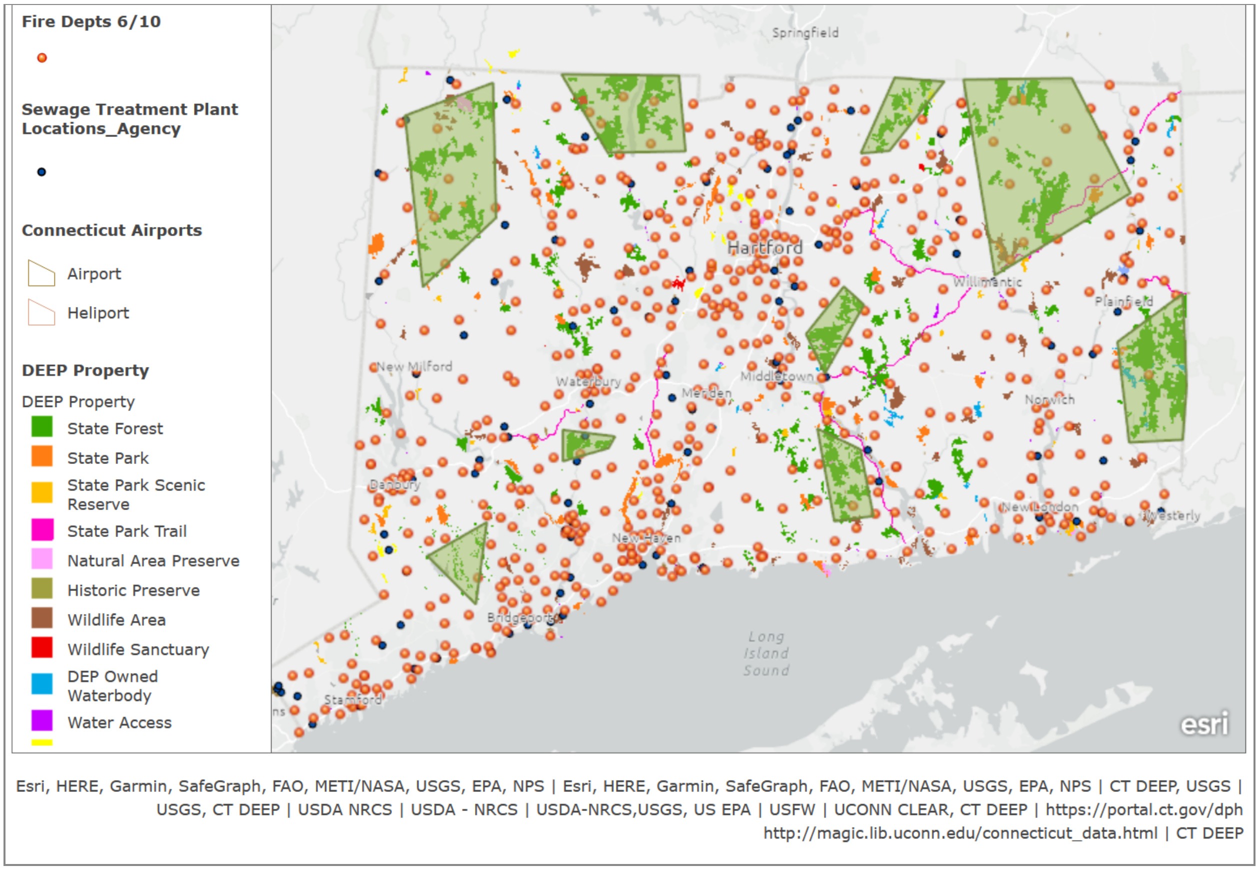
2.1 Applicable Regulations (TM)

The EPA has not yet established standards for PFAS levels. They have established levels for PFOS and PFOA, but these are a minuscule percent of the PFAS chemical list containing over 5,000 variations of the compounds.

While there are no federal water guidelines, there are a few state guidelines that have been created. The problem is that most guidelines have been influenced by large corporations. "For example, in 2001 EPA and West Virginia Department of Environmental Protection (WVDEP) learned that DuPont scientists had found high levels of PFOA in regional drinking water. The following year, DuPont collaborated with WVDEP and a state-appointed C8 Assessment Toxicity Team to develop a screening level of 150,000 ng/L, despite numerous conflicts of interest and DuPont's own internal guideline of 1000 ng/L" (Cordner, 2019). This demonstrates how unreliable the current regulations are and why new guidance should be created. "Of the eight critical studies used to derive PFOA ($n = 5$) or PFOS ($n = 3$) guidelines, five were conducted by PFAS manufacturers (3M or DuPont), two were conducted by the U.S. government (EPA or NIEHS), and one was conducted by academic researchers with funding from the Chinese government. North Carolina's PFOA guideline, the highest in the country, heavily references a risk assessment conducted by industry consultants" (Cordner, 2019). The current studies are heavily influenced by industry and are not scientifically valid because they are clearly biased. The studies cannot be performed by the companies polluting the chemicals under review for clear reason. The companies will simply protect their assets by validating high concentrations of output effluent. Without proper studies performed by unbiased parties, there will not be proper guidelines established. PFAS are clearly being disguised as less harmful than they really are by large corporations that are heavily invested in the use of these substances.

2.2 Summary of Data Available (JJ)

Sampling locations are determined based on the available information on ArcGIS online. Suspected locations of high concentrations of PFAS would be in areas surrounding the major sources of PFAS. These include fire departments, sewage treatment plants, and airports. Using a map shown in **Figure 4**, created to display all of the locations of these sources, the focus was to find areas of low potential for contamination that were also on DEEP owned property to avoid difficulties gaining permission to sample. The DEEP owned property, as well as the type of property, are also shown in **Figure 4**. Many of the sampling locations were chosen in state forests (shown in dark green) because these were easily available for sampling with permission and were generally areas of low density of the PFAS sources. Preliminary thoughts for potential sampling areas are shown in green polygons in **Figure 4**.



Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS | Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS | CT DEEP, USGS | USGS, CT DEEP | USDA NRCS | USDA - NRCS | USDA-NRCS,USGS, US EPA | USFW | UCONN CLEAR, CT DEEP | https://portal.ct.gov/dph http://magic.lib.uconn.edu/connecticut_data.html | CT DEEP

Figure 4. Potential PFAS sources in Connecticut with reference to DEEP property based on DEEP ArcGIS online data for fire departments, airports, and sewage treatment plants. Green polygons represent a portion of the designated sampling properties.

2.3 Guidance for Design (JJ)

Many states that have already begun sampling to determine background concentrations have produced PFAS sampling guidelines that serve as an informant of all the precautions that should be taken when handling samples to be tested for a contaminant that is used in everyday products and standard field equipment. This is helpful to determine sampling procedures or uncover any safety concerns when carrying out field work to determine PFAS concentrations.

Michigan's Department of Environment, Great Lakes, and Energy Protection has established a PFAS action Response team and described in detail many sampling precautions for PFAS. Because it is tested at very small concentrations (ppt), cross-contamination needs to be avoided to prevent false-positives or skewed results. Cross-contamination can happen through water used during drilling or decontamination, sampling equipment, storage equipment, personal protective equipment, field clothing, and personal hygiene products. Anything that comes in direct contact with the samples should be PFAS-free. The information provided from Michigan's

Department of Environment, Great Lakes, and Energy Protection is a guideline for creating our sampling plan and determining which materials are safe to use for PFAS sampling without causing cross contamination.

2.4 Avoiding Contamination (JJ)

Sampling for PFAS follows typical field procedures but contains many other necessary precautions due to its pervasiveness in many different lab equipment and other everyday items. Due to PFAS prevalence and lab detection limits, the smallest contamination can result in inaccurate measurements. Some clothing and cosmetics often worn while sampling that contain PFAS and should be avoided are shown in **Figure 5**.

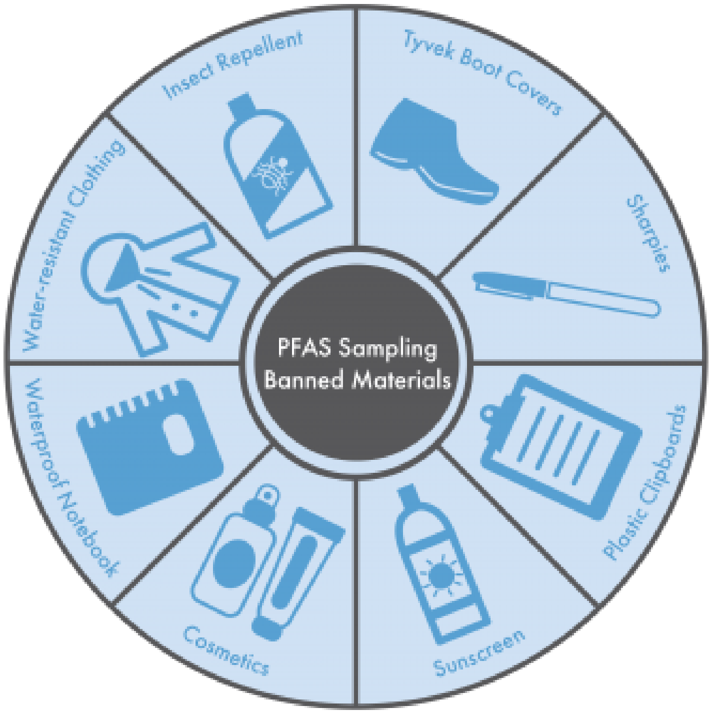


Figure 5. Materials that must be avoided or approved as PFAS-free if used during sampling.

PFAS-free water should be analyzed before field work and should contain only trace amounts, if any, of PFAS compounds that will be tested for, or limitations set by the project proposal. Materials used during sampling should be determined PFAS-free. Information about material makeup can be found in Safety Data Sheets by looking for terms, “perfluoro,” “fluoro,” or “fluorosurfactant,” which indicate the presence of PFAS in the material. Several materials and sampling equipment have been approved for PFAS sampling to ensure no cross-contamination with the samples. These include low-density polyethylene like Ziploc bags or LDPE tubing, materials made of high-density polyethylene (HDPE), polypropylene, silicone, acetate, stainless steel, glass (if it is for a short period of time and the sample is a dry solid as PFAS are known to adsorb to glass in aqueous samples). To store the sample, laboratory-provided PFAS-Free bottles or containers made from HDPE or polypropylene are acceptable. Prohibited materials that are often found in lubricants that aid in any equipment with sliding mechanisms, tubes, wires, hoses, valves, cable ties, and coatings on aluminum, include polytetrafluoroethylene (PTFE), polyvinylidene fluoride (PVDF), polychlorotrifluoroethylene (PCTFE), ethylene-tetrafluoro-ethylene (ETFE), and fluorinated ethylene propylene (FEP). These compounds can be found in brand names such as trademark Teflon and Hostaflon, Kynar, Neoflon, and Tefzel. Sampling materials that will come in direct contact with the samples should be handled minimally and not come in contact with other sampling materials.

3. Design Recommendations and Consideration

3.1 Considerations for Sampling Locations (JJ)

The exact sample locations were chosen based on several considerations. Among the areas of DEEP owned property, the state forests were the main areas where approval would be granted easily, so natural and historic preserves and watershed areas were avoided. General areas were selected away from dense areas of PFAS sources. Google Earth was utilized to determine locations that would be easy to access from a road or a trail. When the samples were collected, the locations may have changed based on the conditions of the area, such as frozen ground, rocks, or signs of lots of human activity, but were recorded using GPS.

3.2 Cost Analysis (Capital and Maintenance) (GR)

The total anticipated cost of this project was $43,400. To estimate this figure we spoke to the director of the Center of Environmental Sciences and Engineering (CESE) at the University of Connecticut Storrs campus to provide us with information on the price to analyze a soil sample for the presence of PFAS. The price per sample is roughly $240, with 110 samples the price of analysis is $26,400. The collection of samples was accomplished by CT DEEP, and we estimated that the collection of samples would cost $15,000 for only employee payment as CT DEEP already possessed the necessary equipment. Sample delivery to Complete Environmental Testing (CET) Labs, was evaluated to $2,000 as gas prices at the time of sampling were $4.50 per gallon.

The soil samples however were processed and analyzed by CET Labs for free as they were interested to see the outcome of the project, which brought the actual overall cost of this project down to $17,000.

Table 2. Breakdown of total cost for sample collection, delivery, and analysis.

Activity	Cost
Sample Collection	$15,000
Sample Delivery	$2,000
Sample Analysis	$26,400
Total	**$43,400**

4. Design Analysis

4.1 New Data Collected and Analysis (GP, GR)

Final analysis reports detailing the concentrations of the following 18 PFAS compounds were received from CET Labs for all 110 soil samples: ADONA, NEtFOSAA, NMeFOSAA, PFBS, PFDA, PFDoA, PFHpA, PFHxA, PFHxS, PFNA, PFOA, PFOS, PFTeDA, PFTrDA, PFUnA, 11Cl-PF3OUdS, 9Cl-PF3ONS, and HFPO-DA. The main compounds to consider are PFOA and PFOS as they were of the first type of these compounds to be manufactured and are therefore the most prevalent in the environment currently. The data reflects this as well, showing much higher concentrations in comparison to the other compounds of which most were undetectable at all properties.

The field and equipment blanks collected at each property showed no detection of any of the listed PFAS compounds, confirming that the environment did not contribute to any PFAS contamination of the taken soil samples.

In general, the PFOA concentrations appear to exceed PFOS concentrations and vary both within properties and across the state for the 0 to 6 inch depth samples. **Figure 6** shows PFOA concentrations with respect to DEEP property at the 0 to 6 inch depth.

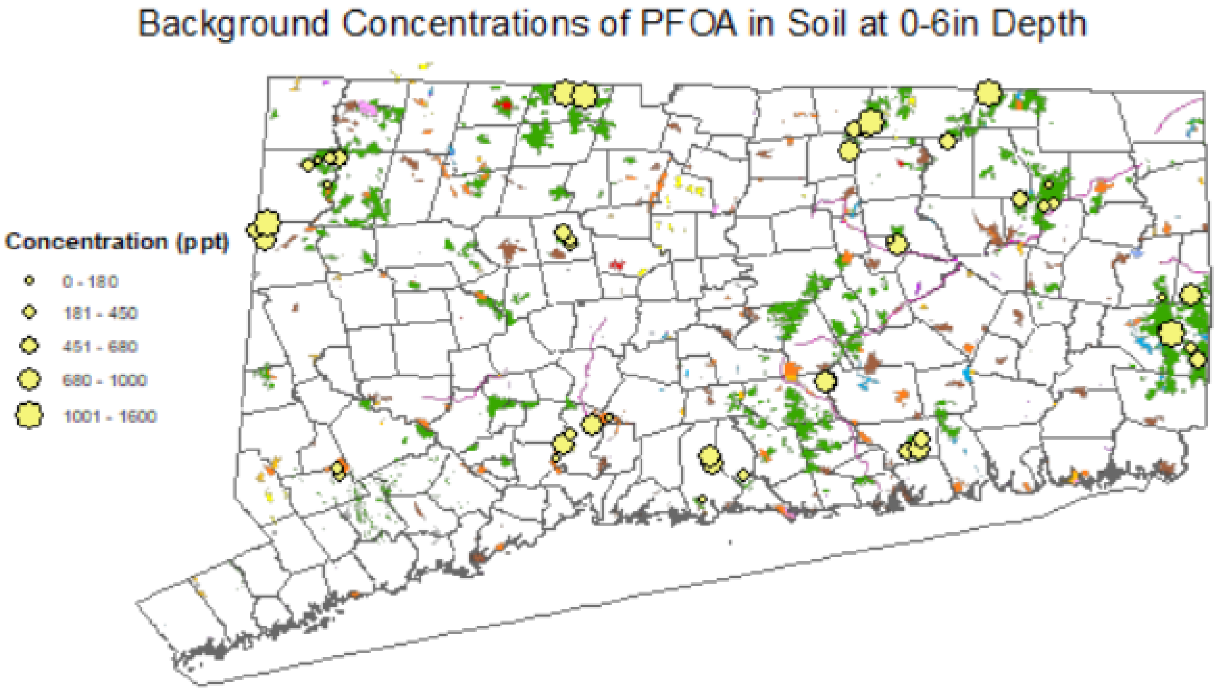


Figure 6. PFOA concentrations at each of the 16 properties sampled at the 0 to 6 inch depth.

The symbol sizes do not appear to follow much of a visible trend. The scattered values suggest that atmospheric deposition could be unevenly distributing PFOA throughout Connecticut's surface soils as atmospheric conditions and chemistry vary widely and change quickly. Another factor could be the amount of precipitation certain areas receive as PFOA and PFOS, being long-chain PFAS compounds, have "high aqueous solubilities and generally…[a] lower sorption potential," causing them to be readily transported in waters rather than remain in soil (Brusseau, 2017). While Connecticut tends to have a high groundwater table, it is unlikely for it to be within the first 0 to 6 inches of any of the properties sampled. Therefore, the downward transport of PFOA could be attributed to any precipitation recharging the groundwater.

The deeper 18 to 24 inch samples for PFOA show more of a consistent trend across properties and the state. **Figure 7** displays these PFOA concentrations, with a smaller concentration scale in comparison to the shallower samples figure above; note the numbers in comparison to circle size as it appears there are larger concentrations than the shallow soils due to similar circle sizes with a different concentration range.

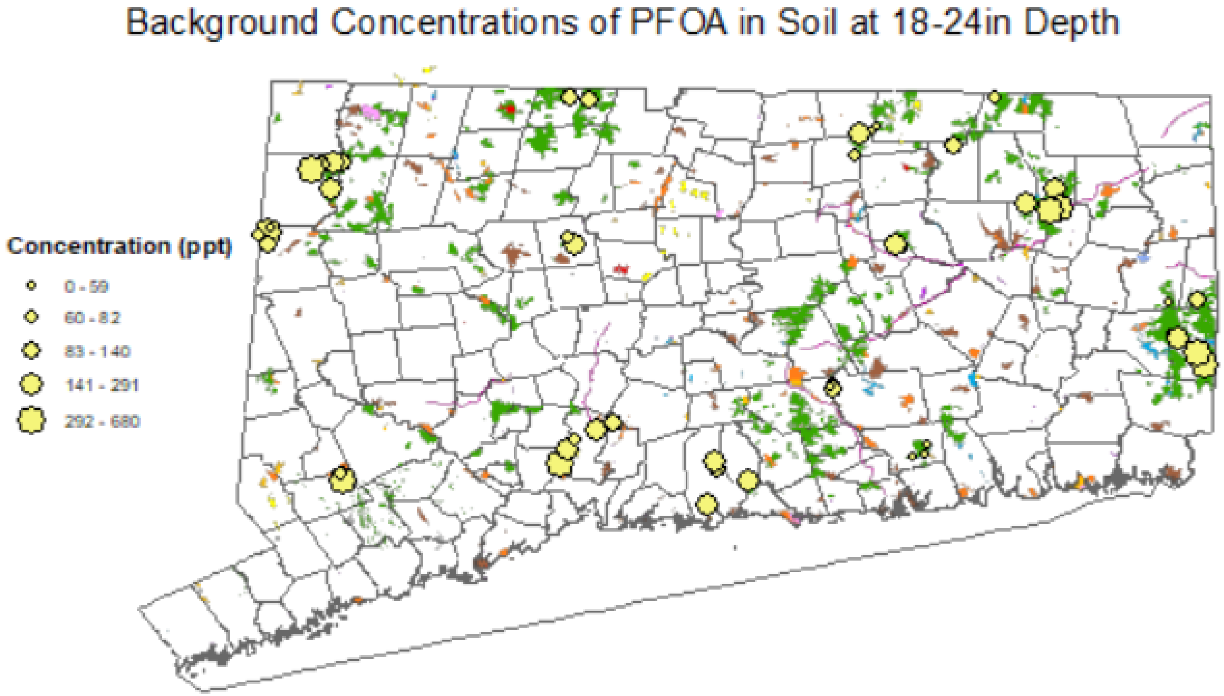


Figure 7. PFOA concentrations at each of the 16 properties sampled at the 18 to 24 inch depth.

Overall, PFOA concentrations at the 18 to 24 inch depth are less than those at the 0 to 6 inch depth by an order of magnitude of about 2. Although the PFOA concentrations are lower at a greater depth, they show a greater consistency compared to those of the shallower depth. The lower concentrations observed in the northwest and some of the northern properties may have higher water tables than other areas or could receive greater precipitation, resulting in the potential for greater downward transport of the contaminant. While PFOA is a long chained compound and is soluble in water, the shorter chained compounds presented in **Table 1** have a greater mobility in water than the long chained compounds. Due to this, one would expect to see higher concentrations of these short chained compounds in the deeper soil samples due to further transport by precipitation and groundwater. The results still show significantly higher concentrations of PFOA and PFOS in comparison to most of the other compounds in the deeper soil samples. These concentrations are higher due to the historical releases of PFOA and PFOS resulting in greater atmospheric deposition over the years and therefore transport by precipitation to a deeper soil layer. The short chained compounds are a more recent development to replace the long chained compounds as a result of their difficulty to destroy and recently discovered negative health effects on humans. Even though the short chained PFAS compounds are more mobile in water, they have not been manufactured and released into the environment for as long as PFOA and PFOS.

Groundwater samples could be more telling of short chain concentrations due to their high solubility. This could be subject for a further study to gain a better perspective of the PFAS concentrations present in different aspects of the environment.

Total PFAS (all compounds summed) concentrations are summarized in **Figure 8** below. The distribution of total PFAS concentration ranges appears to follow the same distribution of PFOA concentrations for the 0 to 6 inch soil. The concentration scale is much larger for total PFAS which can be attributed to several samples exhibiting high ADONA concentrations. Aside from the larger concentration values, areas that had higher PFOA concentrations appear to have higher total PFAS concentrations as well. Again, weather patterns are most likely influencing the atmospheric deposition of all PFAS compounds to be deposited in the same areas.

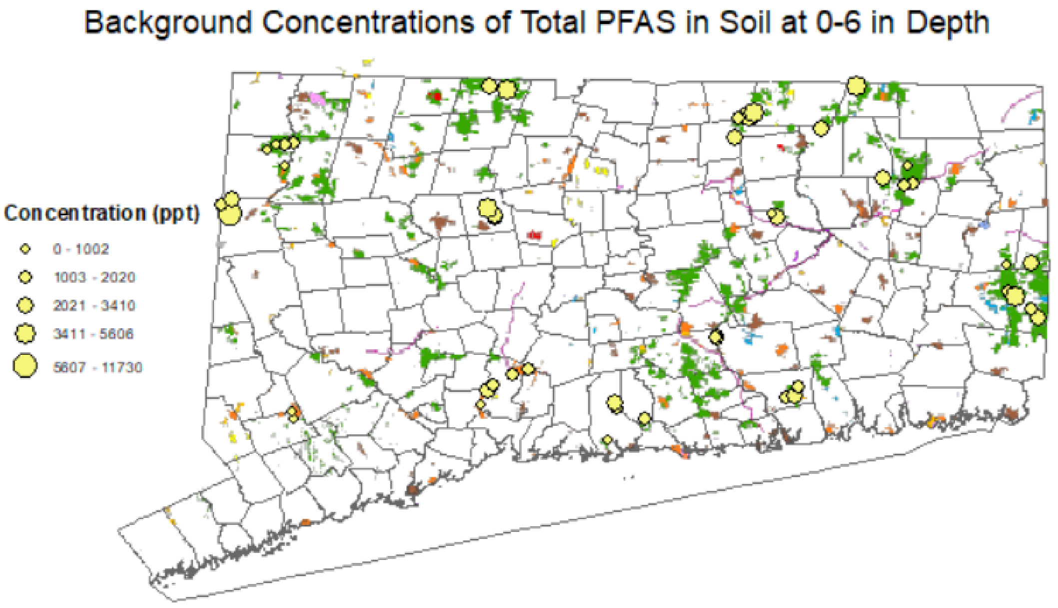


Figure 8. Total PFAS concentrations at each of the 16 properties sampled at the 0 to 6 inch depth.

Total PFAS concentrations for the 18 to 24 inch depth samples are summarized in **Figure 9** below. Again, the total PFAS concentrations at this depth have a similar distribution to that of the PFOA 18 to 24 inch samples, but the concentration values are at a much smaller scale. The highest concentration range shown in **Figure 9** falls within the lowest range for **Figure 8** , illustrating a general decrease in PFAS concentrations with depth.

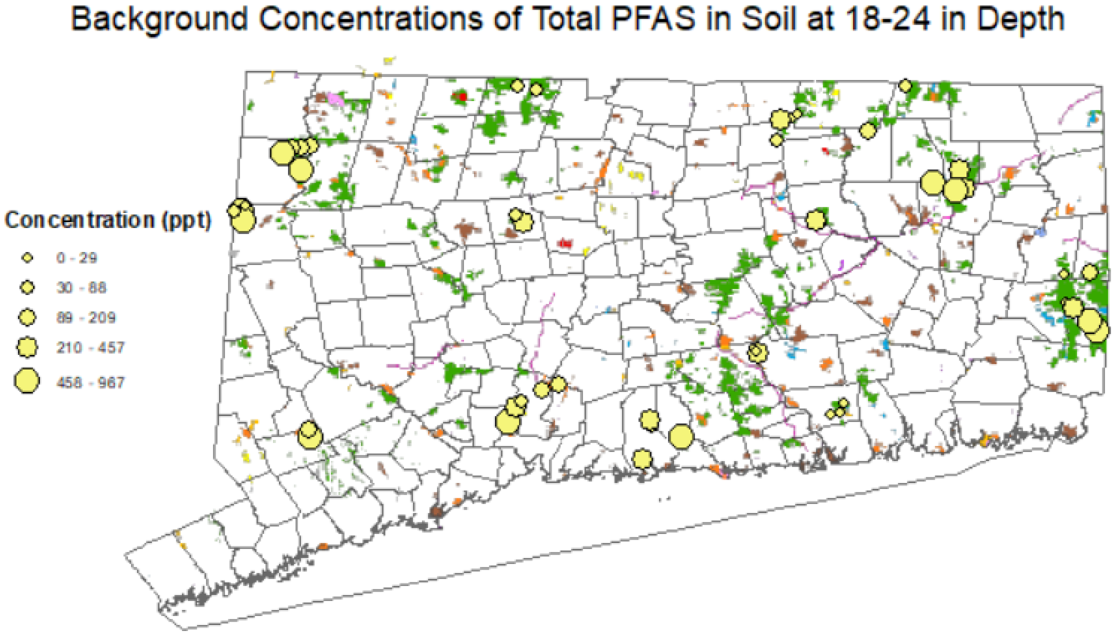


Figure 9. Total PFAS concentrations at each of the 16 properties sampled at the 18 to 24 inch depth.

Overall, the PFAS concentrations across the state are detectable and possibly unexpected, especially in the sampled areas that appeared to be the most "untouched" by potential PFAS sources. Atmospheric deposition will continue to increase the shallow soil concentrations which will increase deeper soil concentrations after transport by precipitation. There may be a point at which the newer short chained compounds exceed the concentrations of the historically produced long chain compounds if manufacturers continue to emit PFAS without regulation.

4.2 Design Options (TM)

Option 1: Sample soils

A - All counties in CT.

B - Less counties, with more resolution of results.

Considerations include sampling depths, driving times, and anticipated results. Depths of 0-2' easily sampled with hand tools. Cross contamination of layers is hard to avoid with close intervals. Driving times impact the amount of samples able to be collected in a given work day.

If fewer counties were samples, more resolution could be added to the maps. However, the goal of the project is to produce background concentrations throughout the entire state of CT.

Option 2: Sample soils and groundwater

Considerations include difficulty taking many samples due to lengthy process and equipment access. Geoprobes mounted on trucks are difficult to take off the main trail in state forests. Well must be developed for 24 hours for accurate results; this requires two separate trips to the same site, doubling the time required to sample. In addition to soil sampling, this is very involved.

4.3 Evaluation of alternative design options (TM)

With the goal for the project being to determine background concentrations of PFAS in the entire state of CT, Option 1, variation A was selected for this project. This is mainly because of time limitations. More sampling is always better, but the project's time frame only allowed for a certain amount of testing. Time spent traveling between locations accounted for a large portion of the project. Another limitation was the total number of samples to be analyzed by CET labs in a reasonable amount of time. Samples have to be preserved on ice so they do not spoil, they cannot be stored indefinitely. Thought was given to potentially only sampling one or two counties in CT, but this would not give a full picture of CT's background concentrations. The decision was made to sample all 8 counties and take as many samples as feasible for the collection team and CET Labs in the project timeframe. More samples could have easily been obtained, but testing would have been delayed. Considering the generosity of CET Labs performing free testing, only so many samples could be sent. With more funding in the future, many more samples can be tested.

Option 2 considered testing groundwater for contamination. To sample groundwater is a much more involved process than soil sampling. A geoprobe unit mounted on the back of a truck is used to drill down and create a micro well. This micro well will access the groundwater and allow for collection of a specimen for analysis. This may sound like a straightforward process but it requires much more time and planning. The truck must be able to drive to the exact location to be sampled. Access in state forests is usually limited to dirt roads traveling through dense forest. It is difficult to find a place for the geoprobe to travel off the road and onto undisturbed soils. Once the location has been found the equipment must be thoroughly decontaminated. The well drilling process itself goes quickly relative to the other steps. A PVC pipe is placed in the ground to keep the groundwater flow open for a sample. To properly use a groundwater microwell, it should be developed for at least 24 hours to reduce contamination and obtain accurate results. This means that each well location must be visited twice to obtain samples, greatly increasing the time frame of this project. Other complications include rejections of the drill if the bedrock layer is too shallow or if boulders are present, both very realistic issues in CT. While it will be valuable to have groundwater results in the future, the workload was too much for this project in the time available. Future testing is required.

Taking into account these limitations, the team established a plan to test 2 samples at each location at depth intervals of 0-6" and 18-24". This allows for a more comprehensive picture of the contamination pathways and extent of penetration into the soils and water table.

4.4 New Testing Required (TM)

Future testing should include more detailed soil testing with the inclusion of groundwater testing. The state of CT has very little data on PFAS, so more research needs to be performed. Groundwater results can help develop transport and fate models for the pathways of contamination PFAS takes in the environment. While this study focused on samples collected from the 0-6" and 18-24" range, other depths should be considered in future testing. Generally the highest levels were recorded in the upper layer of soils, but a few anomalies showed otherwise. A more comprehensive analysis of contamination is required. Many more soil samples need to be collected to increase the resolution of contamination mapping. Once enough data has been collected and analyzed then proper regulations can be implemented to protect and remediate the environment

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Appendix A: Sampling Locations

Table A1: Number of soil samples per location in each Connecticut county.

County	Property	Number of Soil Samples
Tolland	Shenipsit State Forest	5
	Nipmuck State Forest	3
	Nathan Hale State Forest	3
Windham	Natchaug State Forest	4
	Pachaug State Forest	4
New London	Pachaug State Forest-Green Falls	2
	Nehantic State Forest	3
New Haven	Sleeping Giant State Park	2
	West Rock State Park	3
Middlesex	Cockaponset State Forest	4
	Machimoodus State Park	3
Fairfield	Huntington State Park	2
Hartford	Tunxis State Forest	5
	Nassahegon State Forest	5
Litchfield	Housatonic State Forest	7

	Macedonia Brook State Forest	5
Totals	**16**	**55 x 2 = 110**

Table A2: Relative and exact locations of each proposed soil sample within each property.

Property	Relative Description of Sampling Location(s)	Coordinates of Sampling Location(s)
Shenipsit State Forest	Southwest corner of the southern parcel, along Hopkins Rd, off of the White Dot trail	41.9157, -72.44043
	Southwest side of the northern parcel, along Parker Rd	41.95562, -72.43142
	Northwest corner of the northern parcel, along Sodom Rd, off of the White Dot trail	41.97781, -72.40026
	North of the center of the northern parcel, off of Gulf Rd, to the right of the Gulf Stream	41.9678, -72.41339
Nipmuck State Forest	Northernmost parcel in Union, northwest corner of forest's boundaries, west of Paine Hill Rd	42.02332, -72.18688
	Southernmost parcel in Willington, between Polster Rd and the Roaring Brook	41.93101, -72.25954

Property	Relative Description of Sampling Location(s)	Coordinates of Sampling Location(s)
Nathan Hale State Forest	Southwest corner, north of Bear Swamp Rd	41.74999, -72.35371
	Slightly east of Wheeling Rd	41.75844, -72.36234
Natchaug State Forest	Within largest parcel, south of King Rd, east of Pilfershire Rd	41.8578, -72.0781
	North end of eastern parel, between Pumpkin Hill Rd and East Branch Stonehouse Brook	41.8283, -72.12863
	East side of largest parcel, north of the corner of Old Griffin Rd and Fayette Rd, southwest of the Hampton Reservoir	41.8206, -72.06611
Pachaug State Forest	East of the end of Flat Rock Rd, northernmost portion of the forest	41.65134, -71.87182
	West of intersection of Cedar Swamp Rd and Porter Pond Rd	41.65665, -71.8235
	Pachaug State Forest Parking Lot, on southern side of Cutoff road, near the trisection of Trail 1 Rd and Headquarters Rd	41.594831, -71.868050
Pachaug State Forest-Green	Green Falls Pond Rd, parking	41.542264, -71.810301

Property	Relative Description of Sampling Location(s)	Coordinates of Sampling Location(s)
Falls	lot on Northern side of pond, park at campsite then head North into the forest about 1500 ft	
Nehantic State Forest	Northern parking lot in Nehantic State Forest off of Keeny Rd, head about 500ft into woods to the northwest	41.399891, -72.311368
	Parking lot on the northeast side of Uncas Pond off of Keeny Rd, cross the street and head 500ft into the forest	41.380932, -72.314535
Sleeping Giant State Park	Off Blue Trail	41.434198, -72.870846
West Rock State Park	Lake Wintergreen parking area (off trail) off Main st in Hamden	41.360195, -72.966969
	West Rock 2 Park & Ride on W Shepard Ave	41.402377, -72.942958
Cockaponset State Forest	Overbrook Trail on Colonial/Overbrook rd in Madison	41.330025, -72.628433
	Westwoods off Dunk Rock rd in Guilford	41.286745, -72.704378

Property	Relative Description of Sampling Location(s)	Coordinates of Sampling Location(s)
	Route 80 in Guilford, on New England Trail	41.353325, -72.684970
Machimoodus State Park	North corner off of Leesville Rd	41.50327, -72.47554
	Further down Leesville Rd, eastern parcel of park	41.49876, -72.46774
Huntington State Park	End of Dodgingtown Rd in Bethel	41.347350, -73.358562
Tunxis State Forest	Off of Morrison Hill Rd	42.019346, -72.949718
	Northeast of Fosters Pond, off of the east side of West St	42.01096, -72.98051
	Directly east of Center St	42.02276, -72.96821
	Off of Pell Rd	42.026860, -72.903182
Nassahegon State Forest	Off of Miller Rd	41.751694, -72.953245
	Trail off of Stone Rd	41.75542, -72.94056
	Trail off of Stone Rd	41.754896, -72.943222
	West of Cornwall Rd	41.756149, -72.963184
Housatonic State Forest	Off of Smith Hill Rd, west of Rt 7 and the Housatonic River	41.85649, -73.37784

Property	Relative Description of Sampling Location(s)	Coordinates of Sampling Location(s)
	Off of Cream Hill Rd	41.905664, -73.350479
	Off of Clay Bed Rd	41.906943, -73.391853
	Off of Clay Bed Rd	41.905366, -73.375127
	Off of Mt Easter Rd	41.891182, -73.398579
Macedonia Brook State Forest	Off of Macedonia Brook Rd	41.777948, -73.493840
	Off of Macedonia Brook Rd	41.781774, -73.486303
	Trail off of Pond Rd	41.778171, -73.504612
	Trail off of Chippewala Rd	41.785897, -73.488991

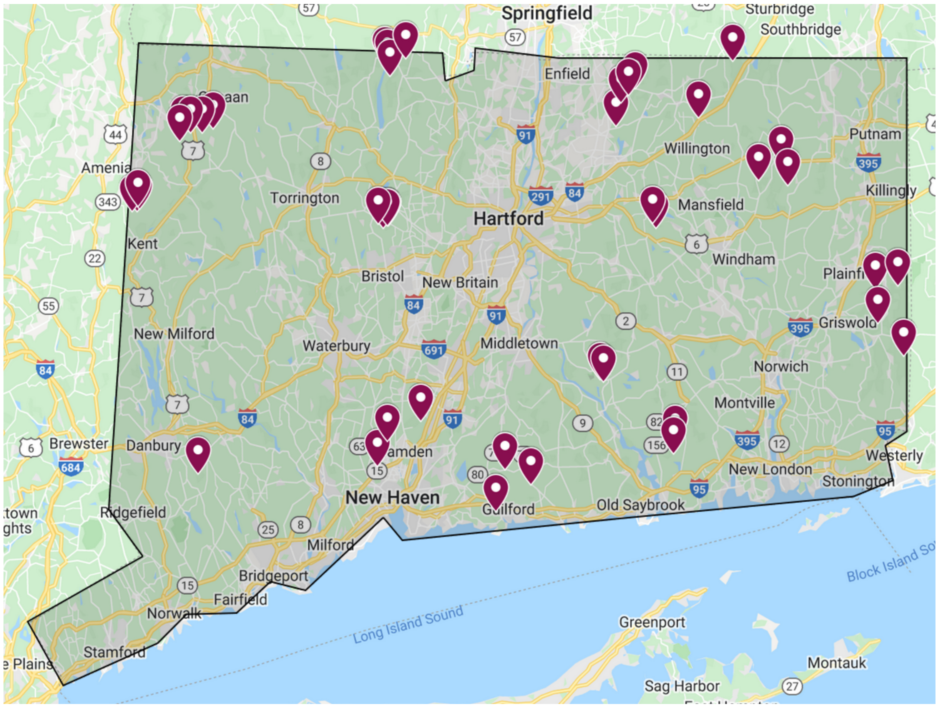

Figure A1. Preliminary sampling locations across all 16 properties.

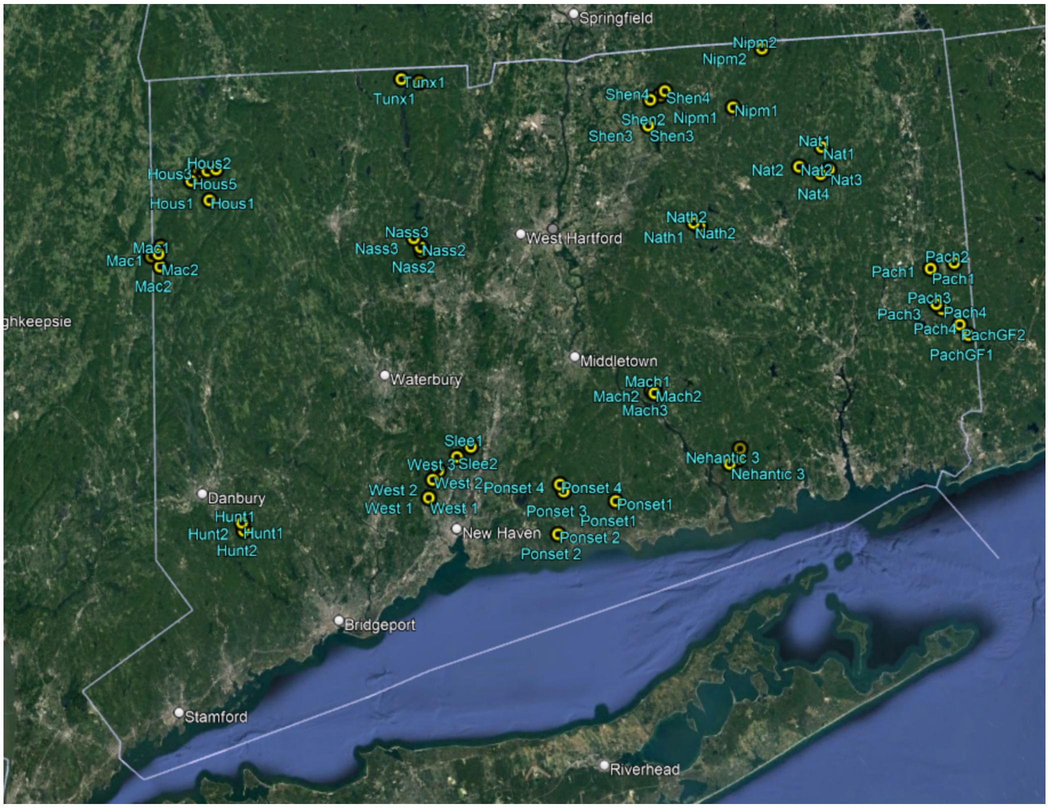

Figure A2. Final sampling locations taken with a GPS device on site after sample collection.