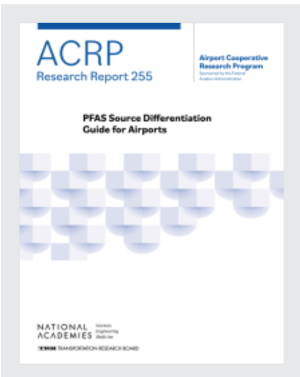

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AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP RESEARCH REPORT 255

PFAS Source Differentiation Guide for Airports

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2023

AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

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FOREWORD

By Joseph D. Navarrete
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ACRP Research Report 255: PFAS Source Differentiation Guide for Airports provides recommended practices for determining the source of per- and polyfluoroalkyl substances (PFAS) detected in soil and water on or near an airport. The report offers guidelines for conducting an initial desktop review, using conventional sampling data for screening, and using advanced forensics methods (which are quickly becoming more commercially available). The report will be of particular interest to practitioners who want to understand, identify, and differentiate potential PFAS sources—both on and off airports—using a lines-of-evidence approach.

Airports face increasing regulatory and technical challenges for addressing PFAS found on or near their facilities. When these substances are found on or near an airport, the source may be attributable to airport activity [for example, from the use of aqueous film forming foam (AFFF) during aircraft rescue and firefighting activities]; however, airports may also have neighbors who use products that contain PFAS. To advance the understanding and use of PFAS source differentiation techniques, there was a need to consolidate available research and best practices into an easy-to-use guide and screening tool.

The research, led by Terracon Consultants, began by inventorying resources and methods for airports to catalog potential PFAS sources on and off airport property. Source profiles were then developed for use in screening potential sources using standard analytical results. These profiles were developed by conducting a statistical analysis of thousands of PFAS environmental sampling results from a variety of sources across the United States. Recommended practices that use a data-driven approach were then identified based on the research.

The guide provides an overview of airport-related PFAS issues, including answers to frequently asked questions; a summary of potential on- and off-airport activities that could involve PFAS; a discussion of hydrogeologic site characteristics and fate and transport issues relevant for source differentiation; and a summary of PFAS sampling and analysis state of practice, including limitations.

Airports may also benefit from using the PFAS Source Differentiation Preliminary Screening Application tool, which can be found by searching for *ACRP Research Report 255: PFAS Source Differentiation Guide for Airports* on the National Academies Press website (nap.nationalacademies.org). The tool can be used to track progress with desktop review efforts to account for on-airport and off-airport PFAS sources as well as for local hydrology, geology, and stormwater infrastructure site characteristics. Appendices list PFAS names and acronyms and approved analytical methods for specific analyte identification.

CONTENTS

Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at nap.nationalacademies.org) retains the color versions.

SUMMARY

PFAS Source Differentiation Guide for Airports

The objective of ACRP Project 02-91, "Development of PFAS Source Differentiation Guidelines for Airports," was to develop recommended practices for determining the sources of per- and polyfluoroalkyl substances (PFAS) detected in soil and water on or near an airport. To accomplish this objective, this guide presents ways in which airports can develop a practical, data-driven approach to address questions concerning whether activities at or near an airport may have contributed to observed PFAS in local environmental media (e.g., water and soils). Understanding potential contributing sources to PFAS impacts and having tools to differentiate those sources can be critical.

KEY POINT

A lines-of-evidence approach for PFAS source differentiation is necessary given the complexities surrounding PFAS and the ubiquity of some common PFAS in the environment.

This guide provides (1) necessary background and foundational information related to PFAS and aqueous film forming foam (AFFF), (2) information about different types of source differentiation environmental investigations, and (3) information about the types of activities that can be performed to develop a lines-of-evidence approach for the identification of potential sources of PFAS found at an airport facility. A lines-of-evidence approach using various methods of collecting information should be pursued when source differentiation is needed. The goal of this approach is to ensure that the decisions made and activities undertaken to investigate PFAS source contribution at or near an airport are supported by data and that they follow an efficient and logical flow of information.

This guide focuses on the following topics:

- Resources to understand and identify potential PFAS sources both on and off airport property as an initial step in source differentiation.
- Guidelines on PFAS sampling and analytical methods with respect to source differentiation.
- Investigative components that support PFAS source differentiation—including PFAS analytical forensic screening.

The guide also describes various methods that can help airports to develop lines of evidence and increase confidence in the resulting source determinations. These methods are presented in the guide in following categories:

- *Desktop Review*

  A desktop review leverages available information to develop a list of potential on-airport sources, off-airport sources, and site-specific characteristics that help to initiate source determinations. This desktop review can be accomplished without the need for environmental sampling; information from this first step can help guide sampling rationale in a data-driven tiered approach. Desktop reviews of on- and off-airport potential PFAS sources—in conjunction with an understanding of site hydrogeological characteristics—may also

provide the foundation of a sampling rationale for further investigations and help airports to interpret sampling data that have already been collected.

At airports with firefighting departments, the PFAS-impacted areas of greatest concern are typically those associated with releases of AFFF during firefighting training or calibration activities and during emergency response. There may also be potential on-airport sources of relevant PFAS associated with hangar fire suppression systems or other tenant activities (e.g., maintenance or manufacturing). However, potential releases of PFAS from these sources are typically in much smaller quantities and are less frequent than those associated with AFFF use in firefighter training and emergency response. Adjacent off-airport industrial activities may also be sources of PFAS discovered in the environment at or near an airport. In addition to airports, other industries may use AFFF (e.g., refineries and chemical plants). Other non-AFFF activities can contribute to PFAS impacts; these can include application of biosolids from wastewater treatment facilities, chrome plating, and landfill leachate. Chapter 3 of this guide provides important considerations and potential resources for compiling this desktop review information.

- *Conventional Sampling and Screening Level Differentiation*

  One approach to source differentiation may be to use standard analytical method results generated during PFAS sampling or environmental investigations. Using those data, airports can conduct screening level evaluations against known PFAS information (including source profiles and fate and transport information) to inform potential source differentiations and further build lines of evidence regarding potential PFAS sources. The screening level source differentiation analysis and tools that were developed during this research project used publicly available analytical data from over 800,000 PFAS analytical results; these samples were collected from locations throughout the United States. These data supported the development of screening level data visualizations for PFAS source differentiation efforts, which are shown in Chapter 6 of this guide.

  The results of the analyses are presented in five types of data visualization of PFAS source categories. The five types of visualization may help airports to compare available PFAS data and to generate lines of evidence that support or refute potential source contribution. There are inherent limitations with all screening level methods, which means that there will not likely be a definitive PFAS signature identified for any single PFAS source. It is also important to note that different PFAS have different fate and transport profiles (both vertical and horizontal) over time and that they are likely to include site-specific geological and hydrogeological factors that affect spatial distribution. This complicates interpretations when comparing sampling data from different spatial, temporal, and geological locations. The screening level visualizations developed as part of this guide, along with fate and transport considerations, are intended to further a lines-of-evidence approach and are not intended to provide a single definitive source determination method.

- *Advanced Forensics Analysis*

  Advanced forensics methods are still in development, but they are rapidly becoming available and validated to support PFAS source differentiation. Current methods and important considerations for them are described in Section 6.4 of this guide. Advanced forensics may be more suited to determining whether the impacts of PFAS originated from AFFF or non-AFFF sources than to differentiating among AFFF sources. Due to the complex PFAS formulations used in diverse applications, a broader suite of analytes for PFAS should be considered if source differentiation is a potential; this may help to better identify non-AFFF sources of PFAS contamination. Specialized methods include non-targeted analysis to screen against a library of hundreds of potential PFAS based on molecular weight and compositional fragments. A broader set of compounds has the potential to provide a more refined PFAS signature for source differentiation and is more likely to include unique, source-specific PFAS. Use of higher resolution analysis provides information on PFAS precursors, which can help to differentiate the AFFF sources from different manufacturers or help to further identify non-AFFF PFAS compounds. The various analytical methods can provide additional lines of evidence and increase confidence in source differentiation conclusions.

- *Interactive Excel-based Tool*
  As a supplement to the three lines-of-evidence methods described, the research team developed an Excel-based tool to assist airports seeking to pursue source differentiation. The tool is designed to guide airports through a comprehensive desktop review that will provide initial information about potential on- and off-airport PFAS sources. In addition, the tool provides a compositional analysis opportunity for airports to input PFAS analytical data and compare results with one of the five screening level approaches developed through this project.

The background information and methods provided within this guide can help airports to generate the lines of evidence that are critical to making an informed, data-driven determination regarding PFAS source differentiation. The source differentiation methods described in this guide are intended only as potential options that an airport can use to explore source differentiation. Each airport has unique characteristics and history that may render certain methods more or less valuable than others. It is not necessarily appropriate for airports to employ all methods identified in this guide.

CHAPTER 1

Introduction

1.1 Purpose

Often the first reaction by the public, media, and local community when per- and polyfluoroalkyl substances (PFAS) are found near an airport is to conclude that the airport is the sole PFAS source; in fact, off-airport sources may be involved. The objective of ACRP Project 02-91, "Development of PFAS Source Differentiation Guidelines for Airports," was to develop a practical, data-driven approach for airports to use when facing questions about whether activities at the airport or from nearby sources may have contributed to observed PFAS in local environmental media (e.g., water and soils). The goal of this guide and its associated tools is to provide resources that can aid the airport industry in understanding and applying methods for PFAS source differentiation. This guide focuses on the following four topics:

- Resources to understand and identify potential PFAS sources both on and off airport property as an initial step in source differentiation.
- Guidelines on PFAS sampling and analytical methods with respect to source differentiation.
- Investigative components that support PFAS source differentiation (including PFAS analytical forensic screening).
- Guidelines related to initial PFAS discovery and assessment as well as airport response and management strategies related to PFAS source differentiation.

1.2 Primer on How to Use This Guide

The PFAS source differentiation efforts described in this guide can be grouped into three primary categories, as shown in Figure 1-1. The first is a desktop review of available information that can be used to develop a thorough understanding of potential on-airport PFAS sources, off-airport PFAS sources, and site characteristics that will help inform on PFAS migration pathways. This desktop review can be accomplished without the need for environmental sampling; information from this first step can help to guide sampling rationale in a data-driven, lines-of-evidence approach. The next step uses standard PFAS analytical methods, which are available from most commercial laboratories. These analytical results can undergo a screening level review to further build lines of evidence regarding potential PFAS sources. Finally, in some instances a third effort may be warranted that includes advanced forensics to further differentiate and potentially identify PFAS sources. This third category would involve laboratory methods that are of significantly higher cost than standard PFAS analytical methods. Each of these categories provides a line of evidence for source differentiation.

> **KEY POINT**
> A lines-of-evidence approach for PFAS source differentiation is necessary given the complexities surrounding PFAS and the ubiquity of some common PFAS in the environment.

There are currently no perfect methods for PFAS source differentiation. However, this guide describes several actions that can help airports to better understand potential PFAS sources and

Figure 1-1. Primary categories of PFAS source differentiation efforts.

to build lines of evidence for them. These actions lay out the process by which airports can navigate source differentiation efforts and are summarized as follows:

- Understand readily ascertainable on-airport sources of relevant PFAS to the extent feasible, including historical and current potential sources (see Section 3.1).
- Evaluate areas near the airport, especially those that are hydraulically upgradient, to determine whether there are industries that use (or have used) PFAS or PFAS-containing products that could potentially contribute to PFAS environmental impacts (see Section 3.2).
- Develop a detailed understanding of site conditions: geological, hydrogeological, soil, and surface water runoff (see Section 3.3).
- Analyze environmental samples for PFAS when appropriate to assess relevant on-airport PFAS occurrence and concentration. Sampling may include upgradient and downgradient samples to investigate off-site PFAS migration onto the airport and the extent of any PFAS groundwater plume (see Chapter 5).
- Evaluate standard PFAS analytical data as a screening step to determine whether any source differentiation trends are evident (see Section 6.3).
- Conduct advanced PFAS source forensics on selected samples as appropriate to potentially differentiate PFAS sources (see Section 6.4).

The information and recommendations in this guide move from the desktop review to standard analytical sampling and ultimately to higher-end forensics to build lines-of-evidence determinations. However, successful PFAS source differentiation is not predicated on each step being completed sequentially. Depending on the complexity of the source assessment, these approaches can be incorporated à la carte or combined in any suitable order. Each airport needs to consider which methods are appropriate for its unique setting and conditions.

This guide is divided into the following seven chapters:

- **Chapter 1** provides a primer on how to use this guide; it outlines its purpose, organization, and expected use. This includes discussion of its intended audience, general PFAS nomenclature, and clarification on PFAS of relevance as it relates to this guide.
- **Chapter 2** presents an overview of the issues related to PFAS that airport environmental managers may face, including answers to frequently asked questions, references to help stay up to date with this rapidly evolving topic, and a brief regulatory review.
- **Chapter 3** provides an overview of the desktop review process to identify potential on- and off-airport PFAS sources and key site characteristics for consideration.

- **Chapter 4** contains a summary overview of the PFAS fate and transport state of the science and why this is important for understanding any source differentiation investigation.
- **Chapter 5** provides an overview of the PFAS sampling and analysis methods, protocols, and best practices for the use of analytical data in source differentiation investigations.
- **Chapter 6** describes the screening level analyses and advanced forensics available to airports for PFAS source differentiation. Chapter 6 also describes the source category screening level analysis that was conducted on a large database of PFAS analytical data compiled for this research effort.
- **Chapter 7** provides an overview of the downloadable application designed to help airport managers implement the source differentiation activities described in this guide—in particular those pertaining to desktop review and preliminary source differentiation screening.

Key points and important technical details are highlighted in call-out boxes throughout the document to emphasize take-away messages, as illustrated in Figure 1-2.

Data are constantly being developed and evaluated across a broad spectrum of organizations, including private consultants, government agencies, academic entities, and research groups. This ever-developing information will add to the universe of PFAS knowledge. Users of this guide should consider recent developments in PFAS research that have occurred since the time this guide was published and should also use trusted resources (including those referenced in this guide) for current information.

1.2.1 Intended Audience for This Guide

Information provided in this guide, in combination with the accompanying Excel-based tool, was developed to assist airport staff, board members, and tenants, as well as environmental regulators, the public, and consultants to understand, plan, and conduct PFAS source differentiation efforts at an airport. This guide and tool are intended to be used in concert with internal airport resources [e.g., legal, public relations, aircraft rescue and firefighting (ARFF), airport operations, and finance] as well as external resources (e.g., qualified PFAS environmental consultants, specialized laboratories, outside legal counsel, and other appropriate resources as needed). For planning purposes, it is important to recognize that implementing a comprehensive and scientifically defensible investigation to identify on- and off-airport sources of PFAS will typically require some level of external resources and expertise.

This guide is written for airports that have a history of aqueous film forming foam (AFFF) use, a need for source differentiation, or both. Only certificated Part 139 airports are required by the FAA to maintain ARFF capabilities and to certify the operational functionality of ARFF equipment on an annual basis. These are typically airports with commercial air service but can also include some general aviation airports.

KEY POINT

Readers should understand that references to airports throughout this guide largely pertain to airports with a history of AFFF use. The broad use of the term *airports* within this guide is not intended to suggest that all airports will have PFAS impacts.

Airports at which Part 139 is not applicable (most general aviation airports) typically do not maintain firefighting capabilities and instead rely on local municipal fire departments to provide emergency response. These

KEY POINT

Key point text boxes summarize significant concepts of this guide.

TECHNICAL DETAIL

Technical detail text boxes provide additional technical background information.

Figure 1-2. Description of text boxes found in this guide.

airports may, however, have hangars with fire suppression systems that are equipped with PFAS-containing AFFF. It should be noted that some of these airports may have previously had a Part 139 operating certificate or may choose to maintain ARFF on-site capabilities (e.g., training of personnel and testing of equipment). Therefore, the history and location-specific decisions for each airport are necessary considerations; generalizations based on current airport certification status may not be accurate with regard to ARFF presence and AFFF use.

1.3 PFAS Chemistry and Nomenclature

PFAS are a family of several thousand fluorinated chemicals that vary widely in chemical and physical properties; they are used in many products and activities. The gray spheres in Figure 1-3 make up the carbon chain and the green spheres represent the fluorine atoms. In a fully fluorinated (or *perfluorinated*) compound, all of the carbons in the chain are bound to fluorine atoms. The carbon–fluorine (C–F) bond is extremely stable and resistant to environmental degradation pathways. As a result, perfluorinated compounds are considered to be *terminal PFAS*—unlikely to degrade under environmental conditions.

In a polyfluorinated compound, the carbon chain is not fully fluorinated, and some of the carbon atoms are attached to hydrogen atoms (the blue spheres in Figure 1-3) or other non-carbon atoms. The carbon–hydrogen (C–H) bond is much weaker than the C–F bond and is susceptible to degradation in the environment. Ultimately, polyfluorinated PFAS can degrade into terminal perfluorinated PFAS; as such, they are called precursors to terminal PFAS. The existence of this transformation process is a key element in determining source attribution.

The chemical nomenclature is an important part of how PFAS are identified and discussed. Short acronyms are often used, but the compound name typically includes hydrocarbon nomenclature that is familiar to most environmental professionals. For example, *deca* indicates a ten-carbon chain, *octa* indicates eight, and so forth. Note that for fully fluorinated PFAS with carboxylic acid functional groups, the total number of carbons includes the carbon in the carboxylic acid group.

TECHNICAL DETAIL

Some PFAS, called *precursors*, can degrade into smaller fully fluorinated compounds called perfluoroalkyl acids (PFAAs). PFAAs are highly stable molecules with varying carbon chain lengths, such as the eight-carbon compound perfluorooctanoic acid (PFOA) or the four-carbon compound perfluorobutanoic acid (PFBA). These are often called *terminal PFAS*.

Fully fluorinated PFAS are called perfluoroalkyl acids (PFAAs) and are also sometimes described as *long-chain* PFAS or *short-chain* PFAS as a way to categorize general environmental behavior and toxicity concerns. The short-chain compounds are generally less biopersistent and less

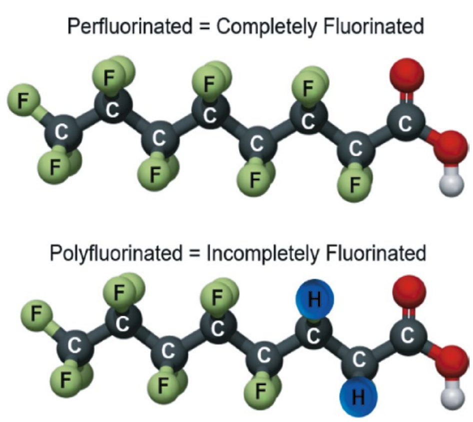


Figure 1-3. PFAS structure examples.

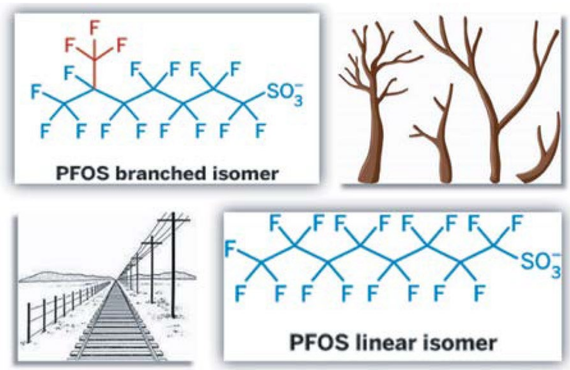


Figure 1-4. Isomer illustration.

bioaccumulative than longer-chain compounds. Long-chain compounds are typically defined as PFAAs with six or more fluorinated carbons. For example, perfluorohexane sulfonate (PFHxS) has six fully fluorinated carbon atoms and is considered a long-chain PFAS; perfluorohexanoic acid (PFHxA) has five fully fluorinated carbon atoms and is considered a short-chain PFAS.

As will be discussed later, source differentiation employs a multiple lines-of-evidence approach. With PFAS, one of those lines of evidence relates to the manufacturing process, specifically the creation of branched and linear PFAS isomers. Branched and linear isomers describe two compounds with the same chemical formula and number of atoms but with a different arrangement of atoms [as illustrated in Figure 1-4 for perfluorooctanesulfonic acid (PFOS)]. Production of branched versus linear isomers is unique to different manufacturing processes.

The electrochemical fluorination (ECF) process of manufacturing PFAS produced approximately 70% linear isomers, with the remaining production resulting in branched isomers. The other manufacturing process, telomerization, yields primarily linear isomers. As a result, measuring the ratios of these isomers may be useful in a forensic investigation of sources. However, AFFF historically could have been manufactured via either an ECF or a telomerization process and could be a mixture of both in a given ARFF system. This is discussed in further detail in Section 1.5.

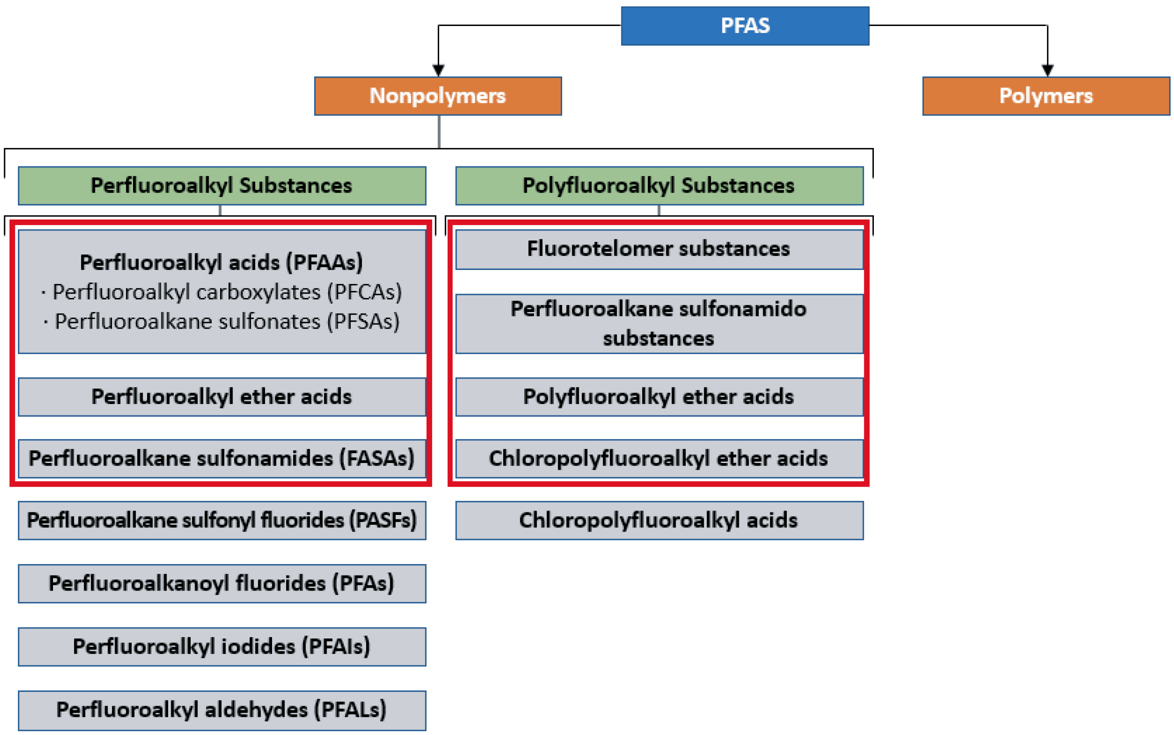
1.4 PFAS of Relevance for This Guide

KEY POINT

Relevant PFAS in this guide are those PFAS with the potential for significant release to the environment, a regulatory focus, and are included in standard targeted analytical methods.

This guide focuses on non-polymer PFAS, which are small molecular weight PFAS that have the highest likelihood of environmental presence (due to manufacturing activities or product use), have received the most regulatory scrutiny, and have had laboratory methods developed to quantify their presence in the environment. Non-polymer PFAS are most likely to be found in the environment due to their use as surfactants or coatings, including PFAS that can degrade over time into terminal PFAAs.

The most significant on-airport source of these PFAS is from the use of AFFF. Figure 1-5, as presented, is slightly modified from Section 2.2 of the Interstate Technology and Regulatory Council (ITRC) PFAS Technical and Regulatory Guidance Document and Fact Sheets (ITRC 2022). It highlights those PFAS subgroups containing substances that can be detected using standard analytical methods. AFFF formulations typically contain PFAS from several of these subgroups. See Chapter 5 for more information on PFAS analytical methods.



Source: Modified from ITRC PFAS Technical and Regulatory Guidance Document and Fact Sheets (ITRC 2022).
Note: Outlined boxes highlight PFAS groups that can be tested for using standard commercial environmental methods and would be most relevant for environmental investigations.

Figure 1-5. PFAS most relevant for environmental source differentiation for airports.

1.5 History of Relevant PFAS in AFFF

Since the late 1960s, PFAS have been included in formulations of AFFF. PFAS surfactant properties allow for quick extinguishment of Class B fuel fires through retention of water and separation of fuel from fire ignition sources. Because of this, the United States Department of Defense (U.S. DOD) required the inclusion of PFAS (fluorocarbon surfactants) in its AFFF specification (MIL-F-24385) from the late 1960s until 2019. In 2019, the military specification was amended to remove the requirement of fluorocarbons in AFFF; however, the fire extinguishing performance requirements remained the same; currently only AFFF products containing PFAS can meet the MIL-F-24385 requirements. Since the implementation of minimum safety standards from the Airport and Airway Development Act of 1970, airports certified under Part 139 were required to use AFFF that can meet this military specification. Since the initial writing of this guide, the U.S. DOD has released MIL-PRF-32725 (U.S. DOD 2023), the performance specification for fluorine-free foam (known as FFF or F3). This specification is in addition to MIL-F-24385, which lists the performance specification of AFFF. Readers are encouraged to consult the latest military specifications by searching for Qualified Products List numbers 24385 (for AFFF) and 32725 (for F3) in the U.S. DOD's Qualified Products Database (U.S. DOD 2022).

Historically, AFFF formulations were made with long-chain (or C8) fluorocarbon surfactants containing PFOS. As concern grew about the environmental and human health impacts of PFAS—most notably the eight-chain perfluorooctanoic acid (PFOA) and PFOS—short-chain (or C6) formulations of AFFF were introduced into the market in the early 2000s. Fluorotelomer-based AFFF was also produced and sold from the 1970s until the mid-2010s. Although these fluorotelomer-based formulations of AFFF did not contain PFOS or PFOA, they did contain polyfluorinated precursors that have been known to transform into perfluoroalkyl carboxylic acids (PFCAs) such as PFOA in the environment.

Modern AFFF is fluorotelomer-based and contains C6 PFAS. Although these formulations of AFFF do not contain or transform into PFOS and PFOA when released into the environment, they can degrade to other short-chain PFAS of relevance, such as PFHxA, perfluoropentanoic acid (PFPeA), and 5:3 fluorotelomer carboxylic acid (FTCA). PFAS source differentiation efforts for which AFFF is a potential contributor should consider the different PFAS present in AFFF formulations over time.

1.6 Considerations for Engaging a Qualified Consultant

There is no single correct approach to developing a plan of action related to investigating PFAS at an airport. The breadth and depth of PFAS knowledge are significantly increasing on an almost daily basis, and this will likely continue for the foreseeable future. Significant research is currently ongoing on a wide range of PFAS topics, including health risk assessments, fate and transport, and remediation.

For airports, airport personnel have increased their knowledge of PFAS and the ways in which historical use of AFFF makes airports a potential source of PFAS identified in the environment. As airport personnel awareness and knowledge increase, questions may arise that require specialized expertise. These may pertain to PFAS chemistry, fate and transport considerations, hydrogeology, geology, and other site characterization information that goes beyond the airport staff's expertise and experience.

The following factors should be considered when assessing the need for a qualified consultant:

- Technical expertise of airport staff
- Available resources to maintain engagement and learning in a rapidly evolving scientific understanding
- Regulatory pressure to address PFAS concerns
- Public engagement and concern about PFAS originating from the airport
- Potential liability from identified PFAS impacts
- Complexity of on-site and off-site characteristics that may impact PFAS source identification
- Perception of third-party involvement in source differentiation beyond airport staff
- Change in PFAS impacts, awareness, regulatory environment, and public engagement that necessitates a more rapid response to PFAS source differentiation

KEY POINT

It is important that an airport work with an experienced PFAS consultant when planning and pursuing source differentiation at their facility.

Relevant information is available through multiple sources, including via Internet queries and on regulatory websites. Reviewing and processing the sheer volume of this information can be time-consuming and difficult—even for an experienced PFAS expert. Consultants can provide support to airports in understanding regulatory developments, trends specific to the state in which the airport is located, and research developments, as well as vet other necessary team members such as outside legal counsel, laboratories, and public relations professionals. Qualified environmental consultants can increase the confidence of airport managers that information is being interpreted correctly and that resources are being used wisely.

CHAPTER 2

Airport PFAS Issue Awareness

2.1 Overview of Airport-Related PFAS Issues

At airports, PFAS-impacted areas of greatest concern are typically associated with releases of AFFF during emergency response training activities and fire and crash incident responses. (Thalheimer et al. 2017). A key challenge in addressing PFAS from AFFF is the need to comply with FAA requirements, specifically that ARFF departments at all Part 139 airports must use AFFF that conforms to military specification MIL-PRF-24385. As of 2022, only AFFF products containing PFAS surfactants were able to meet the performance requirements of this specification. However, in January 2023, the FAA issued *Part 139 CertAlert 23-01: New Military Specification for Performance-Based Standards for Fluorine-Free Aircraft Fire Fighting Foam*, which acknowledged the new F3 military specification and paved the way for future approval of F3 at Part 139 airports (FAA 2023).

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FAA *CertAlert 21-01, AFFF Testing at Certificated Part 139 Airports* provides information on the closed-loop foam proportioning testing systems that are approved for use (FAA 2021).

In addition to specifying the type of AFFF to be used, the FAA also requires airports to ensure the functionality of foam proportioning systems on ARFF vehicles. Historically, this functionality testing required the discharge of AFFF from ARFF vehicles in order to measure the effectiveness of foam output. Recent FAA changes now allow for the use of closed-loop foam proportioning testing systems, which eliminate the need to discharge AFFF to the environment (FAA 2021).

FAA Part 139 annual inspections may also have included the discharge of AFFF during the timed response demonstrations of ARFF departments. Before concerns over PFAS were understood, the FAA often required the use of AFFF during this drill—often in remote areas of the airfield, such as grassy areas adjacent to runways or taxiways. The FAA has now eliminated the need for AFFF discharge during the timed response drill, further reducing the potential for nonemergency-related AFFF discharges at airports (FAA 2019).

AFFF may also be used in tenant hangars that are equipped with fire suppression systems. The risks associated with these systems are situations in which AFFF releases escape the hangar and either infiltrate into the ground or enter the airport's stormwater system, where it can potentially impact the environment. Many of these systems have been converted to high expansion foam (HEF)—which does not contain PFAS—over the years, but hangar suppression systems with HEF may have previously used AFFF.

KEY POINT

Not all hangar fire suppression systems contain AFFF. It is important that an airport understand the types of extinguishing agents being used in hangar fire suppression systems at its facility.

There may also be potential sources of relevant PFAS at an airport that are not associated with firefighting and AFFF. For example, aircraft maintenance facilities may use aircraft hydraulic fluids containing relevant PFAS. In addition, aeronautical and nonaeronautical manufacturing facilities leased by tenants on airport property (e.g., those located in airport business parks) may use products containing PFAS in their manufacturing processes. Releases of PFAS from these sources, however, are typically in much smaller quantities than those associated with AFFF use; AFFF discharges are usually of larger volume and contain significant PFAS content.

Adjacent off-airport industrial activities may also be sources of relevant PFAS discovered in the environment at or near an airport.

KEY POINT

The geology and hydrology of an airport, especially the type of subsurface soils, depth of groundwater, location and depth of nearby drinking water wells, and flow direction of surface and groundwater are important factors in determining sources of on- and off-airport PFAS.

The geology and hydrology surrounding an airport are important factors in understanding PFAS environmental issues because the type and depth of subsurface soils, depth of groundwater, location and depth of nearby drinking water wells, and flow direction of ground and surface waters can influence the movement of PFAS from on- and off-airport sources. Understanding these environmental conditions can be instrumental in determining sources and potential risks of detected PFAS, identifying potentially responsible parties, and responding to environmental regulatory directives and the concerns of the local community.

Chapter 3 provides more information about potential on-airport and off-airport sources of PFAS as well as airport site characteristics for users to consider when developing critical initial lines of evidence for PFAS source differentiation.

2.2 "PFAS 101" Information Sources

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Sources of "PFAS 101" information presented in this section are continually updated. Readers are encouraged to check the main pages of all agencies listed for the newest information.

There are a variety of available resources that document the history, chemical composition, fate and transport characteristics, human health concerns, and regulatory approaches associated with PFAS. The following resources offer validated information regarding PFAS, as well as airport firefighting and environmental regulations associated with their use. This list of resources is not intended to be comprehensive but rather serves as a starting point for learning about PFAS issues.

- **Airport Cooperative Research Program.** The ACRP is managed by the Transportation Research Board of the National Academies of Sciences, Engineering, and Medicine, and is sponsored by FAA. It focuses on applied research on industry issues that other federal research programs do not address. In addition to this study, ACRP has published the following reports to address the potential impacts of PFAS from airport activities.
  - ***ACRP Research Report 173: Use and Potential Impacts of AFFF Containing PFASs at Airports.*** This report provides information on the potential environmental and health impacts of PFAS found in AFFF and describes methods to identify areas of potential concern at an airport as well as methods to implement management and remediation practices for AFFF use. The report includes the Managing AFFF and PFAS at Airports (MAPA) screening tool, which facilitates desktop analyses to identify and rank areas of potential environmental concern from AFFF use; it also supports decision-making for further site investigations (Thalheimer et al. 2017).
  - **ACRP Project 02-93, "PFAS Management at Airports."** This project will culminate in a guide that will assist airports in developing plans for managing PFAS resulting from the use of AFFF at their facilities. The guide will provide information on managing AFFF and on-site PFAS-impacted media, addressing legacy PFAS environmental issues, identifying the migration pathways and risks of PFAS releases, testing and sampling of PFAS, managing risk, conducting remediation, and communicating PFAS issues to internal and external stakeholders (Lindekugel 2023).
- **National Academies of Sciences, Engineering, and Medicine.** In addition to ACRP research, the National Academies of Sciences, Engineering, and Medicine has published guidelines

regarding the human health effects of PFAS exposure, testing for PFAS in humans, and recommended levels of PFAS to inform clinical care for patients at risk (National Academies of Sciences, Engineering and Medicine 2022).

- **United States Environmental Protection Agency (U.S. EPA).** The U.S. EPA maintains a PFAS website that summarizes current understandings of PFAS, including human health and environmental risks as well as actions that the public can take to reduce exposure to PFAS. The website also provides updates on the "PFAS Strategic Roadmap," which sets timelines for the promulgation of PFAS policies and regulations. Data and tools concerning PFAS chemistry, remediation, and toxicity as well as PFAS issues in drinking water, waste, wastewater, and other environmental media are also provided (U.S. EPA 2023).
- **Interstate Technology and Regulatory Council.** The ITRC produces informational documents and training focused on environmental issues and remediation technologies that are intended to broaden technical knowledge and assist with regulatory decision-making. The organization maintains a comprehensive PFAS website that contains (1) fact sheets; (2) videos explaining technical issues; (3) information on chemical and physical properties, fate and transport, and health effects; (4) PFAS-specific considerations with respect to firefighting foams; and (5) a summary of state, national, and international PFAS advisories and regulations. The site is maintained by a cooperative of hundreds of PFAS experts and is updated regularly (ITRC 2022a).
- **State regulatory agencies.** Many states' environmental regulatory agencies have established PFAS websites that, in addition to providing background information on PFAS, also contain state-specific information on promulgated PFAS regulations, laboratory analytical method requirements, and findings from state PFAS sampling. These sites are especially valuable when addressing PFAS at an airport located in these states. A list of states that have website resources about PFAS is maintained by the U.S. EPA. Some states are developing PFAS-specific teams to incorporate multiple state-level departments. The State of Michigan has created the Michigan PFAS Action Response Team (MPART)—a team of seven state agencies that was established in 2017 to ensure coordination in implementing a response to PFAS contamination. The MPART is an excellent resource for PFAS background and guidelines on various topics (U.S. EPA 2023a; State of Michigan 2023).
- **U.S. Department of Defense.** The U.S. DOD, through its Strategic Environmental Research and Development Program and its Environmental Security Technology Certification Program, has developed a PFAS website for U.S. DOD activities that includes (1) an overview of PFAS; (2) discussions of occurrence, fate and transport; (3) treatment technologies; (4) ecotoxicity; and (5) the next generation of fluorine-free, U.S. DOD-approved firefighting foams. Updates on U.S. DOD PFAS research efforts, as well as frequently asked questions about AFFF, are also presented on the website (U.S. DOD 2023a).
- **Federal Aviation Administration.** The FAA maintains a website that provides guidelines and resources regarding AFFF use for operators of Part 139 airports. The content includes (1) strategies to help comply with regulatory directives; (2) information regarding preparation and implementation of emergency plans; (3) firefighter training guidelines; (4) vehicle and equipment requirements; (5) firefighting operational strategies; and (6) a listing of approved extinguishing agents. Links are provided for military specification MIL-F-24385, which defines the properties of AFFF that satisfy Part 139 requirements, as well as for the U.S. DOD's Qualified Products Database, which lists AFFF products that conform to MIL-F-24385. News and updates on the approval and use of fluorine-free foam products is also posted on this website (FAA 2023a).

It is important to note that the science and regulatory understanding regarding PFAS is dynamic. Currently available information is likely to become dated and obsolete as the understanding of these chemicals improves in the years ahead. As this guide ages, a commitment to updating information is recommended to ensure that the latest science, regulatory framework, and environmental concerns are incorporated into any PFAS source differentiation effort.

2.3 Frequently Asked Questions About Airport PFAS and AFFF

This section provides brief answers to common questions related to PFAS source differentiation. Basic information on PFAS is not included in this section but can be found through the publicly available resources listed in Section 2.2.

KEY POINT

Traditional fingerprinting of PFAS sources is unlikely to be effective given the commonality of relevant PFAS used in many sources. However, differentiating between sources using multiple lines of evidence may provide an indication of comingled or unique sources.

Question 1: Is it possible to chemically fingerprint PFAS sources?

There are no guaranteed techniques to identify or fingerprint a given PFAS source because many PFAS sources use the same subset of relevant PFAS and also because standard environmental methods can only test for a small number of them. Further, fate and transport of these compounds in the environment is complex, making source differentiation efforts more difficult. However, forensic tools that provide a closer look at PFAS chemistry can be a useful component of a lines-of-evidence approach for source differentiation. Examples of possible forensic approaches include the following:

- AFFF products from different manufacturers and timeframes can present unique patterns of PFAS analyte distribution. This may allow for a comparative analysis of PFAS analyte distribution to known source distributions.
- The chemical structure of individual PFAS can be useful when compared with existing information—such as origin, timeframe, and likely use. Structural differences include a straight chain of connected carbon atoms (linear isomers) as compared with more complicated structures (branched isomers).
- If a certain eight-carbon chain cyclic PFAS [called perfluoroethylcyclohexane sulfonate (PFECHS), or Chemical Abstracts Services (CAS) Number 335-24-0] is observed, it may have originated from a corrosion inhibitor used in aircraft hydraulic fluids (MPART 2020). PFECHS is not known to be a component of AFFF.
- Specific PFAS can be used as markers for fluoropolymer manufacturing, food packaging and paper coating, and personal care products; these are not currently understood to be associated with AFFF formulations.
- Statistical analysis and visual tools compare the specific PFAS occurrence and distribution in environmental samples to the known PFAS occurrence and distribution within common PFAS sources.

Question 2: What are the typical sources of PFAS at an airport and which of them are of most concern?

Although PFAS can be found in a variety of materials, airports should be most concerned about sources of PFAS that have the potential to substantially contribute to environmental and receptor impact (e.g., drinking water wells and surface waters). The historical use of AFFF by ARFF departments is the most significant potential on-site source of PFAS at airports.

The potential volume of AFFF released into the environment at an airport can be orders of magnitude greater than releases from other PFAS-containing products. Moreover, AFFF releases can be widespread in environmental media and may have been impractical or infeasible to completely contain during use.

The most common scenarios for legacy or current PFAS releases to the environment that are associated with AFFF use at an airport are the following:

- **Emergency responses.** AFFF used to fight fires at aircraft accidents, aircraft hangars, and fuel farms.
- **Precautionary measures.** Deployment of a layer of AFFF foam on a runway for the safe landing of distressed aircraft or on a taxiway or apron to isolate spilled fuel from potential ignition sources (such as sparks or hot aircraft parts).

- **Firefighting trainings.** AFFF used in training firefighters to extinguish fuel-based fires.
- **ARFF equipment calibration and maintenance.** AFFF released during annual foam proportioning system testing on ARFF vehicles in order to meet Part 139 certification requirements. Small volume releases may also occur during routine maintenance of these vehicles.
- **Part 139 timed response drills.** AFFF may have been released during past Part 139 annual inspections as part of an ARFF timed response drill.
- **Tenant hangar fire suppression system releases.** Releases associated with maintenance and operation of tenant hangar systems.
- **Accidental releases.** Accidental releases of AFFF through (1) improper storage, (2) spills, (3) leaks of AFFF at airport and tenant hangars, or (4) nonemergency activation of fire suppression systems in aircraft hangars.

KEY POINT

For airports, the historical use of AFFF by ARFF departments is the most significant potential on-site source of PFAS.

There is increasing awareness of other potential on-site sources of PFAS from aircraft maintenance facilities, rental car wash facilities, and solid waste. Examples of products that may contain other forms of PFAS include some aircraft hydraulic fluids; car wash products; and waste streams containing food packaging, roofing materials, waxes, adhesives, paints, carpets, and furniture textiles. Although products that contain PFAS may be present, their PFAS contribution is likely to be far less significant than historical AFFF use given (1) the lower concentrations of relevant PFAS in these products and (2) fewer direct pathways for any relevant PFAS to the environment. For these reasons, products containing PFAS should be assessed on a case-by-case basis in source differentiation investigations.

See Section 3.1 for more discussion of on-airport PFAS sources.

Question 3: Should airports be concerned about PFAS in their current municipal solid waste streams?

Although there are many PFAS-containing products that can end up in municipal solid waste streams (including solid waste generated at airports), these materials are low on the list of PFAS environmental concerns at the time of this report. This is because of both (1) limited direct exposure pathways and (2) the types and lower amounts of PFAS associated with these products. PFAS from consumer products disposed of within municipal solid waste at airports are likely to be a much lower concern than the types of PFAS associated with AFFF. Common products in solid waste include consumer goods, paper and packaging that contain PFAS, and other materials with stain-resistant coatings.

PFAS in an airport's solid waste stream has the potential to contribute to PFAS impacts at landfills receiving the airport's solid waste. At some time in the future, changes may be made to the way PFAS in municipal solid waste is managed; such changes could increase concerns regarding PFAS-containing solid waste for an airport operator. Although airports should monitor trends in PFAS concerns related to solid waste, impacts associated with AFFF use will remain a more substantial concern for the immediate future.

See Section 3.1 for more discussion of on-airport PFAS sources.

Question 4: Should airports be concerned about PFAS in their sanitary and industrial wastewater discharge?

Although the current regulatory focus at airports is on subsurface impacts, groundwater, and stormwater discharges, industrial wastewater discharges from an airport may have exposure to residual AFFF from previous on-site activities. Airports with industrial discharges from areas of PFAS handling, storage, testing, or application could have PFAS levels that are of concern to their local treatment plant. Furthermore, sanitary sewers that are in contact with PFAS-impacted groundwater could be at risk for infiltration depending on the age and integrity of the sewers.

AFFF that is disposed in sanitary sewers should be an important consideration for airports. Thalheimer et al. (2017) made the following observation:

> Generally, in accordance with the manufacturer's SDSs [safety data sheets], residual AFFF/AFFF wastewater drains to existing infrastructure on the airport property and then is directed to a wastewater treatment facility (i.e., either on-site or via a municipal sewer infrastructure).

The ability for wastewater treatment facilities to treat PFAS varies considerably. Most, if not all, current wastewater treatment facilities are not designed to treat PFAS, although some PFAS can be removed at various stages of the treatment process. Airports should check with their local wastewater treatment facilities to confirm those facilities' acceptance of and ability to treat PFAS in wastewater. Current industry guidelines do not recommend disposal of PFAS-containing wastewater to the sanitary sewer.

Question 5: What types of nonairport sources could bring PFAS onto an airport?

The wide array of industries and consumer products that contain PFAS provides many opportunities for PFAS to migrate onto an airport. Notable potential sources include the following:

- **Industrial activity.** Industrial activity (such as metal plating and surface coating) could involve the use of PFAS-containing materials. Spills or other releases from these activities could introduce PFAS into the environment.
- **Municipal fire departments' training and emergency response.** Non–Part 139 airports often rely on municipal fire departments to provide emergency response. These fire departments could bring PFAS onto the airport when using AFFF during emergency response or during training on airport property.
- **Airborne deposition.** Airborne deposition of PFAS is a concern with respect to certain industries with PFAS-containing emissions. Areas downwind of these emissions could experience surface deposition of PFAS, which has the potential to impact soil, stormwater runoff, and groundwater infiltration as runoff scours the surface depositions.
- **Biosolids application.** Some airports are adjacent to or maintain areas that have historically served (or currently serve) as an application area for wastewater treatment plant (WWTP) biosolids land application—often associated with leased agricultural land. Biosolids have been identified as a WWTP process byproduct that can accumulate PFAS.
- **Groundwater migration from off-airport PFAS-impacted sites.** PFAS-impacted groundwater from areas upgradient from the airport (from the perspective of groundwater flow) can bring PFAS onto the airport through groundwater migration.

See Section 3.2 for more discussion of off-airport PFAS sources.

Question 6: Can rainfall and air deposition be sources of PFAS at an airport?

Recent scientific publications have confirmed the presence of some PFAS in rainwater samples collected worldwide. For example, mean measured concentrations of PFOA and PFOS in urban and rural areas of the United States have been measured at up to 10 nanograms per liter, or parts per trillion (Cousins et al. 2022). This suggests that there may be measurable background concentrations of certain PFAS in air and rainwater throughout the United States, regardless of geographic location.

It is important to note that rainwater or air would constitute a relatively minor source contribution of overall airport PFAS contamination, absent the presence of a nearby or adjacent PFAS source (e.g., an upwind industrial facility with known PFAS emissions). Given the environmental ubiquity of some PFAS in both urban and rural areas, low-level detections (i.e., single digit parts per trillion) of certain PFAS might be considered background concentrations that are not directly attributable to a specific on-site or off-site PFAS source.

Question 7: How do non-AFFF fire extinguishing agents at an airport compare to AFFF, and how might they contribute to PFAS found at the airport?

AFFF used for Class B flammable liquid fires is typically the only extinguishing agent containing PFAS to be found at an airport. Other types of extinguishing agents, including dry chemical agents and Class A foams used to extinguish wood, paper, and brush fires, typically do not contain PFAS. HEFs are sometimes used in hangar suppression systems and do not contain PFAS. At the time of this guide's publishing, MIL-PRF-32725 identified that F3 products will be non-detect for PFAS using U.S. EPA 2nd Draft Method 1633 (U.S. EPA 2022). Understanding the AFFF product types and PFAS that comprise the types of AFFF used at an airport can help when undertaking a PFAS forensics exercise in which multiple AFFF release locations or sources are in question.

PFAS are not currently required to be reported on safety data sheets (SDSs) and may not be listed on the extinguishing agent ingredient list provided with a product's shipping container. For this reason, the manufacturer of the product should be contacted if there are any questions about specific PFAS content. The information needed when contacting a manufacturer about PFAS content includes but is not limited to (1) the name of the product; (2) the type of extinguishing agent (e.g., foam, dry, or chemical); (3) the packaged or manufactured date on the shipping container (if available); and (4) the year of purchase.

Question 8: How can airports tell the chemical difference between AFFF types used at the airport (e.g., military, ARFF, and older AFFF formulations)?

It can be challenging to distinguish the chemical differences between AFFF formulations that have been used at Part 139 and military airports over the years. Since the early 1970s, AFFF used at these facilities in the United States had to meet the requirements of military specification MIL-F-24385, which until recently included a requirement for PFAS surfactants. Prior to 2016, many AFFF formulations contained PFAS with eight fluorinated carbon chains (known as C8 or long-chain PFAS). Some of these long-chain or C8 AFFF formulations may have contained PFOS until the early 2000s or PFOA and other long-chain PFCAs until about 2015, when these products were voluntarily taken off the market.

A U.S. EPA and chemical industry initiative was undertaken in the early 2000s to phase out C8 AFFF because of emerging human health concerns about PFOS and PFOA. As part of this initiative, the industry shifted to fluorotelomer-based AFFF that contained short-chain forms of PFAS with six fluorinated carbon chains (referred to as C6 PFAS), which did not contain or degrade into PFOS or PFOA. C6 AFFF may still contain PFAS surfactants such as PFHxA, PFPeA, and 6:2 fluorotelomer sulfonate (FTS)—some of which can transform over time into their terminal end group (PFAAs with fewer than six carbons).

The timing of the switch from C8 to C6 AFFF varies among airports. Some changed over to C6 products immediately; others transitioned more slowly. Due to the long shelf life of AFFF, some airports (or local municipal emergency response agencies) may still be using legacy C8 AFFF or may have legacy C8 AFFF in their inventory stockpiles.

To determine the difference between AFFF types, laboratory testing may be needed to supplement information provided by the foam manufacturers on the PFAS in their AFFF products. This information may not be readily available due to proprietary formulations.

Question 9: Which PFAS chemically transform over time and what do they transform into?

Some PFAS can chemically transform (i.e., degrade into smaller, stable chemicals), but these PFAS (called precursors) often transform to other PFAS, most notably PFAAs. Although the chemicals in gasoline can

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Precursor PFAS can only transform into terminal PFAAs of equal or smaller carbon chain length.

transform all the way to innocuous end products such as carbon dioxide and water, PFAS transformation generally stops when a highly stable chemical structure is reached. The PFAS that do not appear to degrade any further are designated as terminal PFAAs because the transformation process terminates with a fully fluorinated carbon chain. Only PFAAs with equal to or smaller numbers of carbons can form from the precursor PFAS. This transformation process can be slow, meaning that PFAS released decades ago might still have the ability to transform from one PFAS to a fully fluorinated terminal PFAA.

PFAS transformation is important because the transformation process can change the way PFAS migrate through the environment such that a PFAS environmental sample taken at the release of the source may look very different from the sample taken at the end of the plume. Additionally, PFAS that are not currently of regulatory concern can transform into a regulated PFAS (such as PFOS or PFOA).

Question 10: Do PFAS behave like compounds that airports are more familiar with (such as petroleum products or glycol)?

PFAS have some similarities with petroleum hydrocarbons and glycol in that they can migrate through the environment in soil, groundwater, and surface water. However, PFAS have unique characteristics compared to these other compounds. Due to their strong carbon–fluorine bonds, relevant PFAS remain persistent in the environment and do not readily break down via chemical, physical, or biological processes. This persistence allows PFAS to potentially travel much longer distances and remain in the subsurface for longer periods than petroleum or glycol. Many PFAS are very soluble in water and do not readily sink or float in a way that would make them easy to separate, as is the case with petroleum products. Some PFAS can partially degrade in the environment into terminal PFAAs; these may include specific PFAS of environmental and health concern.

Unlike petroleum products or glycol, PFAS do not have noticeable or detectable physical characteristics (such as odor, oily sheen, or color) that can be used to identify their presence.

See Chapter 4 for more discussion of PFAS fate and transport.

Question 11: How should airports develop a sampling and analysis plan if source identification and differentiation is desired?

There are a number of things an airport should consider when developing a sampling and analysis plan to investigate the presence of multiple potential PFAS sources. Initial steps commonly include a historical analysis of the area of concern and of potential PFAS sources. These may include desktop evaluations (e.g., aerial photo reviews) and in-person interviews of key personnel who may have managed, used, or handled PFAS-containing materials in order to identify specific locations and timing of on-airport releases.

A site investigation work plan is then developed to gather and summarize the location of known releases and the geology, hydrology, and nature of PFAS releases in order to better understand the potential horizontal and vertical extent of PFAS in soil, groundwater, surface water, or all of these. This is often completed in phases as new data becomes available to help inform the sampling work plan.

When source differentiation is desired (or may be desired in the future), analytical methods should be used that include multiple PFAS analytes. Current standard methods can provide analytical results for between 23 and 40 compounds. However, laboratories are increasingly offering additional analytes at an increased cost. Additional analytes may help to differentiate between AFFF and other PFAS sources and should be considered when developing a sampling plan. There are also laboratory tests that provide different types of analytical information about PFAS beyond the standard targeted analyses. These tests can provide information on a particular group of PFAS, such as the total amount of precursor PFAS [i.e., the total oxidizable precursor (TOP) assay]. Most source differentiation efforts can be well served by focusing on targeted analyses. However, there may be cases in which non-targeted, broad PFAS results are of value.

See Section 3.3 for more discussion of site characterization. See Section 5.3 for more discussion of PFAS sampling considerations.

Question 12: If source differentiation may be needed, what laboratory analysis procedures should be considered when having samples tested for PFAS?

After deciding to collect PFAS samples for analysis, the primary decision point is whether to (1) test for a targeted list of specific PFAS, (2) do a proxy analysis for total PFAS or total oxidizable precursors, or (3) run non-targeted analyses (analyses with no internal standards). With a targeted analysis, the list of PFAS that are applicable to the sampling location or to the relevant regulatory program will affect the analytical method that is chosen. This, in combination with the sample matrix, will be the driving factor in method selection. Although the regulatory program may drive the target analyte list, it may be of particular value to go beyond the regulatory requirements when attempting to differentiate PFAS sources. The more compounds that are quantified, the greater the potential for identifying a unique signature.

Considering a broader suite of PFAS analytes can help to improve source differentiation efforts at PFAS-impacted sites. The U.S. EPA 2nd Draft Method 1633—using liquid chromatography with tandem mass spectrometry (LC-MS/MS)—includes 40 PFAS analytes (U.S. EPA 2022). These analytes cover a range of perfluorinated carboxylic acids, perfluorinated sulfonates, electrochemical-based precursors, fluorotelomer-based precursors, biotransformation products, and some of the new PFAS replacement alternatives. Data obtained from such analysis provide preliminary information about the chemistry of potential PFAS sources.

To further characterize and differentiate the sources of PFAS, high resolution mass spectrometry (HRMS) analysis can be used in addition to routine LC-MS/MS methods. The HRMS analysis provides information on a broader list (> 500 PFAS analytes) of PFAS precursors and transformation products than those covered under the targeted analysis using standard methods.

Commercially available PFAS methods such as TOP assay and total organofluorine (TOF) analysis are typically used to understand the total unknown PFAS precursors and the fluorine mass balance in a sample. However, these methods do not specifically identify individual PFAS. Additionally, the TOP assay has not been applied reliably to complex matrices, because not all precursors and intermediates may be converted completely into PFAAs (Zhang et al. 2019; Kidd et al. 2022). These methods are increasingly being included in a lines-of-evidence approach for source identification.

In most cases a total PFAS analysis or a TOP assay is used for screening purposes; these may be useful in identifying PFAS compositional differences between two sampling locations. These data must be interpreted with caution, because the fate and transport of PFAS varies both vertically and horizontally from the release location, and the differences identified may reflect fate and transport properties rather than different sources.

See Chapter 5 for more discussion of PFAS sampling considerations.

Question 13: Can or should an airport test to verify the AFFF formulation of the foam currently used at its facility?

The need to test and verify the formulation of AFFF at an airport will be driven by what questions the airport needs to answer. In general, if an AFFF product is included on the U.S. DOD's Qualified Products Database (which provides a list of approved foam products that meet military specification MIL-F-24385), there should not be a need to test the product for PFAS because information available from the manufacturer and other industry sources can be used to determine its chemical formulation. However, in the absence of this information there may be a need to test and verify an AFFF product. Examples include the following:

- Differentiating the types of AFFF that were used by different entities at an airport, such as might be the case with civilian and military firefighting operations at a joint-use airport.
- Identifying contributions from the legacy use of long-chain AFFF products versus current short-chain AFFF use.
- Verifying the presence or absence of PFAS in different types of Class B foam extinguishing agents (such as hangar suppression systems).

If there is uncertainty about whether a firefighting foam contains PFAS, coordination with the foam manufacturer on laboratory analysis, identifying the ingredients contained within the product, or both may be needed to ascertain this information.

2.4 Regulatory Review

Currently, PFAS regulations are in various stages of development at both state and federal levels, and no complete and comprehensive regulatory overview is available. However, resources to monitor regulatory action and to review applicable actions relevant to an airport are outlined in Section 2.2. In addition, a brief overview of U.S. EPA activity with particular relevance to airports at the time of this guide's writing is provided in this section. These regulatory actions will likely increase focus on PFAS impacts, which may in turn heighten public awareness, concern, and scrutiny of potential PFAS impacts originating from airport operations. This heightened focus may increase the value of or need for airports to pursue PFAS source differentiation in order to better understand airport and nonairport contribution to any identified PFAS impacts.

In February 2019, the U.S. EPA published its first national PFAS action plan (U.S. EPA 2019). The action plan outlined short-term and long-term goals for more than 20 key focus areas. In October 2021, the U.S. EPA issued its PFAS Strategic Roadmap (U.S. EPA 2022a). The roadmap sets timelines by which the U.S. EPA plans to take specific actions and commits it to implementing new policies to safeguard public health, protect the environment, and hold polluters accountable. Also in October 2021, the U.S. EPA issued a National PFAS Testing Strategy designed to increase U.S. EPA's understanding PFAS impacts, including potential hazards to human health and the environment (U.S. EPA 2021).

The following are three initiatives relevant to airports that could elevate the need for PFAS source differentiation:

- **Drinking water.** The U.S. EPA has indicated that it intends to use the Safe Drinking Water Act process to develop maximum contaminant levels (MCLs) for PFOA and PFOS (U.S. EPA 2022). When finalized, these new drinking water standards will require that all public water supplies must meet these standards. Until the MCLs are promulgated, the U.S. EPA has established lifetime health advisories (HAs) for four PFAS. The HAs were updated on June 15, 2022, and include interim levels for PFOA and PFOS that are orders of magnitude lower than previous HAs and are also below current laboratory detection limits. The current HAs are as follows:
  - PFOA: 0.004 parts per trillion (ppt)
  - PFOS: 0.020 ppt
  - PFBS (perfluorobutane sulfonate): 2,000 ppt
  - GenX: 10 ppt

  HAs are not enforceable, but they are often used by federal and state agencies to provide guidelines regarding potential health implications from PFAS in municipal drinking water.

Additionally, many state agencies adopt HAs (in the absence of MCLs) as state-specific drinking water guidelines or standards.

- **Cleanup.** In August 2022, the U.S. EPA proposed a rule to designate PFOA and PFOS as hazardous substances under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). When finalized, this rule will create new reporting obligations, allow access to new funding sources to help with cleanup of PFAS-impacted sites, increase possible liability for potentially responsible parties (PRPs), and increase scrutiny of current and closed Superfund sites.

  One significant implication of the future designation, in particular with regard source differentiation, will be the inclusion of PFOA and PFOS in the Superfund's Joint and Several liability framework. The U.S. EPA could require PRPs to remediate PFOA/PFOS impacts and incur any costs associated with the investigation and cleanup. CERCLA also allows for PRPs to seek cost recovery/allocation from other PRPs who may have caused or contributed to the impacts. There are several PFAS with U.S. EPA Regional Screening Levels (RSLs) available for screening for potential human health risks associated with PFAS in groundwater and soil at impacted sites (U.S. EPA 2022b).
- **Monitoring.** The U.S. EPA plans to use the fifth Unregulated Contaminant Monitoring Rule (UCMR 5) program to complete additional nationwide monitoring of drinking water systems for PFAS contamination (U.S. EPA 2019a). The U.S. EPA has also indicated that PFAS monitoring will be included in federally issued National Pollutant Discharge Elimination System (NPDES) permits at facilities with potential PFAS-impact discharges. NPDES monitoring requirements at the federal level inform state agencies as to what should be included in state-issued NPDES permits.

The U.S. EPA also continues to conduct PFAS research and develop communications to convey important information about PFAS risk to the public.

States have developed and continue to develop state-specific PFAS information websites that include a summary of regulations and pending regulations. These websites are a good place to start to query the state health department or environmental agency responsible for PFAS issues. State websites will often include guidelines on various topics, including sampling and analytical methods.

The following two resources provide excellent sources for reviewing state-by-state regulations across the United States:

- **Interstate Technology and Regulatory Council.** The ITRC provides a summary of state-specific and national PFAS advisories and related information as well as international PFAS information. This information is updated periodically to provide useful information to the public and interested parties in a timely basis (ITRC 2022a).
- **U.S. EPA.** The U.S. EPA maintains a list of states that have website resources about PFAS. The site includes basic information related to PFAS as well as the U.S. EPA PFAS Strategic Roadmap: EPA's Commitments to Action 2021–2024 (U.S. EPA 2023a).

It should be noted that PFAS regulations are constantly changing, and information contained in these national databases should be confirmed with the responsible state agency.

2.5 PFAS Source Differentiation Triggering Events

There are a variety of reasons or triggering events that could lead an airport to undertake a PFAS source differentiation effort. The information may be needed to respond to an external driver, such as a regulatory, legal, or community concern. A PFAS source differentiation effort may also be internally driven by a need to identify and prioritize sources of PFAS detected on or near the airport. The following are some examples of common triggering events that could spur an airport to initiate a PFAS investigation—including a source differentiation project.

- **Compliance with environmental regulatory directive.** The need may exist to address regulatory directives to determine the presence, magnitude, and sources of PFAS in stormwater, surface water, groundwater, or soils.
- **Response to public concerns.** An airport may need to positively respond to public concerns about the airport's contribution to PFAS found in the community.
- **Environmental consciousness.** An airport may be interested in understanding the extent and possible sources of PFAS at its facility as a part of environmental awareness initiatives. The results of initial screening may lead to more detailed forensics investigations to inform decision-making and response to regulatory and community inquiries.
- **Detection of PFAS in groundwater, surface water, or soil.** The detection of PFAS in groundwater, surface water, or soil at or adjacent to an airport may drive the need for a forensics investigation to understand the sources and pathways to the detection location. This information can often be beneficial in determining the origins of PFAS at the detection locations, identifying options to eliminate future migrations, and determining potential remediation opportunities.
- **Infrastructure improvement projects.** Infrastructure improvement projects requiring excavation may drive the need to (1) test whether PFAS is present in soils that are to be excavated and (2) understand the appropriate methods for managing the soil (e.g., reuse, on-site stockpiling, or off-site disposal). Determining the forensic makeup of PFAS in the excavated soil can assist in determining the source, pathway, and excavation and soil management changes that may be needed to complete the infrastructure improvement project.
- **Legacy releases of AFFF.** Source differentiation can be a tool used in determining the source of AFFF at legacy release sites where there could be more than one responsible party. This includes distinguishing whether the source of AFFF is from civil or military firefighting activities (at a joint-use facility) or whether the release is associated with the activation of a tenant fire suppression system.
- **Differentiation with other on-airport PFAS releases.** There may be a need to differentiate the sources of PFAS if there are other known non-AFFF PFAS releases at an airport. These could include leachate from a former on-site landfill, application of biosolids from wastewater treatment plants, and spills or leaks of fluids containing PFAS compounds.
- **Legal liability.** There may be a need to differentiate the source of PFAS for legal liability purposes. This may be needed as part of a legal action in which the airport is a defendant or in an action filed by the airport to assign liability for cleanup responsibility.

2.6 Multiple Source Identification and Cost Allocation Consideration

Using the tools and approaches outlined in this guide, information gathered from a site investigation at an airport might yield several outcomes. One outcome might be that airport activities are solely responsible for observed PFAS contamination. This scenario is plausible when (1) no other known sources of PFAS are identified in the area or (2) environmental sampling data confirm that there are no PFAS impacts in groundwater at upgradient airport property boundaries or at areas known to be unimpacted by airport activities (background areas). A second outcome of an investigation might involve several potential contributors to PFAS contamination discovered at an airport. In this scenario, there may be both (1) a clearly identified AFFF release that has resulted in PFAS impacts to soil and local groundwater on the airport property and (2) PFAS observed in groundwater originating from an off-site, hydraulically upgradient PFAS source.

In cases involving more than one potential source, additional environmental sampling will likely be necessary to assess the PFAS sources and identify PRPs. Environmental regulators (such as the U.S. EPA) have the authority to identify PRPs and to assign responsibility for environmental cleanup costs. If a group of PRPs has been identified, then a cost allocation process is conducted to determine how much each PRP is required to pay. There are methods and tools available to allocate environmental costs to different contributors that account for the severity of the releases, among other factors.

The U.S. EPA has established guidelines on cost allocation on CERCLA sites (U.S. EPA 1994). PFOA and PFOS are soon likely to be listed as CERCLA hazardous substances by the U.S. EPA; several states have already designated them as such. The concepts developed for the cost allocation process under CERCLA could be applicable to PFAS when there are multiple PRP releases contributing to PFAS environmental impacts.

This cost allocation process uses six general factors created by former Senator Al Gore (U.S. EPA 1994; Graves et al. 2000). These are referred to as "Gore factors" and include the following:

1. The ability to distinguish a party's contribution to the discharge, release, or disposal of the waste.
2. The volume of the waste disposed.
3. The toxicity of the waste disposed.
4. The degree of involvement of a party in the generation, treatment, storage, and disposal of waste.
5. The waste management practices of the party.
6. The party's degree of cooperation with regulatory agencies.

These factors are not exhaustive; courts can consider any equitable factor deemed appropriate to a case, particularly in situations where the usefulness of the Gore factors is limited. However, the Gore factors can be a useful starting point for deciding who should pay how much of the cleanup costs for PFAS contamination that originated from more than one source.

For example, if large, historical AFFF releases from an airport fire training site are well-documented and have a particular chemical signature that matches the chemical profile of a groundwater plume, the airport may be found liable for most of the cleanup cost even if a smaller PFAS groundwater plume from another source is flowing into the airport and mixing with the airport plume. In this example, the airport's contribution is distinguishable in the groundwater plume and the quantity of airport PFAS released is higher than the smaller off-airport source. However, if the off-airport plume was of sufficient mass and toxicity when it crossed onto the airport and did not get appreciably larger when mixing with the airport's PFAS source, then the off-site source would likely be allocated a much higher fraction of the cleanup cost.

KEY POINT

Standard cost allocation methods and tools allocate environmental costs to different contributors; such allocation methods consider the severity of the release as well as other factors.

CHAPTER 3

Understanding Potential PFAS Sources

> **KEY POINT**
> A desktop review of on-airport and off-airport potential PFAS sources, in conjunction with an understanding of site characteristics, will provide the foundation for sampling rationale and source differentiation efforts.

PFAS source differentiation should include a thorough understanding of the potential for source contributors both on and off an airport. This can largely be completed through a desktop review of readily available information that can be used to guide further investments in investigative and monitoring efforts. This section provides key considerations and approaches for collecting such information in order to increase understanding of PFAS sources at and around an airport.

3.1 Potential On-Airport PFAS Sources

As an airport considers available information to build a lines-of-evidence approach to PFAS source differentiation, an important early step is to evaluate potential relevant PFAS source contributors at the airport.

ACRP Project 02-93, "Guidebook for PFAS Management at Airports," will culminate in a report that can be referenced for additional activities and products that contain PFAS at an airport (Lindekugel 2023). This section focuses on the relevant PFAS discussed in Section 1.4.

3.1.1 Airport Operator

For airport operators, AFFF is usually the most significant source of PFAS release into the environment. Potential source areas are typically associated with responses to aircraft emergencies; Part 139 certification activities; ARFF vehicle maintenance, spills or leaks during handling and storage, and firefighter training. Table 3-1 lists the typical sources of on-airport AFFF.

3.1.2 Tenant Activity

Aeronautical and nonaeronautical activities conducted by airport tenants can be sources of relevant PFAS releases. Table 3-2 provides examples of these activities.

3.1.3 Historical Land Use

It is important to consider past activities and their use of products containing PFAS on airport property that may be legacy sources of PFAS in the environment. Table 3-3 presents common examples of past activities and land uses that could still be sources of relevant PFAS at an airport.

3.1.4 Where to Find Information About Potential On-airport Sources

One of the more challenging aspects of identifying sources of PFAS detected at airports is locating accurate records regarding the use of AFFF and other PFAS-containing products.

Table 3-1. On-airport AFFF sources.

Source	Comments
AFFF use in emergency response	This includes all activities in which AFFF is used to respond to an emergency involving an aircraft fuel fire or other fuel fire involving a ground vehicle, fuel farm, or hangar. This can also involve off-airport fuel fires for which airport firefighting equipment is deployed or fixed firefighting systems associated with airport fuel farms.
Part 139 certification ARFF truck foam proportioning system calibration	Routine calibration of the foam proportioning systems on ARFF vehicles to demonstrate that the equipment can generate foam at its designed rate is a requirement under Part 139; this test is required annually. Since January 2019, options have been available to perform this test with closed-loop equipment that does not discharge foam. For airports that have not employed the closed-loop technology, the testing is performed by discharging foam from the ARFF vehicle onto the area around the truck.
Part 139 certification AFFF training areas	Airports certified under Part 139 are required to conduct at least one live fire training drill annually. In the past, these training exercises were often conducted on-site using AFFF, either by a mobile fire training unit or at a fire training area. In recent years, this training has been moved to regional fire training facilities designed to contain AFFF runoff. Any on-site training now typically uses water only.
Part 139 certification timed response	A timed response is required as part of annual Part 139 certification in order to demonstrate an airport's ability to quickly respond to an emergency. In the past, these exercises may have included discharges of AFFF to demonstrate the operation of ARFF vehicles. Following the 2021 issuance of *FAA CertAlert 21-01*, *Aqueous Film Forming Foam (AFFF) Testing at Certificated Part 139 Airports*, the FAA no longer requires the discharge of AFFF during timed response exercises if an airport can document that the foam proportioning system was tested within six months of the certification inspection.
Maintenance of ARFF vehicles	AFFF systems on ARFF vehicles may need to be emptied for vehicle maintenance activities. In addition, initial commissioning of the ARFF vehicle may include proof of calibration of the foam proportioning system through a small volume discharge.
Spills and leaks from handling and storage of AFFF	AFFF may be unintentionally released into the environment through spills and leaks. These can occur during the handling and storage of AFFF, during vehicle maintenance activities, or as a result of degraded or damaged AFFF storage containers.
Firefighter training	For airports that have (or have had) firefighter training facilities, some training activities may include (or have included) the application of AFFF. Discharged AFFF from these activities has the potential of entering the environment if it is not contained, collected, and properly disposed.

Table 3-2. Tenant activities that could contribute to releases of PFAS.

Source	Comments
Tenant hangar and fuel farm fire suppression systems	Releases of AFFF from tenant hangar and fuel farm fire suppression systems can be significant sources of PFAS. Releases from these sources can result from emergencies, tests, vandalism, or accidental activation.
Hydraulic fluid releases from aircraft maintenance facilities	Releases of certain aircraft hydraulic fluids through unintentional leaks or spills can be contributors of PFAS at an airport. Although not all aircraft hydraulic fluid contains PFAS, those fluids that are used in many large aircraft hydraulic systems contain PFAS. Under normal operational conditions, hydraulic fluid should not be leaking or released from an aircraft. The quantity and mass of relevant PFAS potentially associated with hydraulic fluid would be significantly less than that associated with AFFF.
On-airport application of biosolids from wastewater treatment facilities	Airports that have large amounts of undevelopable land may have allowed for the application of biosolids from wastewater treatment facilities. Biosolids have the potential to be a source of relevant PFAS if the wastewater treatment plant receives significant amounts of industrial wastewater. Additional discussion on biosolids is included in Section 3.2.
Releases of PFAS from on-airport nonaeronautical industrial activities	Tenant industrial and manufacturing activities that use products and processes involving PFAS can be sources of relevant PFAS at an airport. Examples include aircraft production facilities, aircraft maintenance activities, and industrial operations occurring within an airport business park or similarly leased area.

Table 3-3. Past activities and land uses that could be sources of on-airport PFAS.

Source	Comments
Emergency response sites	Any historical emergency response site at which AFFF may have been used can still be contributing to the release of PFAS into the environment. This includes aircraft incidents or accidents, hangar or building fires, fuel farm fires, and past emergency response preventive measures such as the foaming of a runway prior to the landing of an aircraft experiencing an in-flight emergency.
ARFF truck foam proportioning system calibration sites	Prior to the present-day option of using closed-loop testing systems, all Part 139 ARFF truck foam proportioning system testing was done through the release of AFFF into the environment. Any historical location where ARFF truck foam proportioning system testing was performed could be a potential source of PFAS at an airport.
ARFF training sites	Any historical location where AFFF may have been used for firefighter training could be a source of PFAS. This includes existing and former firefighter training areas. ARFF training involving the use of AFFF could also have occurred on an apron, in a grassy area, or in other remote airfield locations.
Part 139 timed response	Prior to the issuance of *FAA CertAlert 21-01*—which eliminated the required discharge of AFFF during timed response drills—release of AFFF may have occurred as part of an airport's annual Part 139 certification inspection. Potential locations for releases of AFFF may be near the approach end of a runway, on the pavement itself, on an associated connector or parallel taxiway, or at the midpoint of the farthest runway.
Hangar fire suppression system releases	Past releases of AFFF from hangar fire suppression systems can be a source of PFAS. In addition to system activations in fire emergencies, releases may have resulted from inadvertent system activation, new hangar commissioning, and system operation tests.
Former ARFF, maintenance, or AFFF storage buildings	Sites of former ARFF buildings, maintenance buildings, and buildings used to store AFFF should be considered as part of a source differentiation effort. The types of activities that occurred at each site may have released AFFF containing PFAS into the environment, either intentionally or unintentionally.
Airfield soil stockpile sites	Sites where excavated soil from airport development projects has been stockpiled have the potential to be sources of PFAS if the soil was excavated from an area impacted by PFAS.
Military ARFF activities	Airports that are either a former military base or are a joint-use facility may have sites where AFFF was used by the military for training, testing, or in response to an emergency. It is important to note that because of the higher fire risks associated with military aircraft operations, the historical use of AFFF—such as for training and equipment testing—is thought to be more common than similar activities conducted by civilian airport firefighters.
Aircraft maintenance activities	Sites (such as buildings and hangars) where aircraft maintenance activities historically occurred are potential sources of PFAS. Such sources could include plating, surface coatings, hydraulic oils, or other PFAS-containing materials used at the facility.
Industrial activities that occurred on airport property	Past industrial activities on airport property may have released PFAS into the environment. These could be known aeronautical or nonaeronautical activities (e.g., chrome plating or use of former landfills) or activities that occurred on land prior to its acquisition by the airport.
Airport fill locations	Areas of airport land in which fill was used for development projects can be potential sources of PFAS if the soil used to level and prepare land for development was impacted by PFAS.

Until relatively recently, airports were unaware of concerns regarding PFAS, and their environmental and human health threats were not understood. As a result, past practices did not require documenting the volumes and locations of AFFF use. Records about the use of AFFF and other activities of interest that may have occurred at an airport may be sparse or unavailable due to the transfer of records from historical airport ownership transitions—such as city to county and county to airport authority. Similarly, records from other users of AFFF, such as the military and tenants, may be unavailable or nonexistent.

To assist airports in identifying legacy sources of PFAS at their facilities, Table 3-4 summarizes common resources that can often provide useful information about relevant activities.

3.2 Potential Off-Airport PFAS Sources

Off-airport PFAS sources of potential concern typically include (1) industrial and manufacturing sites that use PFAS in their processes; (2) sites that have potential to discharge AFFF; and (3) indirect PFAS sources such as landfills and wastewater treatment works. This section provides more information on these potential off-airport sources and how they (individually or together) can contribute to a detection of PFAS at an airport and its surrounding area.

3.2.1 Industrial and Manufacturing Sites

The use of PFAS in a wide variety of industrial and manufacturing processes increases the complexity of source differentiation due to the number of potential contributors. This includes existing and former industrial and manufacturing sites. However, there are industries and use categories that have been identified to have a higher likelihood of relevant PFAS releases. Understanding these industries and use categories if they exist near an airport can help to focus efforts when reviewing potential PFAS source contributors. Glüge et al. (2020) published an overview of PFAS uses following an in-depth review of available information. The overview identified 21 industry branches and 43 other use categories as shown in Figure 3-1.

> **KEY POINT**
> Source differentiation discussed in this guide is focused on those PFAS that are currently under scrutiny and can be identified in typical, widely accepted laboratory analyses.

This reference to industries and use categories provides an example of the complexity of PFAS source differentiation and the need to carefully consider all available information. Although there are thousands of possible PFAS, many of these are not PFAS of relevance from an environmental source differentiation perspective. For example, industries and use categories that are specific to polymeric PFAS will likely be of little relevance to an environmental investigation if the associated PFAS are polymers that are insoluble in water, unlikely to be present in the environment, and cannot be analyzed using standard commercial environmental analytical methods. This guide and the source differentiation discussed within it are focused on differentiation of those PFAS that are currently under regulatory scrutiny and can be identified in typical, widely accepted laboratory analyses. The information provided in Figure 3-1 should therefore be referenced with the understanding that not all of the industries or uses listed are certain to include PFAS that are relevant to environmental source differentiation. Nonetheless, the industries and use categories provided in the figure can assist airports as they consider the possibility of contributing sources of PFAS in and around their facility.

State PFAS sampling programs have focused on a subset of industrial users and indirect PFAS sources—such as landfills and WWTPs—that can help airports evaluate for these sources near their airport. For example, during the first two years of its statewide PFAS sampling program, the State of California included airports, landfills, chrome platers, WWTPs, refineries, and bulk fuel terminals in its sampling program (State of California 2023). Minnesota's PFAS sampling plan—issued in March 2022—included airports, landfills, WWTPs, chrome platers, auto shredders,

Table 3-4. Resources for information about on-airport PFAS sources.

Resource	Comments
Airport records	Airport records that may provide information about AFFF use, other releases of PFAS, and sites where releases of AFFF and PFAS may have occurred include the following: • Daily operational logs • Part 139 certification inspection records • Accident and incident reports • Environmental spill documentation • Site investigation and cleanup documentation • Airport development project summary reports (impacted soil management) • Airport layout plan property maps • AFFF purchasing records or SDS files These include records from both the current and previous operators of the airport.
Interviews with existing and former airport employees	Interviews with existing and former airport employees can be a valuable source of information on previous activities at an airport. These can include ARFF, airport administration, operations, security, and maintenance employees. Retired ARFF personnel can often provide anecdotal information on past locations of Part 139 inspection related discharges.
National Transportation Safety Board (NTSB) accident database	NTSB aircraft accident and incident databases can provide valuable information regarding the use of AFFF in aircraft emergencies, even if that information is not explicitly stated in accident reports. NTSB aircraft accident databases can also be valuable in determining whether AFFF was used in responding to hangar or building fires (NTSB 2023).
Available military records (if applicable)	If an airport is a joint-use facility or was a former military base, military records may be available on the past use of AFFF. The U.S. DOD may also have investigation or other documents related to PFAS to assist in on-airport source identification.
State AFFF notification records	Some states have established AFFF use notification requirements. Although these notification requirements are relatively new, they will provide important information on the use AFFF at airports and other sites moving forward.
Municipal fire departments	Interviews with local fire departments regarding AFFF capabilities and past practices can help understand its potential application at an airport. Municipal fire departments may have responded to landside emergencies on adjacent property. This information may be particularly valuable for non–Part 139 airports that do not maintain ARFF departments.
Tenant surveys	Information on fuel farms' AFFF use, hangar fire suppression systems with AFFF, aircraft maintenance PFAS sources, and industrial uses of PFAS-containing materials at an airport can be obtained through tenant surveys or interviews. Information should include both current and past practices at the tenant facility to the extent that the information is available.
Property deeds	Property deeds, although not typically a resource that can directly provide information on the volume or frequency of AFFF use, may provide clues about related activity that may have occurred at an airport. Such information may include notation about fire training areas, aircraft accident and incident sites, and industrial land uses; these may be worth investigating to determine whether releases of PFAS occurred.
Historical imagery	Historical aerial photos can help identify and locate former areas of potential PFAS exposure. These include former firefighter training facilities, former landfills, or other land areas that have since undergone development.
News archives	News archives can provide information about AFFF use at an airport through stories about aircraft accidents, fires, and uses of land (such as for manufacturing or industry purposes). Such sources can include newspapers, TV stations, online archives, and community or library archives.

Industries	Other Use Categories	
Aerospace Biotechnology Building and construction Chemical industry Electroless plating Electronic industry Electroplating Energy sector Food production industry Machinery and equipment Manufacture of metal products Mining Nuclear industry Oil & gas industry Pharmaceutical industry Photographic industry Production of plastic and rubber Semiconductor industry Textile production Watchmaking industry Wood industry	Aerosol propellants Air conditioning Ammunition Antifoaming agent Apparel Automotive Cleaning compositions Coatings, paints, and varnishes Conservation of books and manuscripts Cooking and baking ware Dispersions Electronic devices Fingerprint development Firefighting foam Flame retardants Floor covering, including carpets and floor polish Glass Household applications Laboratory supplies, equipment, and instrumentation Leather Lubricants and greases Medical utensils	Metallic and ceramic surfaces Musical instruments Optical devices Paper and packaging Particle physics Personal care products Pesticides Pharmaceuticals Pipes, pumps, fittings, and liners Plastic, rubber, and resins Printing Refrigerant systems Sealants and adhesives Soil remediation Soldering Sport article Stone, concrete, and tile Textiles and upholstery Tracing and tagging Water and effluent treatment Wire and cable insulation, gaskets, and hoses

Source: Glüge et al. (2020).

Figure 3-1. Industries and use categories that may be PFAS source contributors.

and select industries believed to have the potential to contribute to PFAS [MPCA (Minnesota Pollution Control Agency) 2022]. Maine's Department of Environmental Protection required testing of paper mill residuals prior to land spreading (Maine PFAS Task Force 2020). The Florida Department of Environmental Protection sponsored research that identified dry cleaning sites as potential contributors of historical and future PFAS (Barnes et al. 2021).

As an airport looks to refine the lines of evidence for source differentiation of off-airport sources, the complexity of trying to understand which industries may contribute to relevant PFAS presence underscores the value of engaging with a qualified PFAS consultant that can help to assess the potential for contributing sources near an airport.

3.2.2 Landfills

Both existing and closed landfills have the potential to contribute relevant PFAS into the environment through landfill leachate and stormwater runoff. Landfills are considered to be indirect sources of PFAS because the PFAS impacts within a landfill will have originated from some other activity that generated waste that was then disposed of within the landfill. The Minnesota Pollution Control Agency monitored 101 closed landfills; PFAS was detected in 98 of those landfills, as summarized in its Closed Landfill Investment Fund report (MPCA 2021). Due to the likelihood of PFAS within them, landfills represent a significant potential source of relevant PFAS; they could contribute to PFAS impacts near an airport depending on their proximity and relative location with respect to the groundwater flow direction and hydraulic gradient.

Airports should also review historical land use information at the airport itself to determine whether any former landfills or dumpsites existed on airport property. These could represent on-airport sources of PFAS that are not associated with current operations.

3.2.3 Municipal Wastewater Treatment Plants and Biosolids Application Areas

TECHNICAL DETAIL

The term *biosolid* is often used incorrectly to refer to a wide range of WWTP sludge and waste material. Biosolids are wastewater solids (sludge) that have been treated to the standards set for beneficial recycling to land.

KEY POINT

Application of wastewater treatment plant biosolids can be a PFAS source. Airports should be aware of any past or current application of these materials on or adjacent to their airport.

As with landfills, WWTPs represent indirect sources of PFAS. Industries that have historically used PFAS may be discharging PFAS-impacted wastewater into the sanitary sewer or through wastewater sent directly to a WWTP. Because of this, PFAS may be present in the effluent from the WWTP or may accumulate in biosolids or other treatment system waste (residuals). In addition, WWTPs may provide an opportunity to screen for PFAS from upstream industrial uses, if monitoring data are available. WWTPs are increasingly requesting PFAS monitoring from upstream sanitary sewer system users.

WWTPs also represent an indirect source of PFAS through the production of biosolids as a byproduct of the wastewater treatment process. Biosolids have been shown to contain certain PFAS at elevated levels. Biosolids are often land spread as a beneficial reuse option, including on agricultural land in order to provide fertilization benefits. Lindstrom et al. (2011) have indicated that PFAS contained within such biosolids can leach into the groundwater and be taken up by vegetation. Airports in rural areas often have agricultural or undeveloped land on and adjacent to the airport. The proximity of agricultural land and the historical application of WWTP biosolids on that land should be considered when evaluating for potential PFAS sources near an airport.

3.2.4 Where to Find Information on Potential Off-Airport Sources

Understanding the types of entities that may contribute PFAS impacts near an airport is a key aspect of source differentiation. Identifying where those entities are (or have been) can pose challenges. Table 3-5 provides a variety of data sources of methods that can be pursued to investigate and better understand potential PFAS sources near an airport. Each airport's unique conditions and setting may increase or decrease the value of any data source. Furthermore, the availability of applicable PFAS data to an airport can vary significantly between locations, such as the type and volume of information available from state regulatory agencies or local governments.

Filing a data request with local or state agencies using the Freedom of Information Act can also help to collect records should information not be readily available on public websites. It is anticipated that the public attention to and interest in PFAS will continue to drive increasing availability of PFAS information. At the time of the publication of this guide, substantial differences exist with respect to data availability between states and counties.

3.3 Airport Site Characteristics

Although the previous two sections focused on identifying direct PFAS source locations (such as fire training areas, aircraft rescue and fire response sites, or off-airport industrial sites), understanding the transport of PFAS at and in the vicinity of an airport is also critical when evaluating a potential source contribution. This section complements the source information by highlighting the importance of a thorough understanding of the specific airport site characteristics that influence the transport of PFAS. Every airport is situated in unique geologic, hydrogeologic, and hydrologic environments that will affect migration pathways. The availability of this information and the level of detail will vary depending on the airport.

Table 3-5. Resources for information about off-airport PFAS sources.

Data Source	Comments
Environmental site assessment	Phase I environmental site assessments (ESAs) performed by environmental consulting firms can provide a cursory overview of potential environmental impacts in and around an identified area. ESAs could provide information on known conditions and industries in the area that may have a history of PFAS use. ESAs will provide insight on current and historical site conditions through assessments conducted using regulatory database reviews, aerial photography, historical records, fire insurance maps, topographic maps, city directory listings, and other information on surrounding properties. Indicating the intent to evaluate for potential PFAS sources could help to focus the effort on potential PFAS sources.
Toxic Release Inventory	The Toxic Release Inventory (TRI) is part of the Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA) and is an annual reporting program that tracks the management and releases of toxic chemicals. Certain facilities exceeding thresholds of size and chemical use must report to the TRI. Information for each applicable chemical includes maximum amount on-site; releases to air, water, and land; transfer activities; waste management; and pollution prevention activities. The 2020 National Defense Authorization Act added 172 PFAS, with a reporting threshold of 100 pounds, to the TRI. The reporting requirements became effective on January 1, 2020. Information is available to the public and can be queried to determine whether any facility near an airport manufactures, processes, or otherwise uses any of these PFAS in excess of the threshold amount (U.S. EPA 2023b).
National Pollutant Discharge Elimination System permits	NPDES permits authorize the discharge of water from facilities to waters of the United States. NPDES permits often require stormwater sampling—in which PFAS is starting to be included in some states. In October 2021, the U.S. EPA issued the PFAS Strategic Roadmap: EPA's Commitments to Action 2021-2024. This roadmap indicated the U.S. EPA's intention to leverage the NPDES program to "obtain more comprehensive information through monitoring on the sources of PFAS and quantity of PFAS discharged by these sources." In April 2022, the U.S. EPA issued a memorandum further detailing its intention to include PFAS monitoring within U.S. EPA-issued NPDES permits. It should be noted that the U.S. EPA has delegated NPDES permitting authority to 47 states; NPDES monitoring data are often available through a state regulatory agency. PFAS monitoring is being included within state-issued NPDES permits at an increasing rate, and in some states was included ahead of the U.S. EPA's recent push for PFAS monitoring. Given the increasing trend for PFAS monitoring and the public availability of monitoring data generated from the NPDES permit, these data provide an opportunity to review discharge monitoring for evidence of PFAS impacts in the vicinity of an airport. NPDES permits with highest likelihood of PFAS monitoring include industrial stormwater permits, industrial wastewater discharge (individual) permits, and municipal separate storm sewer (MS4) permits. The multi-sector general industrial stormwater NPDES permit authorizes discharges based on industrial category. States often provide online searchable databases for permittees that can be filtered by industry category. Searching for permittees in categories of highest PFAS potential (such as Sector AA: Fabricated Metal Products) can help with discovery of industrial users near an airport.
EPCRA Sections 311–312 reporting	Sections 311 and 312 of the EPCRA require facilities to report inventories of hazardous chemicals present at a facility if they are in excess of the established threshold quantities and relevant emergency response information regarding those chemicals. Information requests from local fire departments, state regulatory agencies, or emergency response planning organizations can provide EPCRA reporting information that may provide insight into the types of products and chemicals being stored and used near an airport.

(continued on next page)

Table 3-5. (Continued).

Data Source	Comments
Federal and state environmental databases	The U.S. EPA as well as many states maintain searchable databases, often with mapping features, that allow for quick review of an area for environmental information. These sites may include information on PFAS sampling, environmental permits, cleanup sites, leaks, spills, and other information that may help to understand the nature of industries near an airport and their historical activity. Based on the information collected, further review of specific information may be warranted to further investigate the potential for PFAS sources. For example, the U.S. EPA's web interface Clean Ups in My Community (U.S. EPA 2022c) enables users to map hazardous waste cleanup locations and grant areas, obtain details about those cleanups and grants, and discover other related information. California's GeoTracker application (State of California 2022) is another example of a data management system in which data can be obtained about PFAS investigations that have occurred across the state.
Superfund (CERCLA) program	CERCLA (commonly referred to as the Superfund) was passed in 1980 to allow the U.S. EPA to clean up contaminated sites. The Superfund program generates a large volume of environmental data that may include PFAS monitoring data or other information to inform on potential PFAS impacts for historical land use. The U.S. EPA maintains a web interface that allows the user to search for Superfund sites (U.S. EPA 2022d) including a searchable map feature.
State PFAS awareness sites	Many state environmental regulatory agencies have established PFAS awareness websites that are dedicated to informing the public about PFAS issues in their community. These sites will often provide easy-to-access PFAS information; this could be leveraged to review for PFAS information in the vicinity of an airport. In addition, these sites often contain the latest information on the state of the science, guiding documents on various PFAS topics, and information on the state's intentions regarding future PFAS monitoring and regulations.
Municipal water supply data	Municipal water supplies are required to monitor those supplies and to make the monitoring results publicly available. Increasingly, this monitoring includes PFAS analytes. In addition, states are increasingly undertaking statewide PFAS sampling efforts to better understand PFAS impacts to drinking water sources. For example, the State of Colorado sampled over 400 water systems in 2020 for PFAS (State of Colorado 2020). Results from water supply monitoring can be used as an indicator of PFAS impacts in an area. This information could help to focus off-airport PFAS source investigations to those areas with the potential to impact the supply water source area.
Wastewater treatment plants	WWTPs generate environmental data as mandated by their NPDES permit requirements; these may include PFAS monitoring. In addition, publicly owned treatment works (POTW) may require upstream industrial users to provide monitoring data of their discharges. These data may include PFAS monitoring. Information requests can be made to the POTW for publicly available information. These data can help to identify industrial sources of PFAS in the vicinity of an airport. In addition to water monitoring data, WWTPs may also have PFAS analytical data from biosolids generated at the WWTP. These biosolids may contain PFAS that were accumulated from incoming wastewater and are often land applied. Biosolids analytical information as well as land application records can help to identify whether any PFAS-containing biosolids have been applied near an airport.
Air quality permits	At the time of this writing, air quality permits do not include PFAS monitoring to a great degree. The trend to conduct PFAS monitoring in air emissions is increasing, although the U.S. EPA has not yet established air emissions standards for PFAS. Some states are monitoring air emissions for PFAS in order to better understand potential exposure. For example, Minnesota has initiated a PFAS monitoring plan in which PFAS air emissions reporting and stack testing is being requested from select industries (MPCA 2022). Review of air quality permits that contain PFAS monitoring or reporting requirements may provide insight to local industries that have significant use of PFAS. This information can be requested from state environmental regulatory agencies.

Table 3-5. (Continued).

Data Source	Comments
Regulated waste reporting	Entities that generate amounts of hazardous or other regulated waste above defined thresholds must report the information to their county; such information may include waste generation of products or chemicals containing PFAS. Review of this information can help to understand the types of chemicals and waste streams being generated by a local industry and whether they have the potential to contribute PFAS to the environment.
Septic system inventories	Septic systems have been implicated as a potential PFAS source (Schaider et al. 2016). These systems are an indirect source similar to that of a WWTP—PFAS from domestic or commercial waste streams can introduce PFAS into the septic treatment system. Subsurface discharge of effluent from septic systems has the potential to impact local groundwater. State or county health departments may maintain records of septic systems in their jurisdictions. If this information is available, it would provide insight as to whether residential septic systems have potential to contribute PFAS to groundwater and downgradient areas impacted by PFAS.
Tank farms (bulk petroleum storage and distribution areas)	Bulk petroleum areas and refineries are often equipped with fire suppression equipment that employs AFFF. These sites therefore represent potential historical and ongoing sources of PFAS exposure. Determining the proximity and location with respect to groundwater flow direction and hydraulic gradient as it relates to an airport will help to determine whether there are other potential sources of AFFF that are contributing to the airport's detection of PFAS. The Internal Revenue Service (IRS) maintains a list of Active Fuel Terminals (IRS 2023) and a list of Active Fuel Refineries (IRS 2023a) that can help locate these facilities. These documents include location information for each facility. States often document their petroleum infrastructure with information that is publicly available. This information can serve as a more in-depth resource than the IRS lists. In addition to these references, a review of aerial photography (current and historical) can also help to identify large tank farms or refineries near an airport. Historical aerial photography is typically part of a Phase I ESA (described earlier in this table). In addition, many online sources are available that contain historical aerial photography.
Inventory of operating or closed, permitted or unpermitted landfills	Landfills represent a potential source of PFAS impacts from leachate and runoff. Many states and counties maintain records of operating or closed, permitted or unpermitted landfills within their areas of jurisdiction. Inquiring with the local regulator regarding information on landfills can help to determine whether landfills or dumpsites have existed on or near an airport.
Emergency response records	Records of emergency response actions can help identify past applications of AFFF near an airport. These could include records of off-airport ARFF responses, municipal fire department records, state-managed AFFF release notification documents, or news archives related to local emergency responses. Emergency response actions related to aircraft accidents, railcar fires, vehicle fires, and fuel-based fires may provide information on AFFF use.
Environmental nonprofit organizations	As PFAS gathers increasing public attention and regulatory scrutiny, environmental nonprofit organizations are compiling publicly available information to heighten public awareness. These sites often include information from the various sources described in this table. However—depending on the ease of data access within a community—this may be a more readily available data source than state websites or other information requests. For example, the Environmental Working Group maintains an interactive national PFAS map that provides a variety of PFAS data across all 50 U.S. states (Environmental Working Group 2022).

Chapter 4 provides an overview of PFAS fate and transport concepts. The information in this section and in Chapter 4 should be considered together when evaluating transport mechanisms for PFAS at an airport and its implications for PFAS source differentiation.

3.3.1 Hydrogeology/Geology/Soils

Subsurface transport of PFAS-impacted groundwater can provide a significant pathway to potential downgradient receptors. Understanding the unique subsurface conditions at an individual airport provides critical support to PFAS source differentiation efforts. The geologic setting and the way in which groundwater moves through the subsurface will help in developing additional lines of evidence and inform the focus of potential investigative resources.

Understanding site characteristics includes identifying the soil types present at an airport and how they can influence groundwater flow. PFAS adsorption will vary with PFAS concentration and soil characteristics, which can further affect potential PFAS transport.

Information that can assist with understanding relevant site characteristics includes the following:

- Groundwater elevations and contour maps (hydraulic gradient)
- Groundwater flow direction
- Bedrock units, bedrock competency, confining layers, and bedrock unit extents
- Depositional environment of water-bearing materials
- Porewater distribution/aquifers present
- Primary and secondary permeability/flow pathways
- Regional groundwater–surface water connectivity
- Soil properties and stratigraphy (including total organic carbon and moisture content)
- Climatological setting (precipitation and prevailing wind direction)
- Manufactured hydraulic conduits created within bedrock or soils (e.g., utility corridors and pipe trenches)

This information can be used to develop a conceptual site model (CSM) that describes the geology and hydrogeology in order to better understand the distribution of PFAS release and potential transport pathways.

Building a CSM as an airport conducts a desktop review of PFAS sources can help focus efforts and eliminate areas with low potential for contribution of PFAS. Groundwater elevation and flow direction will inform the possible origination of upgradient contributions. This information will also eliminate downgradient areas that are not contributing groundwater flow onto the airport property. For example, groundwater impacts at an industrial area that is hydraulically downgradient (from a groundwater perspective) would not be considered a potential source of groundwater impacts at the airport. Competent bedrock (i.e., bedrock with minimal factures, joints, or faults, among other characteristics) and confining layers can also provide information to support whether to include or eliminate potential areas as contributors to groundwater PFAS impacts if there is no hydraulic connectivity between the porewater and the aquifers in question.

TECHNICAL DETAIL

Airports should use their understanding of potential off-airport sources to determine whether significant air deposition of PFAS from nearby stacks is a concern. In this case, both downgradient (from a groundwater perspective) and downwind (from a prevailing wind direction perspective) locations should be considered in the CSM.

Depending on the regional hydrological and hydrogeological setting of an airport, groundwater–surface water connectivity may be an important transport pathway for PFAS. It is well understood that groundwater and surface water can have significant connectivity, allowing contamination to move from one to the other. Where PFAS are present, this provides the opportunity for PFAS to move between groundwater and surface water over time. Because of the persistence of terminal PFAS and its high water solubility, PFAS can travel long distances (often over many years) through these water pathways. Understanding the complexity of these systems can be challenging and should be incorporated into the CSM depending on the proximity of surface water–groundwater interactions.

Soil types can greatly affect groundwater flow rates, which can be modeled to assist with time-of-travel analyses. In addition, knowing these soil types can provide an understanding of vertical versus lateral migration. Soil types will also impact PFAS transport because soils with high organic content may adsorb certain PFAS and thereby slow the time of contaminant travel relative to groundwater movement.

Beyond groundwater movement, there are also potential interactions between surface water and groundwater, especially in those regions with sufficient rainfall to have the surface waters alternate between groundwater discharge zones and groundwater recharge zones. The mobility of PFAS between these settings, akin to that of stormwater (discussed later in this section) can represent a significant transport pathway.

In addition to the natural geologic and hydrogeologic setting, airports have typically undergone substantial development over the decades; this may have established manufactured pathways in which groundwater can migrate. These manufactured pathways can include (1) lateral preferential pathways through utility trenches, (2) pipe bedding, (3) building foundation drains, and (4) other subsurface features placed in soils, on bedrock, or both. Vertical pathways can also be created from the construction of subterranean structures such as basements, vaults, building foundations or caissons, and elevator shafts, as well as from other development requiring penetrations through groundwater-confining layers. These pathways can create connectivity between previously disconnected water-bearing zones and aquifers.

3.3.2 Stormwater Infrastructure

Stormwater infrastructure should be considered when evaluating potential pathways for PFAS transport. Stormwater infrastructure is important not only to understanding the stormwater runoff component from an individual airport (should PFAS releases be transported in the stormwater) but also to understanding the potential for groundwater infiltration into the storm sewer system. Depending on the depth of groundwater in an area, it is possible for portions of a storm sewer system to be set into groundwater. Storm sewers are often not watertight; this can allow the infiltration of groundwater into and out of them. If this infiltrating groundwater is from an area with PFAS impacts, the storm sewer system can discharge PFAS-impacted groundwater and may provide clues to the potential sources of PFAS impacts. Storm sewers may also be a source of PFAS presence in the underlying groundwater.

When PFAS impacts are observed in storm sewer dry-weather flow, investigations made by sampling strategic points upstream within a storm sewer network and collecting water quality information can help to identify where PFAS impacts are being generated within the storm sewer network. This information can help to identify source locations and can potentially differentiate PFAS sources.

Some states are engaging in stormwater PFAS monitoring programs in order to understand their potential impacts in stormwater discharge. This includes dedicated monitoring programs as well as using NPDES permits to require PFAS water quality data collection. As more information becomes available through these monitoring efforts and through NPDES permit PFAS monitoring requirements, additional attention may be focused on airport stormwater discharges.

3.3.3 Physical Setting/Surrounding Land Use

The physical setting and surrounding land use at an airport can determine, on a broad scale, whether off-airport PFAS sources are potential contributors. If an airport is located in a regional topographic low point or high point this can help to screen for the likelihood of off-airport sources contributing to any PFAS impacts observed at the airport. This information can be used in conjunction with a hydrogeologic understanding of water table elevations to focus efforts when exploring potential sources.

The surrounding land use will also dictate the potential for PFAS source contribution from entities operating in the vicinity of the airport. For example, airports sited in rural areas with little to no industrial activity nearby may have a different PFAS source investigation strategy than airports located with nearby industries. The type of surrounding land use may also direct the types of off-airport sources explored. Heavy industries in the proximity of the airport may include surface coating, chrome plating, and other potential PFAS sources. Petroleum refineries could have potential AFFF contributions. Residential areas may include septic systems that can provide a source of PFAS. Rural airports may have adjacent agricultural land on which wastewater treatment plant biosolids have been applied. See Section 3.2 for more discussion on off-airport sources of PFAS.

Incorporating the physical setting into the CSM and the surrounding land use into the PFAS source differentiation desktop review will add further lines of evidence that can increase confidence in the conclusions drawn.

3.3.4 Where to Find Information About Airport Site Characteristics

Availability of the types of information described in earlier sections will depend largely on (1) the resources previously expended toward compiling and summarizing site information and (2) the accessibility of information sources (e.g., past staff and paper records). Many medium to large Part 139 airports will have some or all of this information in some format. The availability of this information at smaller Part 139 airports and at general aviation airports will vary significantly and may be dependent on whether there was a prior need for such information for other purposes, such as airport redevelopment or expansion.

Table 3-6 presents a list of potential data resources for information related to an airport's site characteristics.

Table 3-6. Resources for information about airport site characteristics.

Data Source	Comments
Airport environmental department	Environmental departments may already have a partial or complete CSM (or portions thereof) developed for their airports. These may have been created in conjunction with previous site investigations or groundwater monitoring activities at the airport. A review of environmental reports can help to obtain the desired information. In addition to the airport's environmental department, a file review at the state environmental regulatory agency may also uncover past environmental reports with relevant subsurface information.
Airport planning department	Airport planning and development departments will often maintain records of relevant geologic and soil information. These may include geotechnical reports developed in support of development projects. In addition, master planning documents may also be a source of information. Utility corridors and storm sewer systems may be available from record drawings or archived design drawings. Increasingly, airports may have some of this information incorporated into a geographic information system (GIS) database or contained within an AutoCAD layer for the airport.
Subsurface investigations	Previous subsurface site investigations, often related to an environmental release, will likely contain valuable information regarding geology, hydrogeology, and soil conditions. These documents may be available within airport archives or through an information request to the state regulatory agency. Investigations associated with property adjacent to the airport may also provide valuable insight into the local site characteristics. State environmental regulatory agencies could provide any summary reports from adjacent areas if it is requested.
Watershed districts	Watershed districts may provide surface water drainage maps and other hydrological resources that could help inform an airport's CSM. In addition, as groundwater–surface water interactions are considered, understanding the local watersheds and subwatersheds can provide valuable insight.
Soil maps	The Natural Resources Conservation Service (NRCS), formerly known as the Soil Conservation Service, is an agency of the U.S. Department of Agriculture that maintains soil surveys across the United States. The NRCS maintains the Web Soil Survey, a web-based graphical interface that provides soil maps and interpretative data in a selected area. However, at this time they do not include PFAS information in the interpretative data (NRCS n.d.). In addition, some state or local Soil Conservation Districts may maintain records and/or soil maps with local information.
State geological surveys	All 50 U.S. states have geological surveys that serve the public interest and are focused on providing information related to geology and hydrogeology within the state. Information can include geologic maps, historical records, mineral resources, relevant databases, and other geoscience information. The scope of the information available varies by state. The Association of American State Geologists (AASG) provides links to each state's geological survey (AASG n.d.).
Stormwater Pollution Prevention Plans	Most airports have developed a Stormwater Pollution Prevention Plan (SWPPP) or similar stormwater management document as required by NPDES permits. SWPPPs will often describe the stormwater flow and may include information on storm sewer networks. In addition, some SWPPPs may also provide information on local hydrology or hydrogeology. The SWPPP can typically be obtained through the airport's environmental department.
Environmental review documents	Environmental review documents are often required to support proposed development projects at airports. These could include environmental impact statements and environmental assessments. These documents will include information on a broad array of environmental topics as they relate to the development project. These documents typically include information on land use, zoning, geology, soils, topography, stormwater, and other summary environmental information that could prove valuable. These public documents are often archived with an airport's planning department. An information request to the responsible government unit is also a potential source of past documents.
United States Geological Survey	The United States Geological Survey (USGS) is the science arm for the U.S. Department of the Interior. It has published a large volume of reports on geology, hydrogeology, and hydrology across the United States. Information is publicly available through the USGS Publication Warehouse (USGS n.d.). Publications include a ground water atlas for regions across the country.

CHAPTER 4

PFAS Fate and Transport – State of the Science

4.1 How PFAS Move and Transform and Implications for Airports

Once released to the environment, PFAS can move along several possible transport pathways. Key ways that PFAS transport may occur at airports are (1) by means of vertical movement downward through the soil toward the water table, (2) through horizontal and vertical movement in groundwater underneath the airport, and (3) via stormwater that flows through storm sewers or streams within the airport. Overall, the movement of PFAS in these pathways depends on two things: (1) the chemical characteristics of the specific PFAS, and (2) key site characteristics such as soil type, groundwater flow patterns, and the way that stormwater flows through an airport. Some general concepts about airports' three key transport pathways are summarized in this section.

Soil to groundwater pathway. PFAS that enter the soil can move downward, mostly traveling with rainwater and snowmelt that infiltrates into the soil. Different types of PFAS will move downward at different speeds due to the adsorption or "stickiness" of a particular PFAS to different soil types. Some PFAS are more adsorptive and can accumulate in soils near the surface, which slows movement toward underlying groundwater. Other PFAS, including several key relevant PFAS chemicals that are monitored by environmental regulators, are less adsorptive and can move downward toward groundwater more quickly. Sites with more rainfall, sandier soils, and thin soil layers above the groundwater will be at higher risk of having PFAS enter the groundwater than sites in drier climates that have clayey soils and a thick soil layer above the groundwater. PFAS released in soils above groundwater can move slowly and may take many years to reach groundwater.

Groundwater pathway. PFAS that enter shallow groundwater can form a plume. A groundwater plume is similar to a smoke cloud from a campfire but moves much more slowly through the subsurface. Environmental regulations typically require that an airport with a PFAS groundwater plume determine (1) how far the PFAS have spread from the original source; (2) whether anyone is pumping and using the groundwater; and (3) whether the groundwater is discharging into a stream, lake, or other surface water body. The speed of PFAS movement in groundwater is controlled by the specific type of PFAS and its adherence to soils as well as by the geology of the aquifer the groundwater is flowing through (for example, sandy aquifers have faster-moving groundwater than silty aquifers) and the slope of the water table (groundwater generally moves faster in steep areas than it does in flat areas). The length of PFAS plumes in groundwater can vary considerably—from just a few hundred feet to (in some cases) more than a mile long.

Surface water pathway. PFAS can enter the drainage system at an airport and eventually reach surface water bodies. This typically happens in one of two ways. In the first way, rainfall falls onto surfaces containing PFAS—such as on concrete or soils—where it is entrained in stormwater

Table 4-1. Interpretation of technical terms used in this section.

Term	Translation
Fate and transport	This is the process of a chemical moving through the environment and knowledge of what eventually happens to that chemical.
Unsaturated zone or vadose zone	This refers to the soils from the surface down to the water table. These soils have open pore spaces that are partially filled with water and are also partially filled with air.
Saturated zone or aquifer	This refers to a geologic formation in which all the open space, such as the pores between sand grains, are filled with water. This water is considered to be groundwater.
Water table	This is the depth interval at which the unsaturated zone turns into the saturated zone and is also the depth at which groundwater is located.
Sorption or adherence	This is a process by which chemicals adhere to certain soil types and/or organic matter in the soils. This adherence is not permanent but will slow the movement of any chemicals that are *sorbed* to the soils. This adherence occurs in both the unsaturated zone and the saturated zone (groundwater aquifers). The amount of adherence is controlled by the chemical structure of PFAS, the soil type, and the organic matter content of the soil.
Parts per billion	This is a term that is used to indicate the concentration of a particular chemical in groundwater or soil. A part per billion can be understood as being the same as one cent out of 10 million dollars. This is often designated in PFAS laboratory results as parts per billion (ppb). It can also be expressed as micrograms per liter (μg/L) in water samples or as micrograms per kilogram (μg/kg) in soils.
Parts per trillion	This is a term that is used to indicate the concentration of a particular chemical in groundwater or soil. A part per trillion can be compared to traveling six inches out of 93 million miles. This is often designated in PFAS laboratory results as ppt. It can also be referred to as nanograms per liter in water samples (ng/L) or nanograms per kilogram (ng/kg) in soils.

runoff that then flows to natural surface water (e.g., streams, rivers, lakes, or bays), often via airport storm sewers or drainage ditches. The second way PFAS can enter surface water is when a PFAS groundwater plume is shallow enough that the groundwater enters the surface water at a spring or other discharge point in a stream or lake.

Another factor that complicates PFAS fate and transport is the degradation of PFAS precursors that chemically transform to other types of PFAS (terminal PFAAs) with the help of naturally occurring bacteria in the soil or through chemical reactions. In general, many of these precursors are understood to have greater adherence (i.e., to be stickier) than the terminal PFAAs, thereby providing a source of the less adsorptive and faster-moving terminal PFAAs.

The movement of PFAS through the environment is complicated, and environmental scientists and engineers use a specialized language to describe how, when, and where this movement occurs. Table 4-1 describes some of this complex scientific language in more conventional terms.

4.2 How PFAS Are Different from and Similar to Typical Airport Releases

PFAS have some properties that are very different from the soil and groundwater pollutants that airport environmental managers typically deal with. Table 4-2 provides a high-level comparison of PFAS releases to soil and groundwater to releases of fuels and chlorinated solvents. Although some properties are similar, other characteristics of PFAS make addressing them a much different challenge for airport environmental managers than what they may be used to.

Table 4-2. Comparing other types of chemical releases to PFAS releases at airports.

Factor	Fuels	Chlorinated Solvents	PFAS
Volume used at airports	Can be large	Moderate to small	Small
When large-scale manufacturing began	1920s	1950s	1970s (AFFF)
Common types of releases (sources) at airports	Fuel infrastructure: leaking tanks, pipelines, spills	Machine shops, degreasers	Fire training, storage, emergency response sites
Common sources outside of airports	Gas stations	Industrial areas	Plating shops, wastewater sludge, landfills
Number of different chemicals measured during environmental investigations	4–10	5–10	40 or more
Typical concentration level allowed in drinking water	Low parts per billion	Low parts per billion	Low parts per trillion
Soil and groundwater remediation technologies that completely destroy the groundwater contaminants present in the ground	Yes	Yes	Under development
Typical groundwater remediation technologies used	Bioremediation, chemical oxidation, thermal treatment		Pump and treat, particulate injection, capping
Complete transformation to benign end products in soil and groundwater possible	Yes	Yes, but more slowly	No
Surface water impacts are a common concern	No	No	Yes

CHAPTER 5

PFAS Sampling and Analysis

5.1 PFAS Analytical Methods State of the Science

5.1.1 History of PFAS Analytical Methods

Within the last decade, there has been a dramatic increase in the methods available to analyze for PFAS and to understand their presence in the environment. Understanding the options, the strengths and limitations of each, and the rationale for selecting one method over another are of prime importance for airport environmental managers in their efforts to interpret analytical data.

Drinking water methods. Drinking water was the initial focus for method development by the U.S. EPA. Beginning in 2008, a drinking water method for the analysis of 14 PFAS—EPA Method 537—was published, widely accepted, and implemented. This method was updated to version 537.1 at the end of 2018, extending the analyte list to 18 compounds, primarily to add four short-chain PFAS (Shoemaker and Tettenhorst 2018).

The U.S. EPA stipulated that this method be calibrated to quantify branched isomers where analytical standards are available (U.S. EPA 2016). The conventional approach has been to report the sum of branched and linear isomers as a single concentration. A determination that separate branched and linear data would be useful in a forensics investigation would require a unique analytical method and nonstandard reporting from the laboratory.

TECHNICAL DETAIL

Branched and linear isomers describe two compounds with the same chemical formula and the same number (but different arrangement) of atoms.

At the end of 2019, the U.S. EPA published a second drinking water method: EPA Method 533 (U.S. EPA 2019b). This method was specifically generated to target additional short-chain PFAS (a total of 25 PFAS) that would be monitored for during the UCMR 5 (U.S. EPA 2019a). It is anticipated that the two U.S. EPA methods (537.1 and 533) would be used in concert, as this is the only way to capture the full range of target analytes proposed by the U.S. EPA. This monitoring requires awareness of the different requirements for each sample collected—one for EPA Method 537.1 and the other for EPA Method 533. These methods apply only to potable water and only provide data on the limited number of PFAS.

Methods for environmental matrices. As the need for assessing PFAS in multiple media increased, and in the absence of standard reference methods, commercial laboratories started testing for PFAS using in-house methods. These methods were classified as "user-defined methods" and are commonly referred to as "Method 537 modified." As of 2022, these methods are able to support a wide range of matrices—from routine environmental waters and soils to complex leachate, concrete, AFFF product formulations, and air. In addition, the achievable target analyte list has also been increasing, with up to 80 or more individual PFAS supported at the time of this writing.

Although these methods are modified and therefore do not represent a standardized procedure, the U.S. DOD and U.S. DOE address PFAS data quality assurance criteria in Table B-15

KEY POINT

It is common for a state agency or an individual program to require compliance with Table B-15 of the QSM for commercial and non-federal projects. The QSM is not an analytical method, but it does provide quality assurance procedures.

of their Quality Systems Manual (QSM), providing the industry with a reference against which to standardize user-defined PFAS methodology (U.S. DOD and U.S. DOE 2021). These requirements can be used when there is a need to measure quality assurance.

In August of 2021, the U.S. EPA, in partnership with the U.S. DOD, released Draft Method 1633 for PFAS in non-potable water, soil, and tissue matrices; the 2nd Draft Method 1633 was released in July of 2022 (U.S. EPA 2022). This method is modeled after preexisting user-defined methodology and is limited to capturing 40 PFAS. As part of the federal rule-making process, this method began a multi-lab validation effort, with participation from 10 laboratories at the beginning of 2022. Pending completion of the validation effort, the U.S. DOD and the U.S. EPA will review the data and finalize the method.

KEY POINT

When leveraging previously collected PFAS information for source differentiation efforts, it is important to understand which analytes and detection limits were used in past analyses.

KEY POINT

Site-specific investigations will need to be aware of potential state-specific analytical requirements. In general, the more analytes that can be quantified by the lab, the stronger the potential forensic power of the analysis will be.

5.1.2 Target Analyte List Importance

Different PFAS analytical methods have unique target analyte lists. See Table A-2 in Appendix A for a comparison of PFAS analytes across currently available analytical methods. The target analyte lists for PFAS continue to grow and change. These developments will play a key role in the evolution of forensic techniques to differentiate sources. For PFAS source differentiation, analytical methods with the greater number of PFAS analytes should be considered. This is further explained in Chapter 6.

States may mandate the inclusion of select PFAS in their analytical requirements. For example, as of this writing, Wisconsin uses a target list of 33 compounds (State of Wisconsin 2021), California has established a target list of 41 compounds (State of California 2020), and Michigan has a list of 31 compounds (State of Michigan 2023a).

5.1.3 Additional Enhanced Method Considerations

Although standard methods are available for the analysis of a few dozen PFAS, the quantitative analysis of other PFAS is difficult due to the sheer quantity of compounds and the lack of reference materials. Because of this, the full extent and distribution of PFAS precursors, intermediates, and terminal products in the environment has not been assessed. There are techniques available for capturing a total number (as opposed to speciated results for several thousand chemicals).

TECHNICAL DETAIL

The TOP assay attempts to reveal the total mass of unknown PFAS oxidizable precursors that may ultimately transform to terminal PFAAs, such as PFOA, PFHxA, and PFBA.

The TOP assay is a pretreatment technique (combined with the targeted analysis) that is used to estimate the portion of the total mass of unknown PFAS—specifically the oxidizable precursors that may ultimately transform into terminal PFAAs. The TOP assay specifically measures conversion of polyfluorinated precursors to a subset of the alkyl acids (carboxylic acids) and includes compounds like PFOA, PFHxA, and PFBA. Although this technique will not capture the full mass of unknown PFAS or all potential terminal end products, its real utility lies in capturing the unknowns present at a site that have the potential to transform into regulated PFAAs over time.

Other methods are available; however, they may have limited applicability to source differentiation investigations. For example, in order to capture more of the unknown mass of PFAS, combustion ion chromatography (CIC) is a relatively new technique being deployed as a proxy analysis for total PFAS. This technology can capture total organic fluorine with reporting limits in the single digits or in the lower ppb range. It is not uncommon to see a large difference between the conventional targeted LC-MS/MS analysis and the total organic fluorine results in environmental samples—meaning that there are potentially considerable amounts of unknown PFAS in those samples. These unknown PFAS are most likely to be precursor compounds that have the potential to transform in the environment into short-chain or stable perfluorinated chemicals. For source differentiation, differences in the total organofluorine measurements or in TOP assay results may indicate potentially different sources but would need to be verified with additional lines of evidence.

KEY POINT

Unknown PFAS are most likely to be precursor compounds that have the potential to degrade into stable terminal PFAAs. These are mostly captured using standard analytical methods.

Differences in the total organofluorine measurements or in TOP assay results may indicate different sources, but this would need to be verified with additional lines of evidence.

5.1.4 Non-Targeted Analyses

Because of the many individual PFAS within the family of chemicals, the ability to test for unknowns—otherwise referred to as non-targeted analysis—has become very attractive. A traditional laboratory analysis requires the laboratory to be specific about what is being looked for in a sample. This requires setting up a method and calibrating an instrument with reference materials in order to look for those specific constituents. The reference materials are manufactured versions of the compounds that are of interest in the environment. It is with these standards that the lab can identify the specific target compounds of concern in a sample and report a concentration.

With advanced technology, certain instruments and procedures no longer require reference material to detect specific compounds. However, this methodology cannot provide accurate quantification of the detected compound—only detection and relative abundance. In this mode, the instrument scans for all chemicals and the complexity lie in sorting through the data to identify PFAS and which of them appear to be more abundant than others.

Non-targeted analysis presents opportunities across a wide range of PFAS-related applications, ranging from discovery of additional analytes of interest to elucidation of environmental transformation pathways to unique characterization of product formulations. Multiple academic institutions and the U.S. EPA's Office of Research and Development have made notable advancements in terms of discovery of next generation PFAS and characterization of product formulations. Refer to Chapter 6 for additional discussion.

5.1.5 PFAS Analytical Toolbox

With the current state of the science there is no silver bullet for acquiring all of the data needed to support a comprehensive PFAS source differentiation effort, nor is there a one-size-fits-all approach for every site. The toolbox that is currently available includes a variety of analytical options that continue to evolve.

The strengths and weaknesses of the various analytical techniques shown in Figure 5-1 demonstrate the ways that they can be employed, either in concert or in series. It is of paramount importance that airports partner with consultants and laboratories to establish site-specific data objectives and to craft an analytical strategy that will result in defensible and usable data at each step in the process.

Table 5-1 summarizes the final methods that are currently available for aqueous and solid matrices and provides a high-level summary of their respective strengths and weaknesses. Importantly, analytical methods are continuing to evolve and improve; several draft methods are in development.

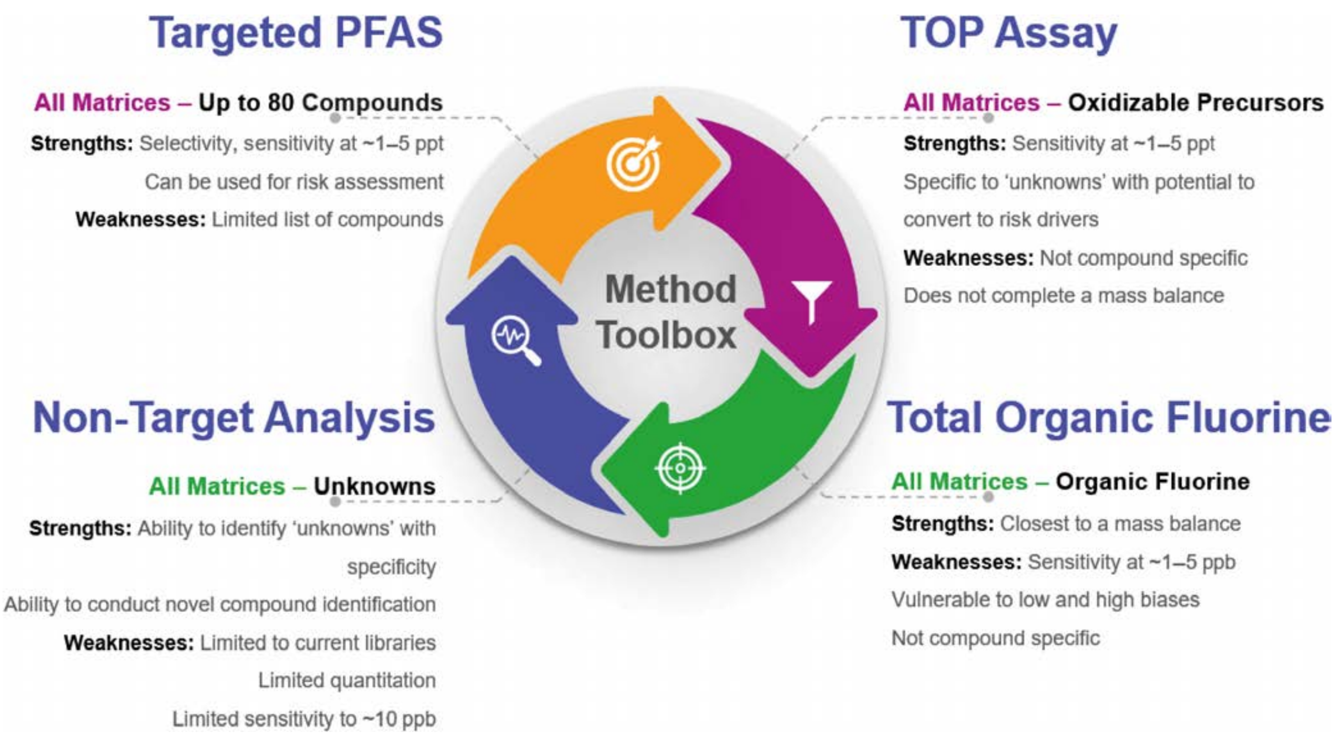


Figure 5-1. Analytical method toolbox.

Table 5-1. Current final analytical methods for PFAS in water, soil, sediment, and biosolids.

Method	Date Published	Matrix	Strengths	Limitations
Method 537.1	November 2018	Potable water	· Promulgated U.S. EPA method	· Drinking water only · Does not use isotope dilution · 18 PFAS only
Method 533	December 2019	Potable water	· Promulgated U.S. EPA method · Isotope dilution	· Targets some short-chain PFAS · 25 PFAS only
ASTM D7979	February 2015	Potable and non-potable water	· ASTM established method · Isotope dilution allowable	· May not use isotope dilution · Largely sampling for saturated PFAS
Method 8327	July 2021	Non-potable water, soil, sediment, biosolids, other	· None	· Will not meet U.S. DOD requirements and is not typically recommended
In-house methods (537 modified)	Not applicable	Potable and non-potable water, soil, sediment, other	· Performance based · May use isotope dilution	· Not an established method · May not use isotope dilution · Can be applicable to other matrices with caution · Requires careful quality assurance
ISO* 25101	March 2009	Potable and non-potable water	· Established method · Isotope dilution	· PFOA and PFOS only
ASTM D7968	2014	Soil	· ASTM established method · Isotope dilution allowable, but not required	· Isotope dilution is only an option

*ISO = International Organization for Standardization

5.2 PFAS Sampling Protocols and Best Practices

The widespread use and distribution of PFAS in industrial and consumer products and target PFAS detection limits in the low ppt range create a heightened concern for potential for sample contamination. A complicating factor is the lack of published U.S. EPA collection methods or sample collection guidelines for addressing PFAS in various media (Denly et al. 2019).

A common thread throughout many PFAS sampling documents is to completely prohibit the use of PFAS-containing products on a project site. Given that these conservative precautionary principles may unnecessarily restrict field materials, equipment, or procedures that present a low risk of biasing sample results, it is valuable to know which guidelines are based on scientific principles and which may include misinformation or unsubstantiated information. The National Ground Water Association is currently finalizing a document providing this analysis. Furthermore—as concluded by Bartlett and Davis (2018) and Rodowa et al. (2020)—if standard sample collection protocols are followed, many items should never contact the sample media. Therefore, a more conservative approach should be reserved for times when sampling equipment and other items have the potential to come in contact with the sample media.

TECHNICAL DETAIL

Ensuring that sample contamination has not occurred in the field is primarily done through the use of equipment blanks and field reagent blanks (FRBs). Equipment blanks measure potential contamination from the equipment used to collect the samples. Field reagent blanks are used to measure PFAS that may have been on a person or in the sampling environment and that could have contaminated the primary samples. An FRB also serves as a trip blank, which is used to measure the potential for contamination during transit.

In lieu of federal guidelines, several states and organizations have developed state-specific protocols, ranging from simple annotated checklists to comprehensive sampling informational documents. The State of Michigan's Department of Environment, Great Lakes, and Energy (EGLE) published a PFAS Sampling Guide (EGLE 2018); it has come to be used widely across the United States. Unlike most of the guidelines available, which consist of generic precautions or simple checklists of prohibited and acceptable items to consider during sampling, this document provides a step-by-step tutorial that is specific to collecting certain media. Until such a time that a more current and comprehensive guiding document is validated and published, the Michigan state guidelines are considered a valuable resource when evaluating sampling protocols for source differentiation.

KEY POINT

Until such time that a comprehensive guiding document is validated and published, state sampling guidelines such as those provided by the State of Michigan (EGLE 2018) remain a valuable resource for sampling protocols.

PFAS tend to adsorb to the surfaces they come in contact with. Therefore, sample collection containers are of particular importance. There are a variety of acceptable PFAS sampling bottle types that are referenced under different methods, programs, or procedures. It is important—whichever container type is used—that the bottles come from the laboratory performing the analysis or that the vendor has demonstrated that the bottles provided are indeed PFAS-free. This is also true for the deionized water that the laboratory provides for collecting field quality control.

KEY POINT

For all PFAS sampling efforts, quality control samples are critical and should be confirmed to be PFAS-free.

Through all of this uncertainty and variability, it is critical to collect meaningful quality control samples to provide a high degree of confidence in the protocols and in the data interpretation, regardless of the protocols selected.

TECHNICAL DETAIL

It is important to recognize that the claim of "PFAS-free" for any given product or process is directly dependent on how the materials were exposed to the sample media, the analytes that were tested for, and the detection limits that were achieved.

5.3 Potential Interferences

Environmental matrices can be complex. At this time, commercial laboratories have not encountered discrete analytical interferences attributable to fuels, solvents, and other chemicals broadly used at airports that would interfere with the reliable detection of PFAS. These

TECHNICAL DETAIL

Discrete analytical interferences are chemicals that specifically interfere with the identification and quantification of another compound due to similarity in chemical structures.

products do not typically have a chemical structure that would create a discrete interference for PFAS analytes.

There are, however, bulk interferences that are fairly common, depending on the matrix and the type of site. Samples with high levels of any organic contaminants or with high salinity may require dilutions to protect the instrument detector. Where interferences cannot be resolved, the impact or lack of impact on the data quality is narrated in the laboratory report.

CHAPTER 6

PFAS Source Screening and Advanced Forensics

6.1 Source Identification Screening and Advanced Forensics

Identifying potential sources of relevant PFAS at a particular site using analytical data relies on collecting and interpreting information on the type and distribution of PFAS that may have been used or that have been detected. PFAS are typically present as mixtures of multiple compounds, both in the original sources and in environmental samples. As a result, the development of various quantitative and statistical approaches for evaluating compositional data can provide significant value for source differentiation. These data must then be placed into context with the desktop exercise data (i.e., the site's environmental setting), including the proximity of other users of PFAS-containing products and the potential discharges associated with their operations, as discussed in Chapter 3.

Due to the complexity of PFAS data (including the potential overlap of specific PFAS present in different sources) as well the relevant fate and transport processes, forensic studies require a lines-of-evidence approach. However, this same complexity can also provide significant benefits when evaluating sources. For example, the number of PFAS that may be present and quantifiable (especially using high resolution techniques), along with the differences in how these compounds behave in the environment, can result in a highly robust dataset and support the development of chemical signatures for different PFAS products to help differentiate between sources.

Depending on the quantity and quality of the data, different forensic approaches can be applied to help identify possible sources, including screening level and high resolution advanced approaches. The two columns in Table 6-1 provide a side-by-side comparison of screening level and advanced forensic approaches for PFAS source differentiation.

6.2 Overview of Common PFAS Source Identification Screening Methods

The data generated during PFAS site characterization or source differentiation efforts can be quite complex due to the presence of many different PFAS in a sample. This can create challenges for interpreting the data. Because of this complexity, most screening level approaches attempt to take a large amount of data and simplify it in order to aid interpretation. All methods should be used in combination with additional lines of evidence, as they are not likely to be conclusive on their own.

Common approaches that may offer insights for a site-specific evaluation include the following:

- **Concentration ratios.** One or more concentration ratios between two different compounds can be used as a simple screening technique. For example, PFHxS to PFOS ratios within a

Table 6-1. Comparison of approaches for PFAS source differentiation.

Screening Level Approaches	Higher Resolution or Advanced Forensic Approaches
A screening level forensic approach typically relies on available information about historical and current site operations and characterization data obtained using standard analytical methods for PFAS in environmental samples. It is likely to be most applicable in the following situations: (1) sites for which PFAS data are available and there is a need to evaluate the likely source or sources (2) sites for which little or no PFAS data are available and there is a desire to implement a preliminary site assessment to deliver useful data for potential subsequent screening level forensics A screening level evaluation could include (1) PFAS detection frequency assessments to establish which compounds might be most important, (2) evaluation of the relative magnitude of these detections across a particular site to establish the locations of likely sources, and (3) various methods for visualizing PFAS composition in order to better understand how this composition changes across the site.	A high resolution forensic approach is expected to rely on advanced analytical techniques that include (1) non-target compounds that are quantified using proprietary methods developed by specialty commercial or academic research labs, and (2) methods that attempt to quantify the total PFAS in a sample (e.g., TOP assay). These analytical methods are discussed in more detail in Chapter 5. This approach would be most applicable in cases where a screening level approach yields inconclusive findings or further lines of evidence are desired. The exact methodology may differ depending on the supplier of the services, but the overall approach involves expanding the number of analytes that can be identified and then comparing them to a library of signatures of different PFAS-containing products or sources.

specific range have been used as an indicator of an AFFF source (McGuire et al. 2014), and PFHxS to PFOA ratios have proven useful for differentiating between AFFF and manufacturing sources of PFAS in drinking water (Guelfo and Adamson 2018). Similarly, ratios of the different isomers of an individual compound may prove useful for identifying contributions from specific products or processes. Ratios are easy to calculate, but interpretation of the data needs to account for processes like transformation and partitioning, which might affect the individual compounds differently.

- **Isomer ratios.** Isomers are compounds that share the same chemical formula (i.e., consisting of the same number of carbons, fluorines, and other components) but that have slightly different chemical structures (see Section 1.3). Individual PFAS may be present in different isomer forms, and the relative abundance of different isomers within a sample can be used to help infer the source of the PFAS (Charbonnet et al. 2021).

  The presence of branched isomers in a sample can be measured using standard methods that are employed by commercial analytical labs. If present, these branched isomers indicate that the PFAS originated from the specific ECF manufacturing process, and this helps to establish that products associated with this process are contributing to the PFAS measured in that sample. The percentage of branched isomers in ECF-based products falls within a relatively narrow range (ITRC 2022). If the percentage of branched isomers in a sample is below this range, then it is a potential line of evidence that PFAS-containing products generated through telomer-based manufacturing processes are also present. This is because the telomerization process is expected to generate only linear isomers, so a sample containing PFAS from these products will naturally lower the percentage of branched isomers in cases where mixed sources are present. If a sample contains only linear isomers, then this would suggest that the PFAS source consists only of telomer-based products. Modern AFFF formulations

TECHNICAL DETAIL

Branched and linear isomers describe two compounds with the same chemical formula and same number but different arrangement of atoms.

KEY POINT

The two different manufacturing processes for PFAS—ECF and telomerization—result either in a mixture of branched and linear PFAS (ECF) or purely linear PFAS isomers. This information might be useful as a line of evidence to help distinguish between sources.

contain PFAS manufactured using the telomerization process. Older AFFF formulations may contain PFAS manufactured using either ECF manufacturing or telomerization. In the United States, production of AFFF formulations using ECF manufacturing was phased out in the early 2000s.

Another important consideration is the fact that the branched isomer of a particular PFAS (e.g., PFOS) will travel slightly faster in groundwater than the linear isomer of the same compound due to differences in how the isomers interact with soils. This could lead to increases in the branched isomer percentage in samples collected downgradient of where the PFAS was released (Nickerson et al. 2020). In these cases, the branched isomer percentage in downgradient samples would be higher than what was in the original released products. The potential changes in the isomer profile over time and space should be carefully considered if isomer data are being used to support source differentiation efforts.

- **Pie charts and other data visualization techniques.** These are simple graphics that aim to show the relative contribution of multiple compounds to the overall PFAS concentration on the same plot. They can help airports to visualize compositional differences between samples, and any resulting groupings can be evaluated further to determine whether there are reasons to expect that they represent chemical fingerprints of different sources. These also may be useful in showing mixing between PFAS sources or shifts in source signatures along a transport pathway (e.g., while migrating in groundwater). Pie charts and bar charts are common approaches and are familiar to many users. Ternary and radial diagrams are also frequently used for visualizing PFAS composition data but may require users to invest more time in order to understand and interpret them.
- **Principal component analysis (PCA) and hierarchical cluster analysis (HCA).** These statistical methods are used to transform data associated with many variables (e.g., PFAS measured within a sample) to graphically represent differences among the members of the dataset. PCA essentially constructs new variables that represent the most important components of the underlying data and then plots the data (usually in two dimensions) for each sample based on those variables. This organizes the data so that it is easier for analysts to see if there are distinct clusters of samples (each of which may be associated with different sources or releases) and which sets of samples may overlap (and are thus not clearly distinguishable). HCA uses a different approach to clustering samples with similar characteristics and shows these relationships in a dendrogram. Both PCA and HCA have been applied extensively for PFAS forensics (Zhang et al. 2019; Guelfo and Adamson 2018; Feng et al. 2020). However, these methods require a relatively high level of statistical expertise, both in terms of performing the analyses and communicating the results. As a result, they may not be applicable for all users.

KEY POINT

Multiple methods should be used at a particular site. This is important because source differentiation relies on a lines-of-evidence approach. Employing multiple data evaluation and visualization methods is highly recommended to avoid overinterpretation of site data that might occur if only one method is used.

6.3 PFAS Source Screening Level Analysis

To support the overall goal of improved guidelines for PFAS source differentiation, a number of screening approaches were applied to a comprehensive PFAS database compiled from various public and proprietary data repositories. This novel project database includes over 800,000 PFAS analytical data that contain information on PFAS composition from samples that are representative of multiple PFAS sources. These data therefore provide a reasonable basis for understanding the range of PFAS that might be associated with a particular source. The results of this research are discussed further in this section, with graphical representations that can help airports to compare available data to those compositional generalities identified during this research. Limitations of the preliminary screening approach are discussed in Section 6.3.3.

A high-level compositional analysis comparing the percentage makeup of certain broad PFAS families has been incorporated into the downloadable PFAS source differentiation tool, which allows the user to enter site-specific PFAS sampling information and compare those results to the screening level output developed through this research. Chapter 7 discusses the tool in more detail. Additional data visualization not included in the downloadable tool are given in Section 6.3.2 and provide further options for comparing site-specific data to the screening level source category elucidated by the compiled database.

6.3.1 PFAS Source Screening Methods

KEY POINT

The novel comprehensive database compiled for the research conducted as part of this guide provides the opportunity to examine and extract PFAS data from the past ten years in order to understand how screening level characteristics for AFFF and non-AFFF PFAS might be developed and leveraged.

The research presented in this guide utilized data visualizations and statistical analyses of a large PFAS database comprised of many different environmental sources to identify data relationships associated with different potential PFAS sources. These data supported the development of screening level data visualizations for PFAS source differentiation efforts. These visualizations may help airports to compare available PFAS data and generate lines of evidence to support or refute potential source contribution.

A general description of how these data were collected and analyzed is presented in this section along with the results, key findings, and limitations of applied screening methods.

Data Collection

Datasets from various state and federal sources were identified and compiled. Data sources included the following:

- Eurofins Analytical Laboratory data for U.S. DOD facilities (McKnight 2022)
- California's Groundwater Ambient Monitoring and Assessment Program data accessible through the state's GeoTracker website (State of California 2022)
- Colorado Department of Public Health Water System PFAS testing data (State of Colorado 2020)
- Data compiled from publicly available state and federal PFAS databases, including
  - Maine (State of Maine 2022),
  - Michigan (State of Michigan 2021),
  - Minnesota (MPCA 2022a),
  - New York (Fisher and Phillips 2019),
  - Pennsylvania (State of Pennsylvania 2022),
  - Washington (Lakewood Water District 2021), and
  - U.S. EPA (National Water Quality Monitoring Council 2022).

In addition, state databases from North Carolina, Florida, and Wisconsin were evaluated but were not included in the overall comprehensive dataset because of data limitations (such as non-compatible data formats and lack of spatial data). In total, over 800,000 usable PFAS data were compiled from these sources.

Data Evaluation

Multiple approaches were used to evaluate the hundreds of thousands of PFAS analytical results from these datasets and to help establish whether statistically significant compositional ratios, clusters, or other source screening characteristics are present. The methods used during this evaluation were tailored so that they were appropriate for the different project datasets. For example, the U.S. DOD analytical test results are essentially "blind" data, meaning that location information and other pertinent sample identification information have been redacted. In this case, the only differentiator is that the dataset is known to be associated with airport facilities and U.S. DOD facilities; significant PFAS detections are assumed to be from an AFFF release.

In contrast, the state PFAS data have more robust geographic information and are often identified by a suspected source or industry type (e.g., remediation site, landfill, or airport). The data were categorized based on source information provided using the following descriptors: AFFF (airport or U.S. DOD), landfill, wastewater treatment plant, chrome plating facility, drinking water, industrial, and other cleanup site. Consequently, the evaluation of these datasets used exploratory methods but also benefited from a greater ability to sort the data in order to make inferences. For example, differences in the PFAS composition of samples from one set of sites (categorized by industry type) can be compared to those from other sets of sites to better understand whether the presence or absence and the magnitude of specific constituents are associated with expected sources.

As a result, the evaluation of these data focused on exploratory methods to see whether there were any underlying patterns in the PFAS data. This included descriptive summary statistics that provided information on the relative detection frequency and concentration ranges for particular compounds that could be considered representative of AFFF and non-AFFF sources. Compositional analysis can also help to illustrate whether subsets of samples form distinct clusters, although the reasons that sample sets cluster may be harder to distinguish due to the nature of this dataset. Although the PFAS sources for the facility types represented in this dataset would be expected to overlap, any differences that may be observed between these categories could provide forensic value.

The key steps in the evaluation of these datasets were exploratory analyses to identify possible characteristics (profiles) that help to distinguish PFAS in environmental samples collected from airports as well as differences between AFFF PFAS profiles and PFAS profiles obtained from other types of sites. PFAS data from an individual source may not always fit the assigned source category (for example, an industrial site that was impacted by AFFF use). Individual outliers did not substantially impact source category results because of the large volume of data collected and analyzed.

TECHNICAL DETAIL

Individual source data used in this research may not always align with the assigned source category. However, outliers did not substantially impact source category results due to the volume of data collected and analyzed.

The following key metrics provide a simple, screening level approach for building these PFAS profiles:

- **Frequency of detection.** This metric provides insight on the relative prevalence of individual PFAS within each dataset. For example, compounds that are frequently detected in samples from one site type but not from others help to distinguish which PFAS are most likely associated with different sources. The absence (or low frequency of detection) of specific PFAS in samples from one site type can also be used in a similar manner.
- **Concentration distribution.** These data help to establish the relative magnitude of individual PFAS found in environmental samples from the different sites. The median concentration of individual PFAS in samples with detection are used in this evaluation. These data provide insight on the relative contribution of different PFAS within a particular site type as well as the relative magnitude of PFAS associated with different sources.
- **Compositional data and ratios.** These data and ratios show the general distribution of PFAS within sample groupings. This includes the percentage of total PFAS associated with PFCAs, perfluoroalkyl sulfonic acids (PFSAs), and non-PFAAs in aggregated data. Use of this metric also includes quantifying the concentration ratios for frequently detected PFAS to understand whether there are general differences between possible PFAS sources.

These metrics can then be shown in data visualizations that allow comparison across different site types.

Several other methods were used in preliminary evaluations of the data, including PCA and HCA, but the results of the evaluations are not shown due to the complexity in presenting and describing those results. The focus of this guide is to use methods that are accessible to airports and that generate results that are relatively easy to communicate to other parties. This information is designed to inform airports that are making initial screening level source determinations using standard PFAS analytical methods or determining whether more robust source identification and forensic analysis is warranted.

6.3.2 PFAS Source Screening Analysis Discussion

The results of the research analyses are presented in five different types of data visualization of PFAS source categories. These five types, summarized in this section with a brief discussion of the results, include the following:

- PFAS compositional distribution pie charts
- PFAS concentration distribution box plots
- PFAS median concentration and detection frequency heat maps
- PFAS median concentration and detection frequency cross-plots
- PFAS median log concentration ratio dot and radial plots

These data visualizations are provided in this guide in order to give airports an opportunity to compare available site-specific data with the results from the PFAS source category analyses. Depending on the amount of data available, airports may find one type of visualization for their dataset more valuable or applicable than the others. For example, median concentration and detection frequency comparisons would require a sufficient amount of data to have statistical validity, whereas the compositional distribution can potentially be applied to a single set of PFAS analytical results.

For this reason, the compositional distribution pie charts summarized in this section have been included in the downloadable PFAS source differentiation tool associated with this research (see Chapter 7). This allows users of the tool to input site-specific data; the resulting pie charts can be compared with broad source categories developed through this research to help build lines of evidence toward source differentiation.

TECHNICAL DETAIL

The value of analytical screening tools may vary depending on the amount of data available. Median concentration and frequency of detection require larger amounts of data to allow for meaningful comparisons, whereas compositional distributions can potentially have value using a single sampling event.

Compositional Distribution

The compositional distribution analysis is represented through simple pie charts; this can be an easy and effective initial PFAS source differentiation screening tool. The visualizations in Figure 6-1 show the distribution across three broad PFAS families for the various source categories. The data in Figure 6-1 represent the median percentage of PFSAs and PFCAs in all samples in which PFAS were detected. The other percentage represents the remaining PFAS that were not accounted for in the PFSA and PFCA percentages. This screening tool can be applied to a single set of data, however, the greater number of samples and correspondingly large volume of PFAS results will increase confidence in the trends observed. **Importantly, compositional changes may occur over time and over distance from the same source; therefore, this line of evidence must be interpreted carefully.** For example, an AFFF source may initially appear similar to the airport compositional distribution but could over time begin to appear more like WWTP or landfills as a portion of PFAS degrade into carboxylic terminal groups, thus increasing the

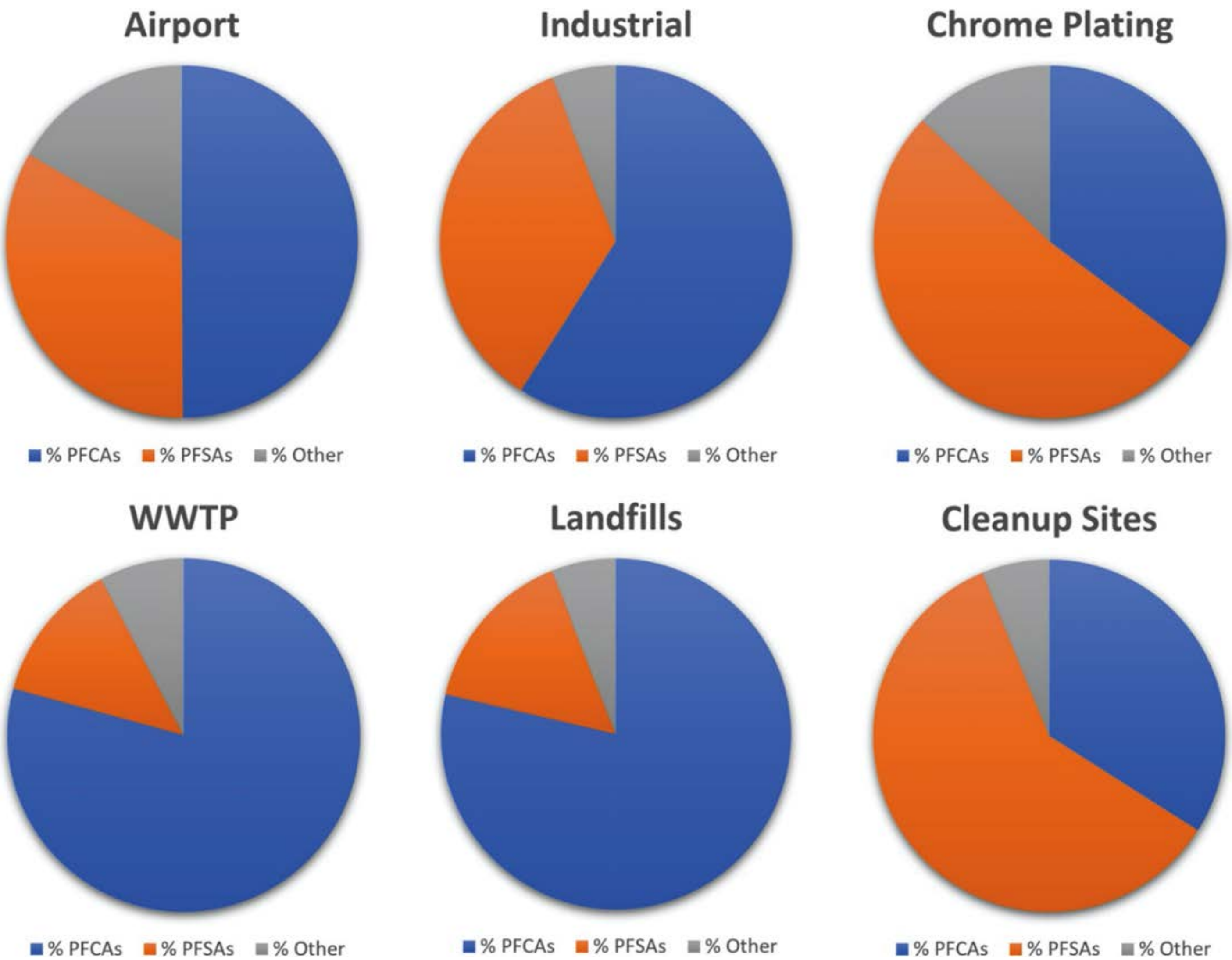


Figure 6-1. PFAS compositional distribution.

composition of PFCAs in the overall sample. These are tools to aid in building a lines-of-evidence approach but should not be considered definitive from a source differentiation perspective.

Concentration Distribution

Another data visualization developed through the research that can be a helpful initial source screening option is PFAS concentration distributions. Figures 6-2 through 6-7 show a series of box plots of the PFAS concentration distributions for six of the primary source categories in the state and federal database. These box plots show the concentration distribution of aggregated data from the various source categories. Each box plot shows the median, 25th percentile, 75th percentile, minimum, and maximum concentrations for detections of individual PFAS. Compounds with no data represented on the figures are PFAS that were non-detect or not analyzed in the dataset.

See Table A-1 in Appendix A for a list of the PFAS acronyms and their corresponding chemical names used within the various data visualizations.

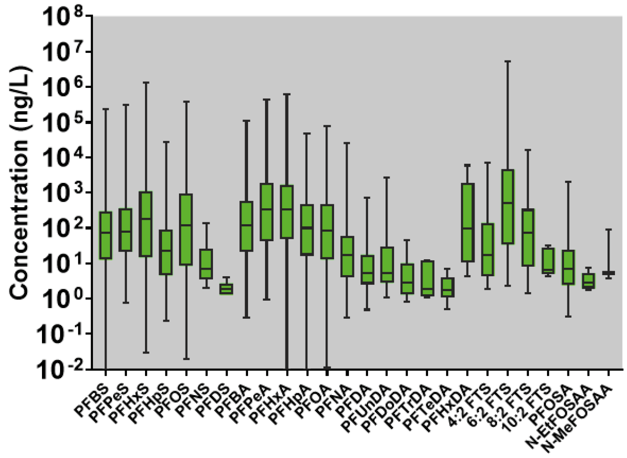


Figure 6-2. Airport category PFAS concentrations.

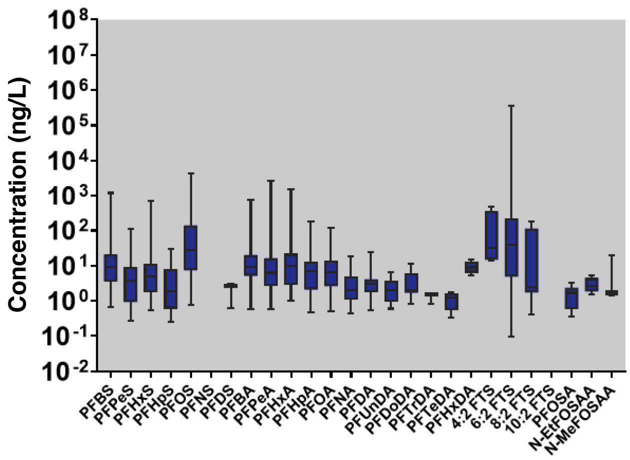


Figure 6-3. Chrome plating category PFAS concentrations.

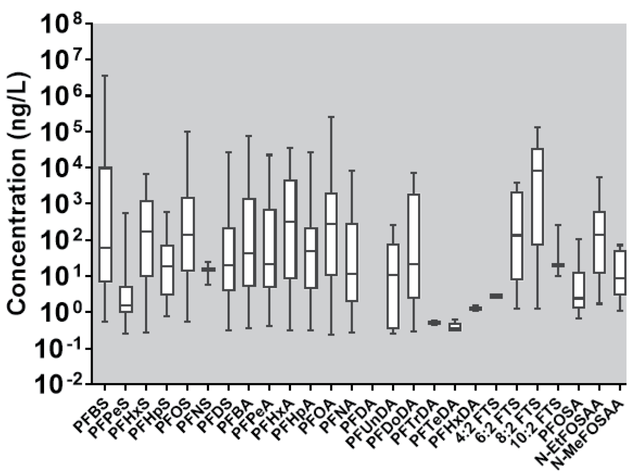


Figure 6-4. Industrial category PFAS concentrations.

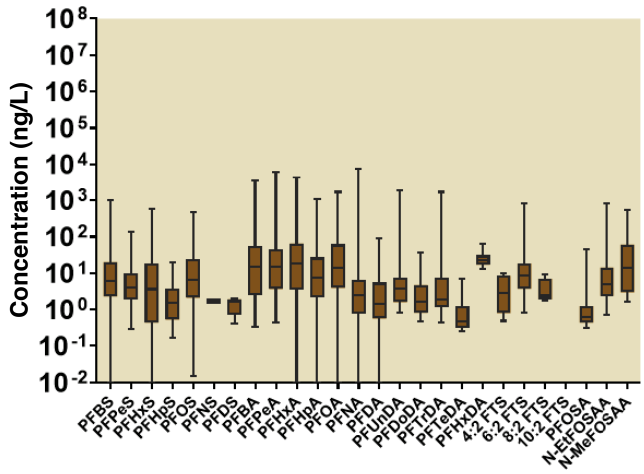


Figure 6-5. Landfill category PFAS concentrations.

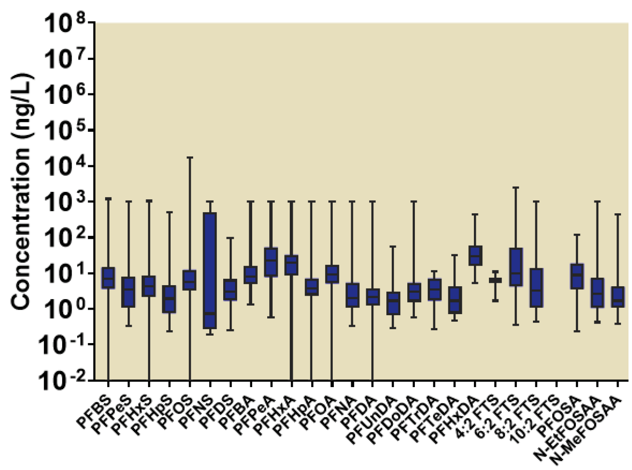


Figure 6-6. Wastewater category PFAS concentrations.

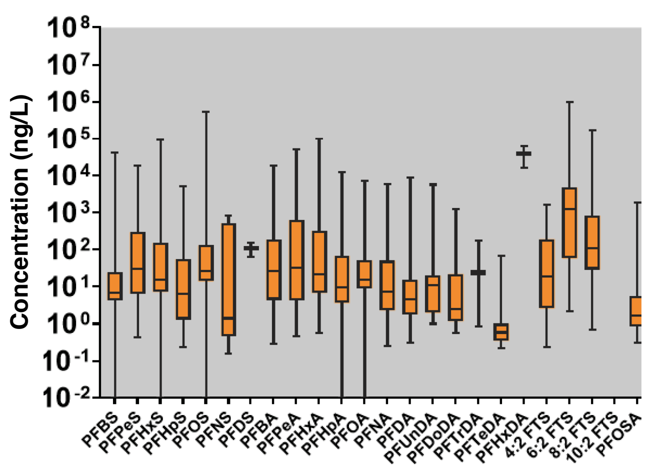


Figure 6-7. Other cleanup category PFAS concentrations.

The individual PFAS are placed in the same order on each plot for easier visualization, with the understanding that (1) the analyte list differs slightly for each source category and (2) data for some analytes are not shown because they were either not detected or not reported.

The primary utility of these plots is to reflect the relative magnitude of concentrations associated with each site type, as well as the relative magnitude of concentrations associated with individual PFAS within these sites (when detected). For example, the concentrations at airport sites are routinely higher than those at most other sites, with the exception of some of the “other” cleanup sites. This can help bound the expected contributions from nonairport sites, and it provides a basic understanding of how likely it is that the PFAS in samples with relatively high concentrations could be solely or primarily attributed to a nonairport source. Note that these plots only show the compound-specific concentration distributions for samples in which the compounds were detected.

A box plot of the PFAS concentration distributions from the Eurofins database is shown in Figure 6-8. This includes samples that were reportedly collected from U.S. DOD facilities and airports. Given that the primary consideration at these types of sites is PFAS releases due to AFFF use, similarities with the airport site data from the state and federal database would be expected. A comparison of Figure 6-8 with Figure 6-2 confirms that the two datasets exhibit similar overall patterns.

Notable differences include (1) that the Eurofins U.S. DOD/airport data show lower median concentrations of most PFAS that are C8 or less; and (2) that the Eurofins U.S. DOD/airport data exhibit higher maximum concentrations of many compounds, including PFOS, PFHxS, PFOA, and most PFCAs. This may reflect differences in the site investigation strategies for the sites in the Eurofins database (e.g., U.S. DOD sites that may be further along in the source characterization process).

Median Concentration and Detection Frequency

A series of other simple data visualizations were also developed using the state and federal database, with the goal of further comparing the PFAS compositions across different source categories. For example, Figure 6-9 provides heat maps for numerous PFAS and depict the frequency of detection and median concentration for the source categories. These are helpful screening level tools for establishing which compounds tend to be particularly relevant for different types

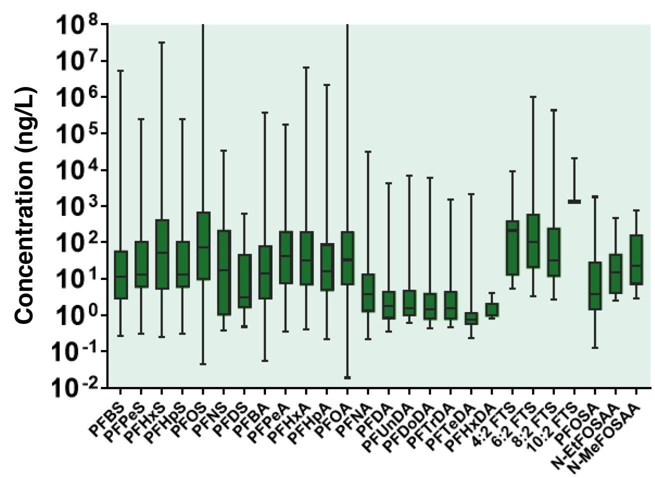


Figure 6-8. PFAS concentrations—Eurofins U.S. DOD/airport category.

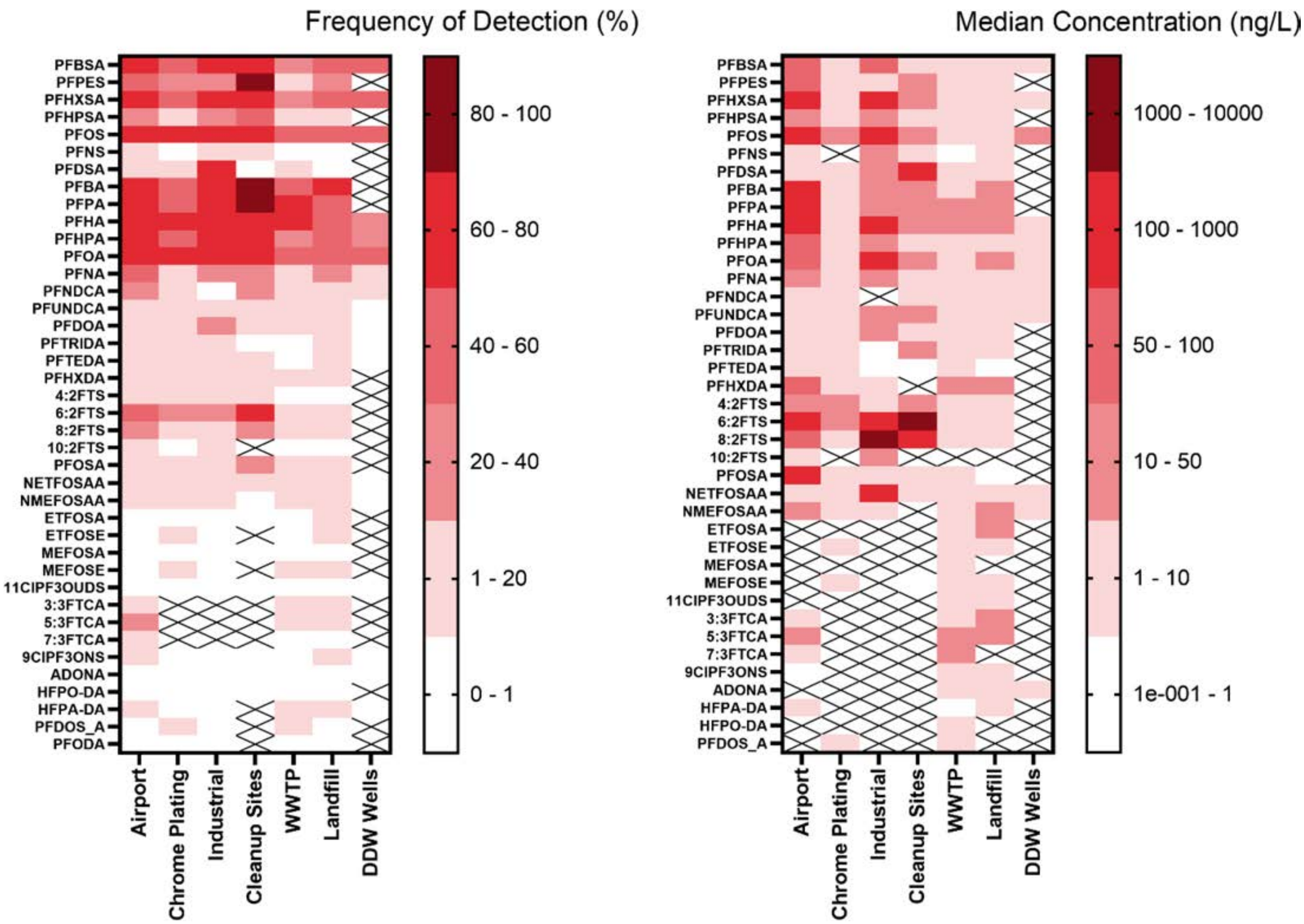


Figure 6-9. Heat maps for PFAS source categories.

of sources within these datasets. In the left panel of Figure 6-9 (Frequency of Detection), PFAS that were not analyzed for a particular source type are designated with an X. In the right panel (Median Concentration), PFAS that were not analyzed or not detected are designated with an X. Not all PFAS were analyzed in each sample.

The detection frequency and median concentration dataset for individual compounds have also been combined into simple cross-plots that serve as a representative PFAS signature for each source category (see Figures 6-10 through 6-16). Each symbol corresponds to one of the individual PFAS that have been detected in one or more samples. Compounds that fall into the shaded area in the upper right of each plot represent PFAS that are detected relatively frequently and at relatively high concentrations. Each symbol shows the frequency of detection for an individual PFAS (*y*-axis) relative to the median concentration in all samples with detections (*x*-axis). Not all PFAS were analyzed in each sample. Not shown are PFAS that were not detected in any sample.

The heat maps and cross-plots showing frequency of detection and median concentration require more than one set of sample data to generate meaningful information. The larger the volume of data available, the higher the potential benefit will be in comparing site-specific data to the data visualizations shown in Figures 6-9 through 6-16.

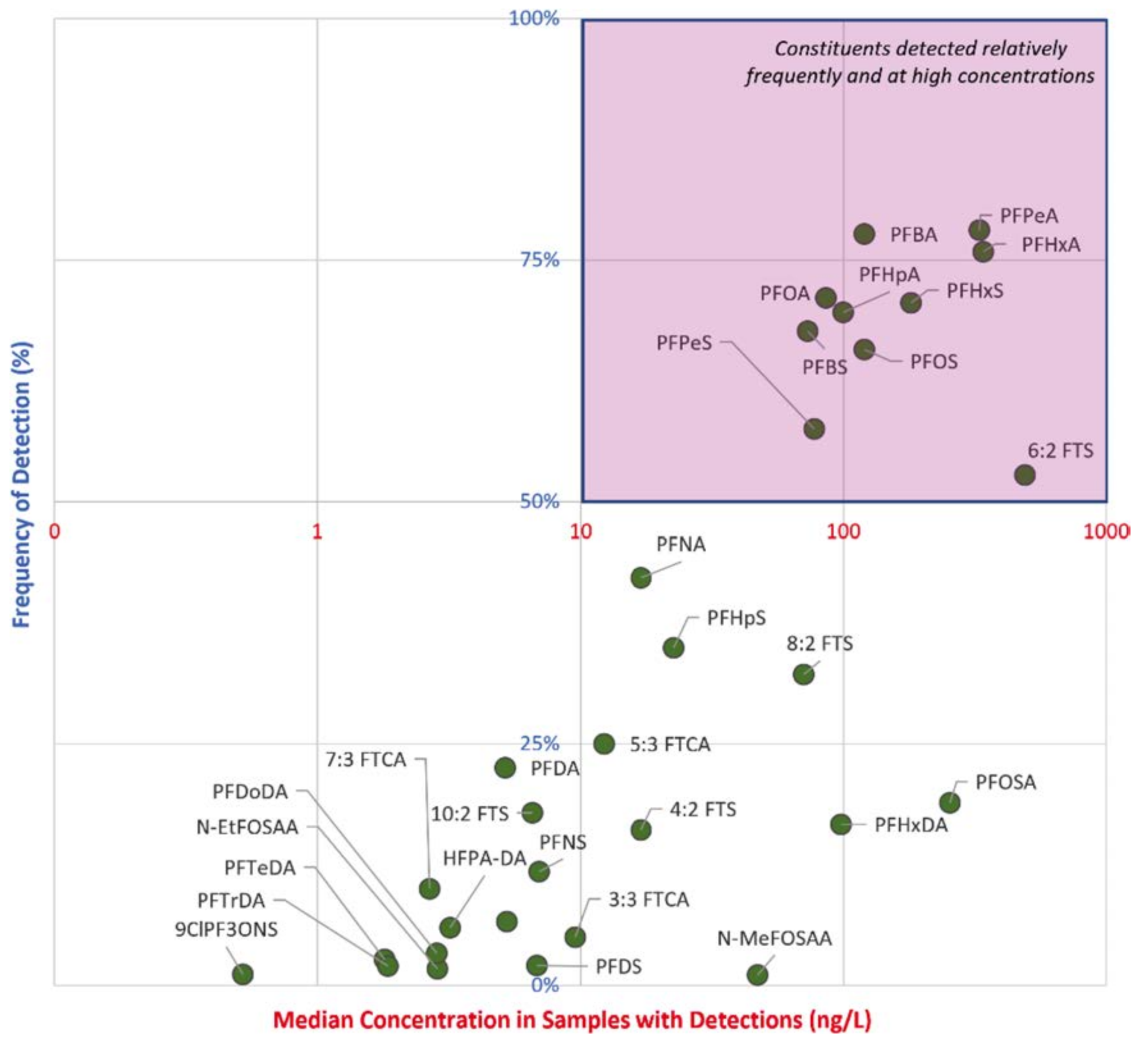


Figure 6-10. Airport category detection frequency and median concentration.

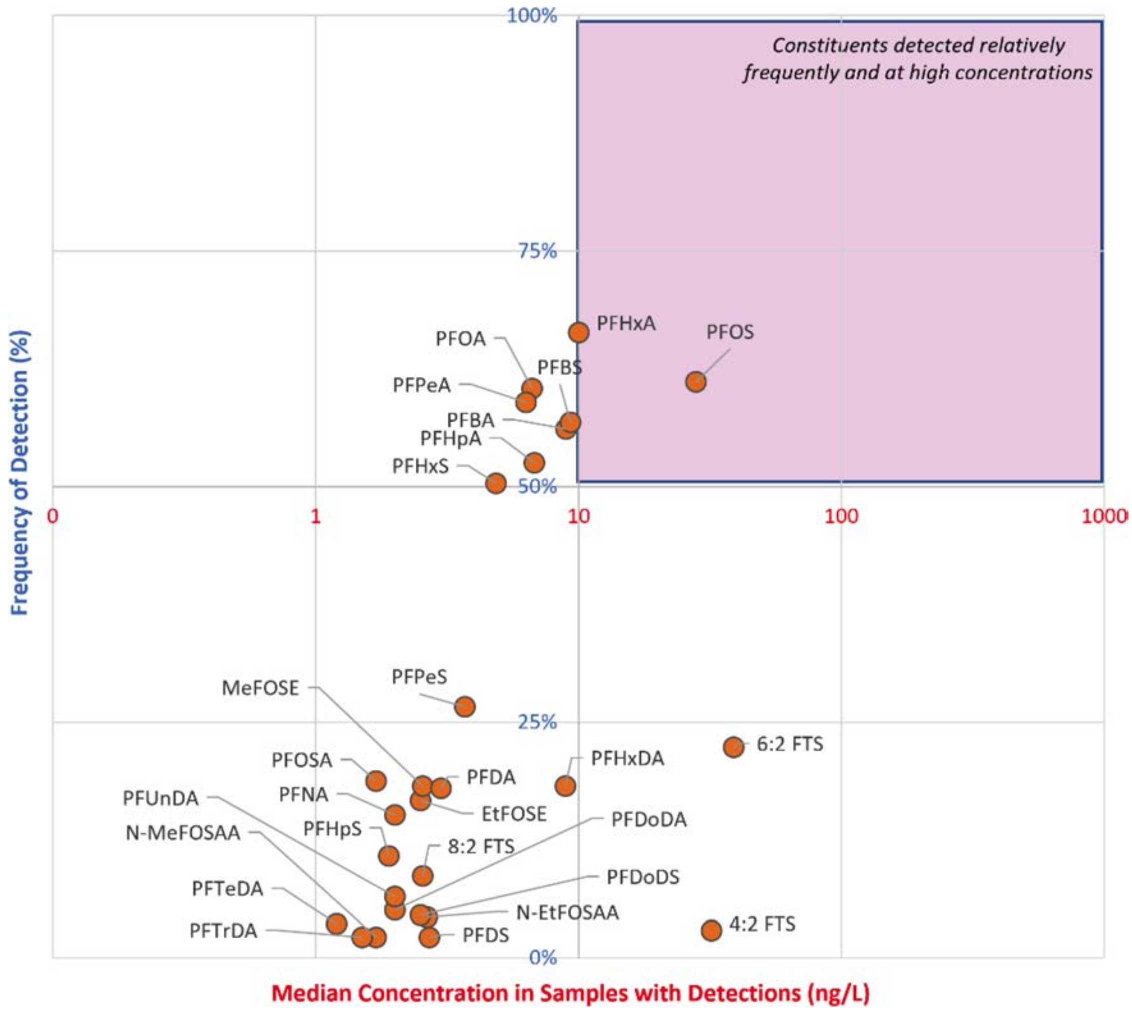


Figure 6-11. Chrome plating category detection frequency and median concentration.

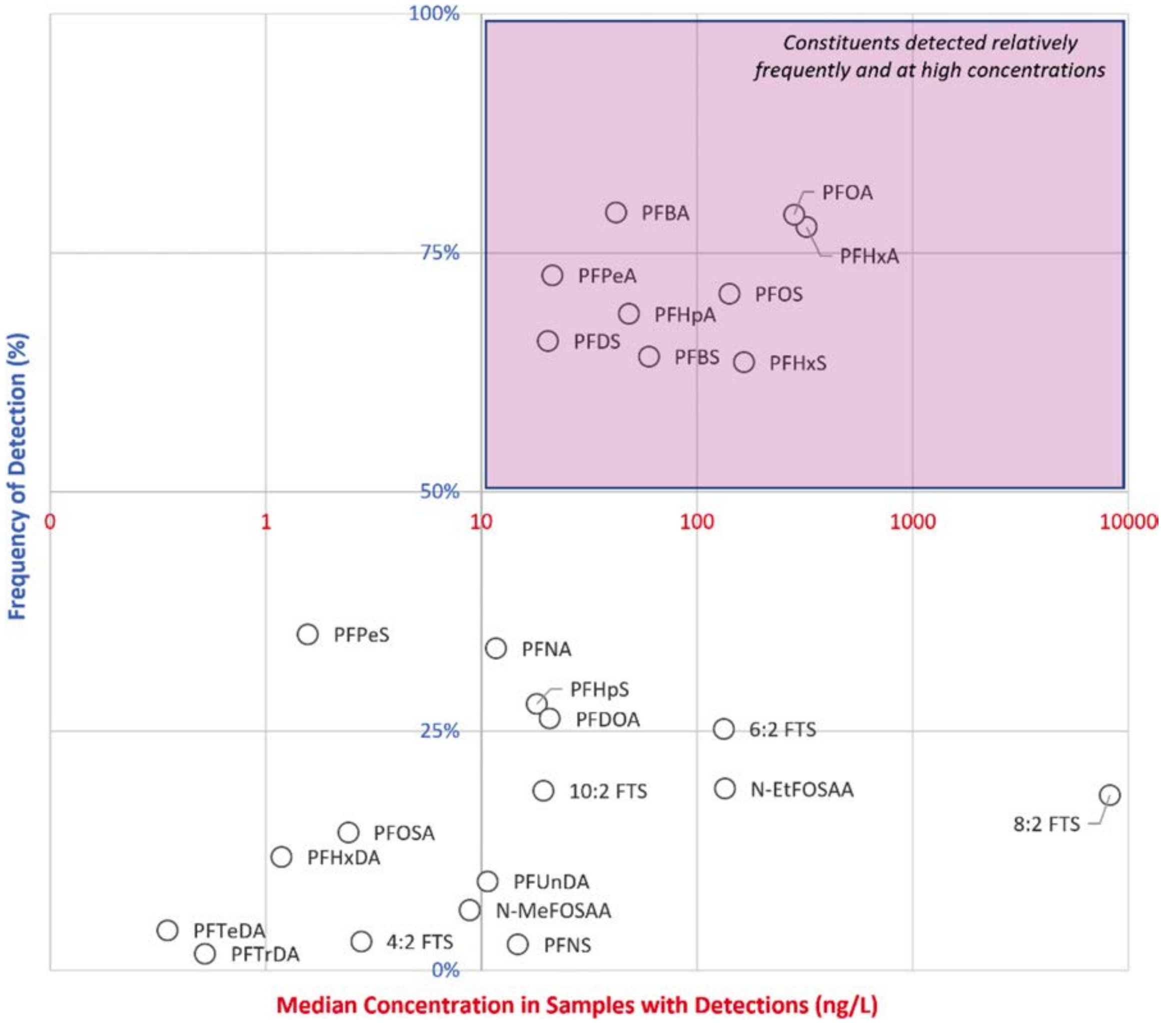


Figure 6-12. Industrial category detection frequency and median concentration.

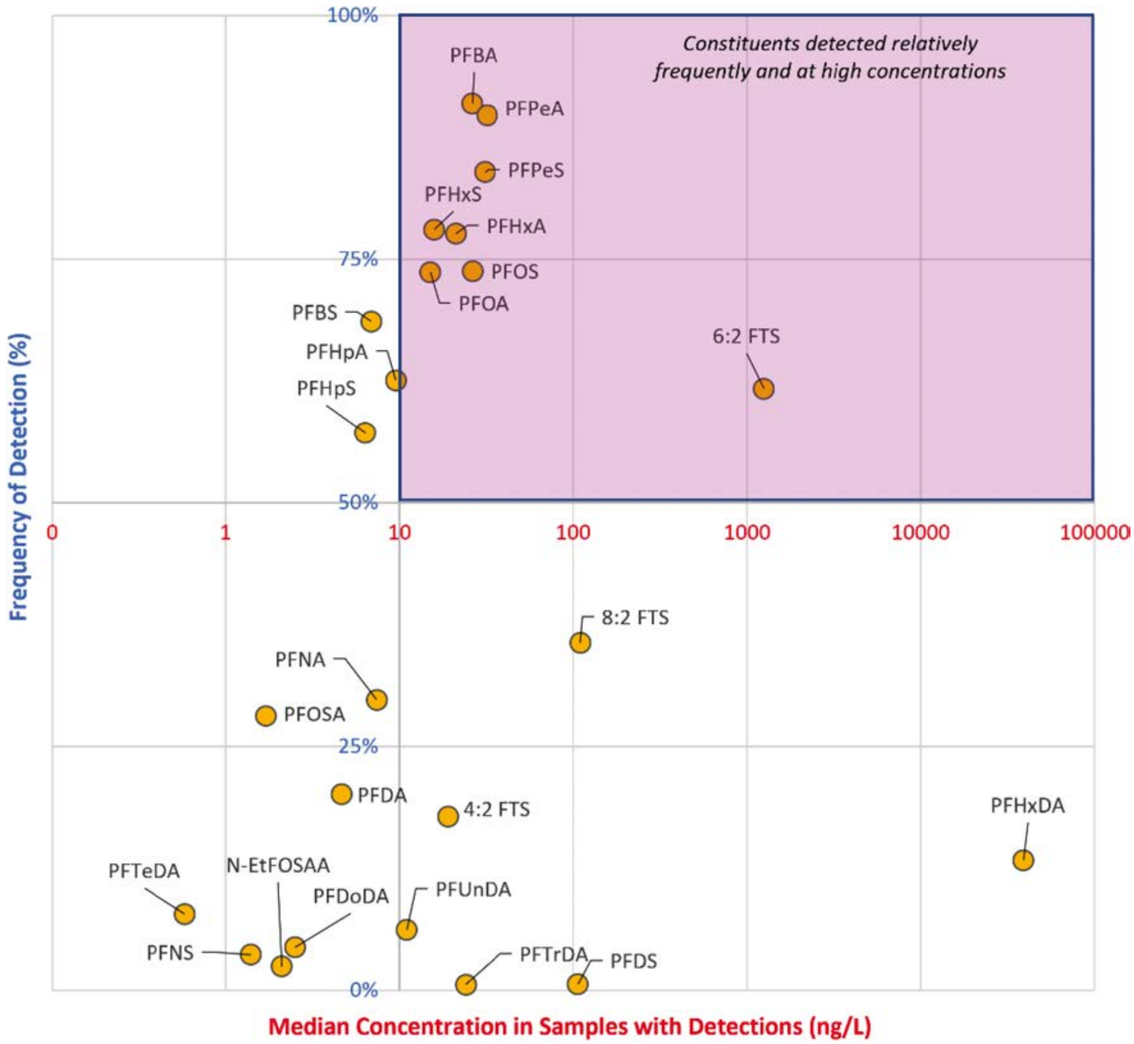


Figure 6-13. Other cleanup site category detection frequency and median concentration.

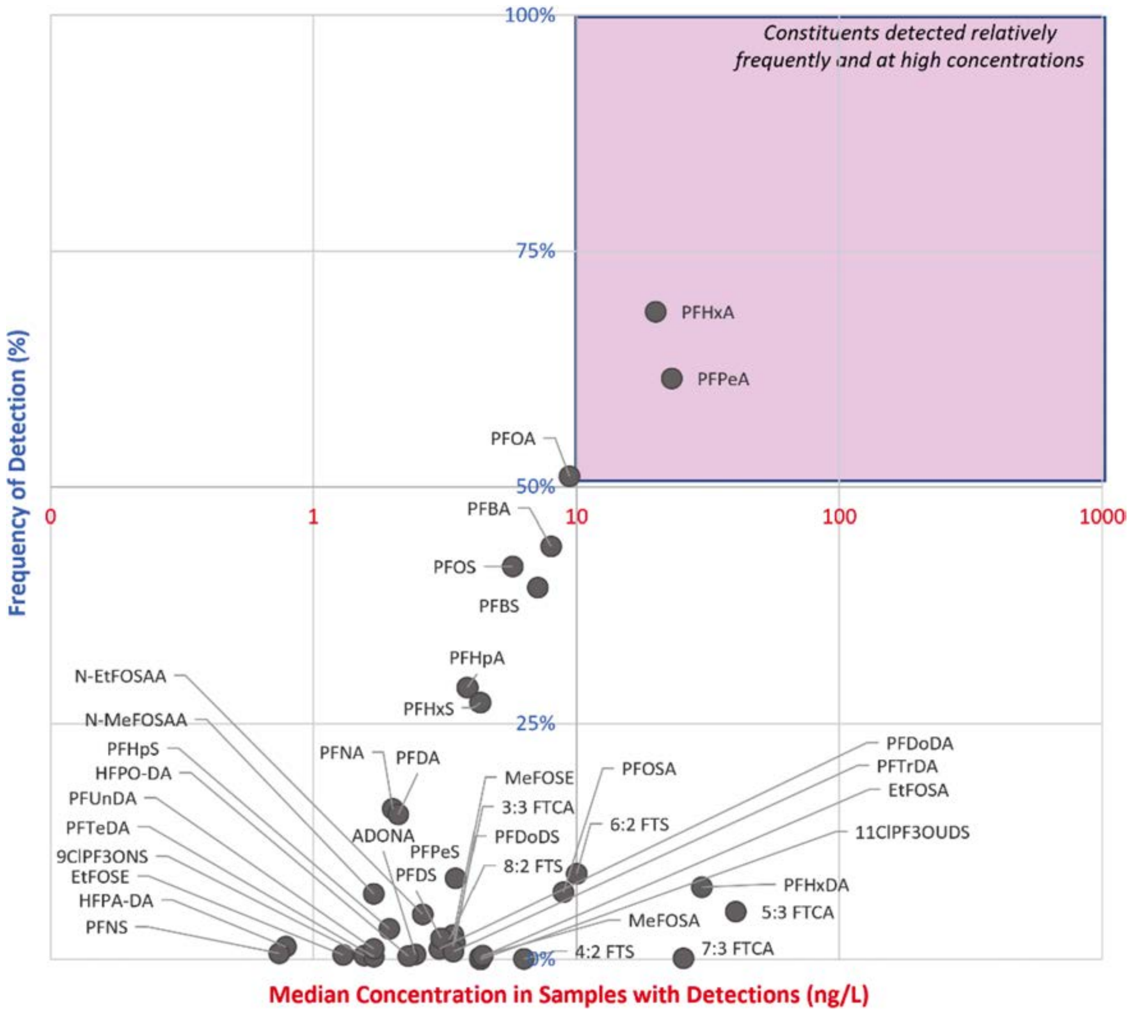


Figure 6-14. Wastewater treatment plant category detection frequency and median concentration.

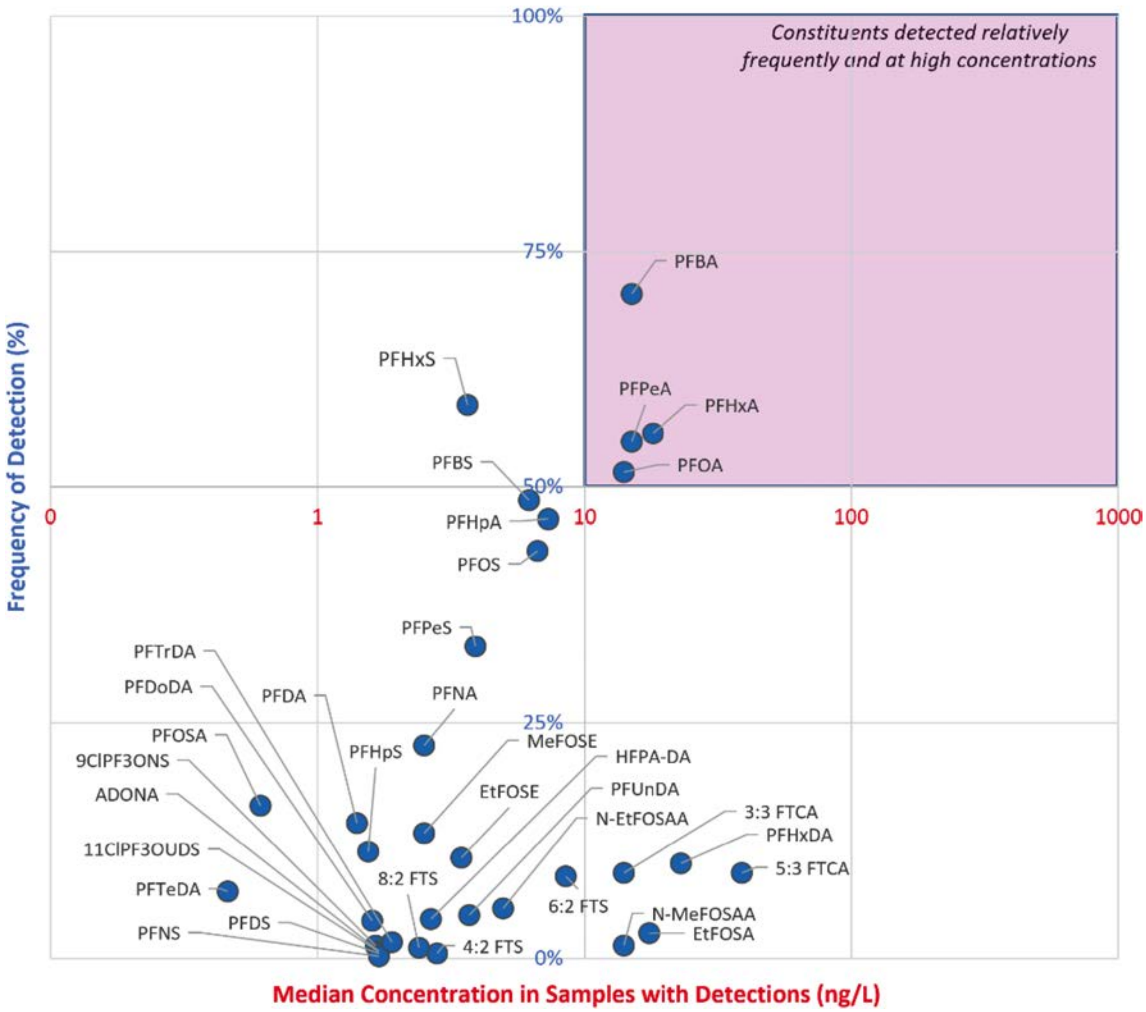


Figure 6-15. Landfill category detection frequency and median concentration.

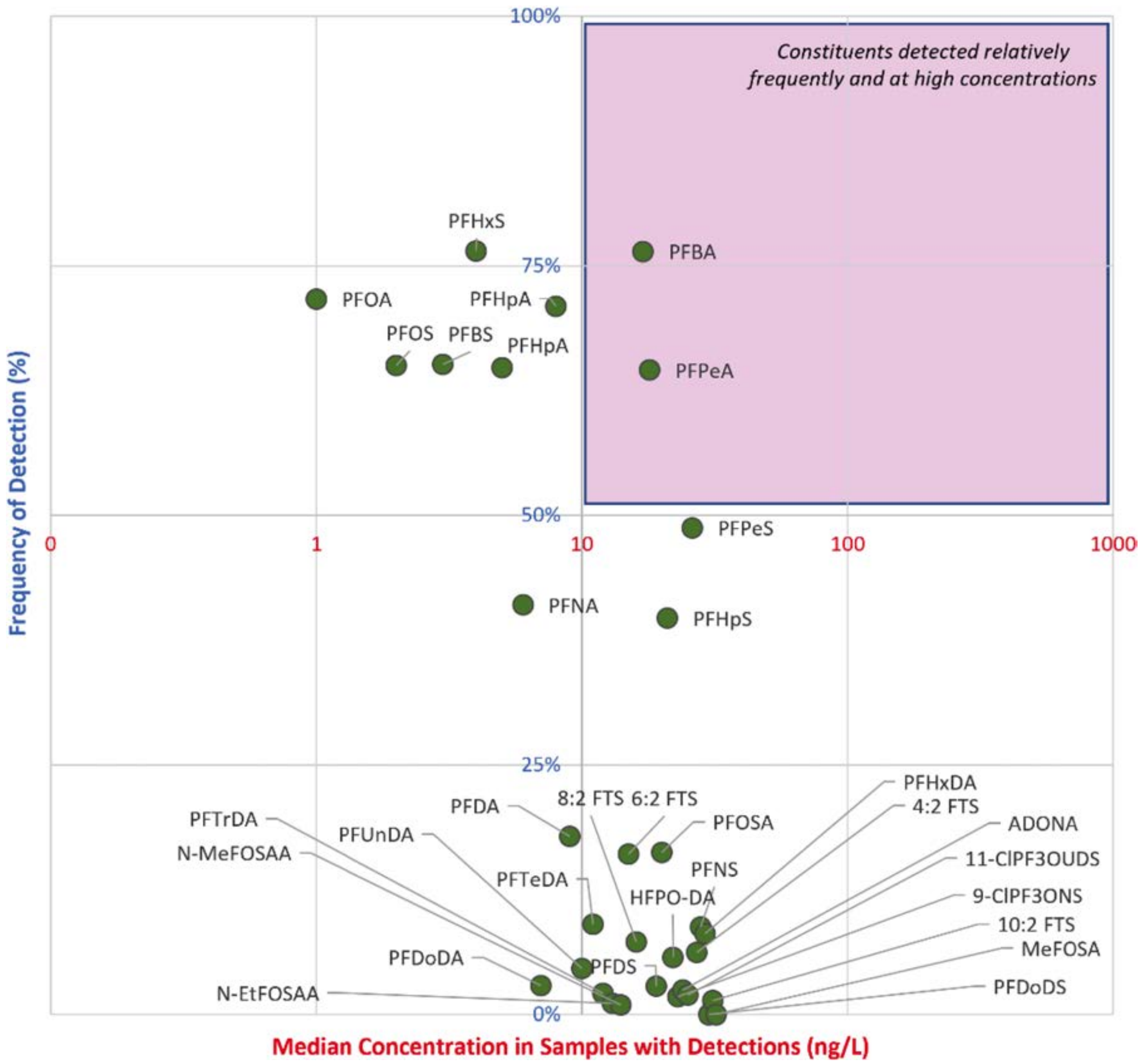


Figure 6-16. Eurofins U.S. DOD/airport category detection frequency and median concentration.

Median Log Concentration Ratios

Additional graphical representations of various statistical analyses can be helpful to further support a lines-of-evidence approach. Figure 6-17 and Figure 6-18 show the results of a median log concentration ratio analysis displayed on two different visualization types. These figures provide comparative review opportunities of the compiled data and also highlight that different visualizations may be more appropriate for communicating complicated results to external stakeholders. For the dot and radial plots shown in these figures, each symbol represents the median of the log concentration ratio of the designated PFAS compound pairs.

Summary and Key Points

Collectively, these graphical representations are intended as launching points for source screening in situations where data from samples with a known or unknown PFAS source could be compared to larger source datasets to establish consistencies or discrepancies. A summary of the primary findings from the database statistical review for each of the different source categories is described in Table 6-2.

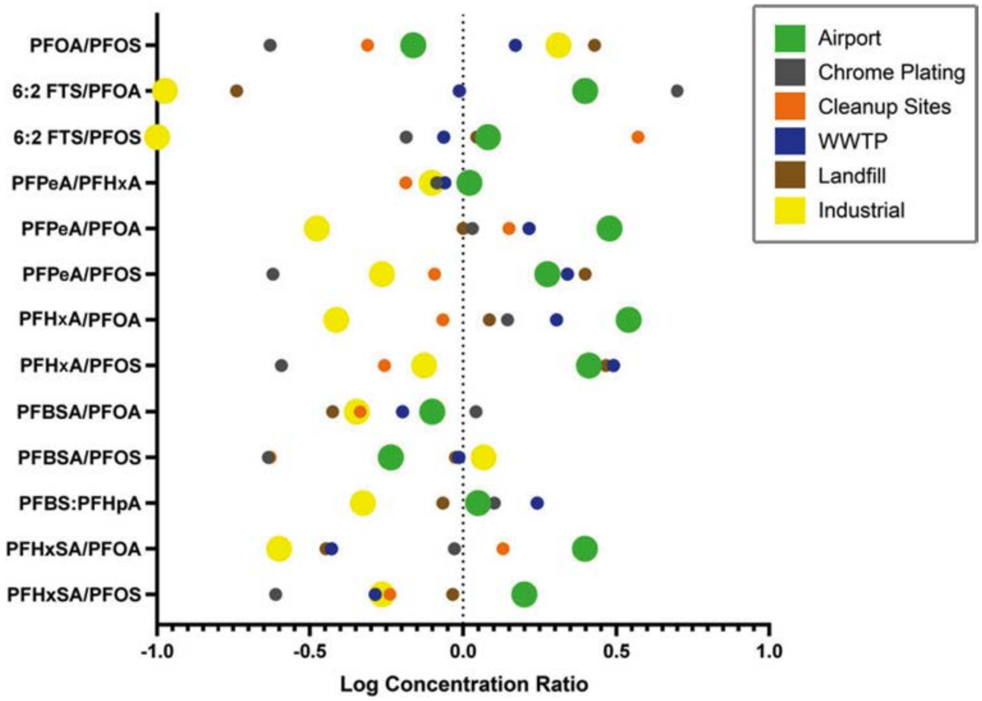


Figure 6-17. Median concentration ratios dot plot.

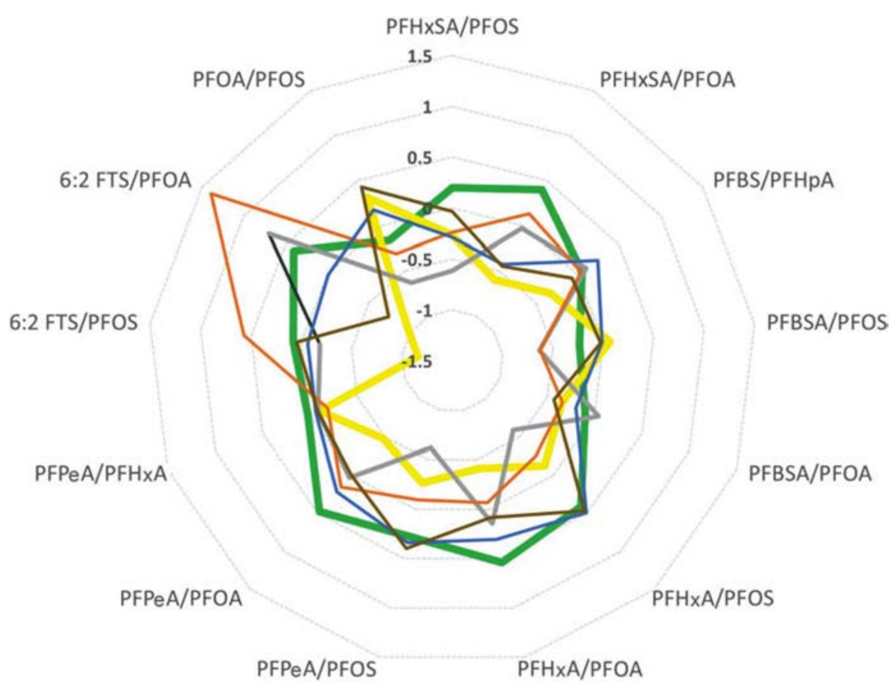


Figure 6-18. Median concentration ratios radial plot.

Table 6-2. Database exploratory review summary of findings.

Airport Sites	In the airport dataset, compounds that are detected relatively frequently and at relatively high concentrations (i.e., compounds that fall into the shaded area in the upper right of the cross-plot in Figure 6-10) include PFOS and carboxylic acids that have eight or fewer fully fluorinated carbons (≤ C8). Other PFAS that appear to be relevant for airport sites include FTS—particularly 6:2 FTS. Longer-chain PFAAs are less abundant within this set of sites. These same patterns can be observed in the respective heat maps for the airport datasets. Note that many other PFAS were either not detected in the existing airport dataset or were detected in fewer than 5% of all samples. This group consists largely of longer-chain PFAAs, polyfluorinated precursor compounds, and newer replacement PFAS. These results suggest that these compounds are less likely to be associated with airport sites and are potentially attributable to other PFAS sources. It should be noted that these compounds were analyzed in only a subset of samples (typically 10%– 25%) from airport sites, so these observations are based on a limited sample size. Based on the aggregated data, PFCAs were the dominant group of PFAS present in the airport dataset, representing 50% of the total PFAS in samples with detections. PFSAs represented in 33% of the total PFAS in these samples, while compounds other than PFCAs and PFSAs constituted the remaining 17% of the total PFAS. The latter percentage is the highest among all of the other (nonairport) site types that were evaluated, likely reflecting the influence of several key polyfluorinated precursor compounds (6:2 FTS and PFOSA) in the airport dataset. In addition, the ratio of PFHxS to both PFOS and PFOA were both relatively high in this dataset and were distinguishable from other types of sources.
Chrome Plating Sites	The PFAS profile for chrome plating sites is somewhat similar to that of airport sites. PFAAs with a chain length ≤ C8 were the dominant PFAS, with PFOS as the most frequently detected compound and also the compound exhibiting the highest median concentration (see Figure 6-11). PFSAs were a high percentage (52%) of the total PFAS in the chrome plating dataset. In addition, 6:2 FTS was detected at high concentrations in many samples. The relative importance of PFOS and 6:2 FTS is consistent with the specific PFAS-related processes that have been reported for this industry (i.e., fume suppressants). Overall, concentrations at chrome plating sites were lower than those observed at airport sites. In addition, short-chain PFAAs (C4 to C6) were much less frequently detected and were present at lower concentrations at these sites compared to their concentrations at the airport sites. A substantial number of PFAS were either not detected or were detected at very low frequencies at chrome plating sites, which is similar to observations at the airport sites. An exception is that longer-chain PFAS (> C8) were largely absent from the chrome plating sites, while many longer-chain PFAS were detected at airport sites (albeit at low frequencies and in low concentrations).
Industrial Sites	The PFAS profile for industrial sites shares some similarities to that for airport sites, in that PFAAs with a chain length of C8 or less were the dominant PFAS, but multiple longer-chain PFAS were present relative to other source types (see Figure 6-12). In general, concentrations from the industrial dataset were higher than those associated with any of the other source types, including airports. This confirms that these industrial sources represent potentially strong sources in groundwater after release. Another key differentiator for the industrial dataset is the predominance of PFCAs relative to PFSAs and other PFAS (non-PFAAs). The median PFCA percentage for the industrial dataset was 60%, which was substantially greater than the categories that could be considered potential direct sources of PFAS (i.e., chrome plating, airport, and cleanup sites). Several compounds with a chain length of C8 or greater exhibited high detection frequencies, concentrations, or both in the industrial data, including 8:2 FTS, 10:2 FTS, and perfluorodecane sulfonic acid (PFDS)—a C10 compound. The abundance of these longer-chain compounds provides some contrast to chrome plating sources as well as to indirect sources like wastewater and landfill. However, there is a relative lack of 6:2 FTS and PFHxS in the industrial dataset, which results in clearly different ratios of 6:2 FTS to PFOA, 6:2 FTS to PFOS, PFHxS to PFOA, and PFHxS to PFOS when compared to those for the airport sites (see Figure 6-10). The newer replacement PFAS for longer-chain PFAS [e.g., dodecafluoro-3H-4, 8-dioxanoate (ADONA), hexafluoropropylene oxide dimer acid (HFPO-DA), and the ethanesulfonic acids 9Cl-PF3ONS and 11Cl-PF3OudS] were not detected in this dataset. This may have been due to the relatively low number of analyses of these compounds, as they were analyzed in only 6%–15% of the industrial samples.

Table 6-2. (Continued).

Wastewater Treatment Plant and Landfill Sites	The PFAS profiles for wastewater treatment plant sites and the landfill sites were both relatively similar to each other while being dissimilar to that for airport sites. Overall concentrations for PFAS (both total and individual) and detection frequencies were much lower at these site types. The primary contributors were short-chain (C6 or less) perfluoro carboxylic acids like PFHxA and perfluorophosphonic acid (PFPA), with much less representation from PFSAs than were seen in the airport or chrome plating sites. This is reflected in the high median percentage of PFSAs in both the wastewater treatment plant (79%) and landfill datasets (78%), as shown in Figure 6-14 and Figure 6-15. The concentration ratios for these two datasets are also very similar, with some key differences from the airport dataset (e.g., a much lower PFHxS to PFOA ratio). In addition, a wide number of PFAS were detected in one or more samples from the wastewater treatment plant and landfill sites, including multiple longer-chain, polyfluorinated, and replacement PFAS. The detection frequencies for these compounds were typically low (<1%); this may be attributable to the larger dataset for these source types. However, the large number of compounds with at least one detection is consistent with the assumption that PFAS in wastewater and landfills represent an aggregation of PFAS from many other direct sources and household products. In addition, biological activity is an important component of both wastewater treatment and the landfilling of wastes. The PFAS profiles for both the wastewater treatment plant sites and landfill sites show a relative lack of contribution from FTSs, which suggests that these intermediates are being further transformed at these sites. In addition, known transformation intermediates like 3:3 FTCA and 5:3 FTCA were detected at relatively high frequencies in both the wastewater treatment plant and landfill datasets, although the number of analyses of these compounds is somewhat limited. Collectively, these results also suggest that the resulting PFAS profiles from these indirect sources are different from those of sites where the sources of PFAS are more defined.
Other Cleanup Sites	The PFAS profile for other cleanup sites is closer to those for airport sites and industrial sites than it is for the other site types. Other cleanup sites have higher detection frequencies of many PFAS than the other site categories, although concentrations are typically lower than for airport sites. The profile is dominated by PFAAs (typically C8 or less) and FTSs. Note that this site type category represents sites that are in a state cleanup program but have not yet been assigned to another site type. It is possible that these sites share similar PFAS sources (e.g., AFFF) with site types that have been more clearly defined.

Collectively, the PFAS listed in Table 6-3 were of both high concentration and high detection frequency (i.e., the shaded portion of the cross-plots in Figures 6-10 through 6-16) for each source type. For this dataset, these could be considered important indicators for each source type.

Note that extensive data from drinking water wells were compiled in the project database. However, these data were not included in the results shown. This is due in part to the low detection frequencies for all individual PFAS within the drinking water dataset, which limits the evaluation options and the applicability of the results. In addition, the primary goal of this effort was to provide information to support source differentiation. Given that the sources of PFAS detected in these drinking water wells are unknown, it was not appropriate to make inferences in evaluating the data.

Table 6-3. High detection and frequency PFAS for source categories.

Source Type	Airport	Chrome Plating	Industrial Sites	Other Cleanup Sites	Wastewater Treatment Plants	Landfill
Compounds that exhibited high median concentrations and high frequencies of detection	PFPeA PFHxA PFBA PFHxS PFOS PFHpA PFOA PFBS PFPeS 6:2 FTS	PFOS PFHxA 6:2 FTS	PFOA PFHxA PFOS PFHxS PFHpA PFHxS PFBS PFBA PFPeA PFDS	PFBA PFPeA PFPeS PFHxS PFOS PFHxA PFOA 6:2 FTS	PFHxA PFPeA	PFBA PFHxA PFPeA PFOA

6.3.3 PFAS Source Screening Limitations

There are several inherent limitations with all screening level methods that end users should recognize, including the screening framework developed by this research project. Although not an all-inclusive list, several of the most important limitations include the following:

> **KEY POINT**
>
> PFAS source screening and the resulting data visualizations display central tendencies across the whole source category dataset. They do not provide definitive values for PFAS from a particular source category.

- **Widely varying PFAS data within source types.** There is no such thing as a definitive PFAS signature for each source type. The PFAS profile in a sample from one airport might look quite different from the PFAS profile in a sample from another airport. This is due to many factors, including the use of different PFAS-containing products (e.g., different AFFF formulations), their release history, and the effects of fate and transport processes on the PFAS profiles over time and distance. This variability is reflected in the wide range of concentrations shown in the box plots for airports and other source types (Figures 6-2 through 6-8). The visualizations show the central tendency—that is, the median values across the entire dataset. This should not be interpreted as a single definitive value for PFAS from that particular source. For example, the airport data show that the median percentage of PFSAs in that set of samples was 33%, but it should be recognized that there were samples from airport sites that consisted of 100% PFSAs.
- **Limited and varying numbers of PFAS that are reported.** PFAS analytical methods are improving and increasing the number of PFAS that can be detected and quantified. However, current methods still only provide information on a small number of compounds. In many cases, data are only available for between 14 and 24 different compounds because of lab capabilities and site-specific reporting requirements. Similarly, the same set of PFAS were not necessarily analyzed at all airport sites, and the PFAS analyzed at airport sites were not necessarily the same as those analyzed at landfills or at wastewater treatment plants. This can complicate interpretation of the data and create challenges when making comparisons.
- **Limited data on precursors.** Current analytical methods focus largely on terminal PFAAs. However, several PFAS-containing products (e.g., modern AFFF formulations) would be expected to have a high content of polyfluorinated compounds present at the time of release. The number of polyfluorinated compounds that are part of current target analyte lists is still relatively small. Some of these compounds may prove to be diagnostic of particular sources, including those associated with airports, but the data are missing from existing datasets.
- **Common set of PFAS among different source types.** Because there were only a few primary manufacturers of PFAS, products that contain PFAS tend to have several compounds in common (e.g., PFAAs) and may even share similar chemical signatures. This makes it harder to differentiate between PFAS sources, especially those that represent aggregated sources like landfills and wastewater treatment plants. This difficulty is compounded by the degradation that occurs following the release of PFAS to the environment, which eventually converts any polyfluorinated precursor compounds to a limited set of perfluorinated end products (PFAAs) that would be shared among all PFAS source types.
- **Limited temporal records.** The majority of PFAS data have been collected in the past five years and may have occurred during just one sampling event, meaning that the data are just a snapshot of the PFAS history at that time. This means that there is less certainty about whether the data are representative. It also means that considerable time may have passed since the earliest PFAS releases occurred, so the current PFAS chemical profile might look significantly different than it would have in the original source.

> **KEY POINT**
>
> Screening tools provide one potential line of evidence and should be combined with other relevant information to increase confidence in source differentiation findings. Broad screening tools such as those presented should not be considered definitive.

It is important to note that the observations presented for each categorization of PFAS source is based on the analysis that was conducted specific to the dataset collected for this effort and should not be considered a definitive representative assumption for all PFAS sources. A lines-of-evidence approach is critically important for source differentiation. The approach discussed in this section represents one potential line of evidence and should be combined with all other relevant, site-specific information.

6.4 Advanced Source Identification Forensics

As the scientific understanding of PFAS impacts continues to evolve and grow, new analytical methods and advanced forensic techniques are being developed. These advanced techniques can help to strengthen PFAS source differentiation findings with state of the science and more robust analytical processes. Technical expertise in laboratory analytical chemistry and data evaluation will be required.

Advanced forensic techniques are likely to be most applicable (1) as a confirmation step at sites for which a screening level approach has already provided reasonable lines of evidence that identify a particular source (or sources) of PFAS; and (2) for sites at which screening level forensic approaches were inconclusive, so higher resolution data are needed to make a more convincing identification. The latter may be especially warranted for cases in which source allocation is of particular importance (e.g., litigation)].

For the research community evaluating AFFF release sites, a significant focus is to better define what an AFFF source PFAS profile should look like. As a result, it is reasonable to expect that more advanced source identification methods are best suited for establishing whether PFAS originated from an AFFF source or a non-AFFF source. Identifying a specific non-AFFF source may be more difficult unless there is a clear source-specific PFAS signature. It is recommended that airports considering advanced PFAS source identification forensics engage with a qualified PFAS expert on these topics. Use of the advanced methods described in Section 6.4.1 might require additional support from experts in laboratory analytical chemistry and analytical data evaluation.

TECHNICAL DETAIL

Advanced forensics may be more suited to determining whether PFAS impacts originated from AFFF or non-AFFF sources than they are for differentiating between AFFF sources.

6.4.1 PFAS Signature Evaluation State of the Science

The scientific basis for PFAS source differentiation is improving as continued research and development in this area provide more information on the composition of PFAS that can be expected from various sources. Given that the composition of a PFAS mixture undergoes changes once it is released into the environment and moves spatially and over time, identifying a single true signature of a source in an environmental sample (i.e., a sample of groundwater or surface water) is unlikely. However, there are ongoing research efforts that should contribute to more refined source differentiation than is possible using the screening level approaches previously described.

Advanced methods fall into the following general categories:

- **Improved analytical methods that help develop expanded PFAS libraries.** The total number of individual PFAS that can be detected and identified within an environmental sample is expanding with improved analytical methods. Due to the complex PFAS formulations used in diverse applications, considering a broader suite of analytes for PFAS analysis may help to better identify non-AFFF sources of PFAS contamination. Although commercially available analytical standards and analytical methods offer only a limited number of PFAS analytes, many commercial laboratories are now offering expanded suites of PFAS analytes [e.g., disubstituted polyfluoroalkyl phosphate esters (diPAPs) and PFECHS]. Additionally, non-targeted analysis can screen against a library of hundreds of potential PFAS based on molecular weight and compositional fragments.

- **Source identification via focused analysis of PFAS-containing products and environmental samples.** These product-specific compositional libraries provide an understanding of the actual PFAS that are (or were) present in different products or source types. It is an important step in benchmarking the expected PFAS composition from different types of sources, which can then be used to categorize the possible origin of PFAS in an environmental sample.
- **Alternative sample processing and analysis methods that alter the PFAS composition in ways that are designed to simplify source differentiation.** For example, the TOP assay (described in Section 5.1 of this guide) provides an estimate of the unknown PFAS precursors present in a sample. The procedure degrades, via strong oxidation, precursor PFAS present in an individual sample into terminal carboxylic PFAAs that can be readily quantified. Measuring the change in terminal PFAAs prior to oxidation and post oxidation provides an estimate of the mass of total unknown precursor PFAS. If two samples each have a vastly different mass of unknown precursor PFAS, this provides a distinguishing line of evidence that they may be from a different source. In general, data from samples that are from the same source and that have undergone the same natural fate and transport processes would look similar to each other.
- **Various statistical methods that leverage the expanded number of PFAS that are generated through higher resolution analytical methods.** Commercial laboratories and specialized laboratories are continuously increasing the number of PFAS that can be identified and quantified in an environmental sample (i.e., the PFAS library). An expanded suite of PFAS analytes allows for increased statistical power to identify different compositional profiles. Researchers are also utilizing advanced computational tools to bring even more discriminating power to analyses. This can include machine learning applications, in which PFAS data from a set of samples are used to develop a model of the general profile of PFAS from a particular source. That model is then used to predict the likely PFAS source in other samples.

Currently, most of these methodologies have limited or no commercial availability. However, the expectation is that many of these research-driven efforts will lead to databases, tools, or analytical approaches that will be tested as case studies and perhaps adopted by commercial labs and other entities in the future.

6.4.2 High Resolution Mass Spectrometry Overview

PFAAs that are routinely measured using targeted analysis are commonly found across different PFAS sources. Performing HRMS for non-targeted analysis in addition to the targeted analysis provides information on a broader list of PFAS precursors and transformation products not covered under the targeted analysis. A broader set of compounds has the potential to provide a more refined PFAS signature for source differentiation and is more likely to include unique, source-specific PFAS.

HRMS analysis is typically performed in both positive and negative ionization modes; therefore anionic, neutral, cationic and zwitterionic analytes could be detected; routine targeted methods only analyze for anionic and some neutral species. Studies have shown that cationic and zwitterionic PFAS analytes contribute from 20% to 95% of the total PFAS mass in AFFF formulations depending on the matrix (Liu et al. 2022; Nickerson et al. 2020), therefore, it is possible that standard targeted analysis misses the majority of PFAS mass from an AFFF release. AFFF contains many unknown PFAS precursors that can potentially transform to more persistent PFAAs. In some cases, these precursors and transformation products may provide unique signatures related to different AFFF manufacturers; these may provide an indication of the manufacturing process used by a certain manufacturer or (in some cases) information on different formulations.

Although AFFF use is a common source of PFAS at airports, its use is not exclusive to airports. Other places AFFF may be used include U.S. DOD sites for fire training and firefighting operations and oil and gas facilities, where it may be used in emergency response. If there is a site near an airport facility that may also have used AFFF, and if the AFFF used by each facility is from different manufacturers, targeted analysis would show similar types and of concentrations of PFAAs but HRMS non-targeted analysis may reveal unique differences between the AFFF sources.

When performing forensic analysis, it is important to obtain information on other unique analytes that might provide more specific diagnostic analytes to the suspected sources. Use of HRMS suspect screening analysis provides information on PFAS precursors, such as 6:2 fluorotelomer thioether amido sulfonic acid, betaines, and others; these can help to differentiate AFFF sources from different manufacturers or help to identify non-AFFF PFAS compounds.

6.4.3 Practical Considerations for HRMS Forensic Analysis

PFAS concentration ranges. Routinely used triple-quadrupole mass spectrometry (MS) instruments used for PFAS target analysis are highly sensitive compared to the time-of-flight MS (TOFMS) instruments used for high resolution MS analysis. Typically, high resolution MS methods have slightly higher limits of detection (LODs) compared to standard LC-MS/MS methods. The instrumental LODs of TOFMS are approximately a factor of 10 lower than those for triple-quadrupole MS and cover a smaller linear range (Berger et al. 2004).

Concentrations of some of the unknown precursors and transformation products might be higher compared to those of the known target PFAS analytes. It is recommended that this be discussed with the subject matter experts at the analytical laboratory prior to planning for the sampling campaign and analysis of the samples. In some cases, the laboratory may suggest analysis of a few key samples prior to conducting more in-depth investigations with a larger sampling program.

Qualitative data. It is important to note that, because of the lack of analytical standards for many of the extended list of PFAS analytes monitored using suspect screening analysis, the data obtained from HRMS methods are often qualitative. However, such qualitative information on hundreds of PFAS analytes could be applied for the forensic analysis using machine learning tools.

PFAS turnaround times (TATs). Typically, HRMS methods generate extensive data; processing of such data can often be time-consuming. Typical TATs of HRMS methods range from three to six months or longer. It is recommended that airport managers consider these longer TATs when planning PFAS investigations.

6.4.4 Currently Available HRMS Approach

A recent overview of high resolution forensic approaches cited the use of HRMS and advanced statistical machine learning tools as being helpful for identifying PFAS sources (Charbonnet et al. 2021). Consistent with this approach, a commercially available advanced analytical tool has been developed for PFAS source differentiation and tracking using HRMS techniques in combination with PFAS targeted analysis and advanced statistical analysis.

The technique includes a mass spectral PFAS source library based on HRMS analysis of known PFAS sources, including PFAS targeted analysis with available authentic standards. These sources include manufacturing, metal plating, paper and textile industry processes, landfill leachates, and AFFF formulations, among others. The library also includes the application of machine learning tools for the identification and differentiation of PFAS sources. The developed library is used to compare and differentiate the PFAS composition and trends seen in field-derived samples during a site investigation.

6.4.5 Advanced Forensic Challenges and Lessons Learned

Many of the more advanced forensic approaches are still in development, but they are generating valuable information for PFAS source differentiation. For example, the analysis of different AFFF products has provided further confirmation that modern AFFF formulations largely consist of PFAS that are not measured by standard analytical methods. It is only after these constituents are transformed to PFAAs in the environment that they become detectable. This highlights the complications of using standard methods that only include target PFAS for site characterization and source differentiation.

> **KEY POINT**
>
> Wastewater effluent and landfill leachate may look similar even with advanced forensics because PFAS inputs may be aggregated from various sources.

An additional consideration is that it may prove easier to differentiate between PFAS that originates from AFFF than from non-AFFF sources. Although there are many different AFFF products, including many legacy products that are no longer available for commercial use, there has been considerable recent work in analyzing these compounds for their PFAS content. In spite of this, it should be noted that PFAS from wastewater treatment plants and landfill leachate represents an aggregation from many different (and likely unidentified) PFAS sources. Even with advanced forensic techniques, these may look relatively similar to each other and can be difficult to separate.

6.4.6 Advanced Forensic Techniques Limitations

Current limitations associated with using these advanced forensic techniques include the following:

- **Results are not necessarily definitive.** At this stage, the certainty with which any PFAS sample could be assigned to a particular source is unknown and may vary widely (even within a site). There may be some site data that clearly support that the PFAS originated from a particular source, while other data could be less definitive due to confounding factors. The user may need to employ professional judgment.
- **Data are difficult to communicate to nontechnical audiences.** The results may rely on statistical approaches that are unfamiliar to an end user and are not readily transparent. In many cases, the user may not have the technical expertise to interpret and independently verify the results or to effectively communicate them to stakeholders.
- **Data are generated using nonstandardized methods.** These methods typically rely on rigorous quality assurance and quality control protocols, but these protocols may differ depending on who is performing the analysis. The data should not be used for compliance purposes.
- **Compound identification and quantification is not as definitive.** Unlike standard PFAS analyses that quantify a series of target compounds, advanced forensic methods attempt to identify compounds from a larger suspect list. This means that compound identification is more tentative (with a higher potential for false positives) and that the concentration is an estimate due to the lack of a calibration standard for many of these compounds.
- **Commercial availability is limited.** There are only a few commercial labs that offer these types of services, and there is no accreditation process for those that do so. Academic research labs may also provide relevant services, but these may prove to be challenging to incorporate into investigations because there are fewer standardized processes for sample processing and data transmittal.
- **Regulators may lack familiarity with the data and methods.** Regulators may not have significant experience with reviewing this type of forensic data. Engaging with regulators early in the data collection process may help them to buy into the use of these procedures and make them more likely to accept the results.

> **KEY POINT**
>
> Data may be difficult to communicate to nontechnical audiences. In addition, regulators may not have background with PFAS forensics.

- **Cost can be higher than when using standard methods.** A user should expect that the cost associated with these services is higher on a per-sample or project basis than is the cost of using more standard methods. Costs are less standardized and may vary depending on the service provider, location, number of samples, or level of evaluation being provided. Source tracking tools generated through funded research efforts may eventually become publicly available at no direct cost, though it is expected that these would require some expertise from the user to enter and interpret the data.

CHAPTER 7

PFAS Source Differentiation Downloadable Tool

7.1 Application Overview

To help airports implement the PFAS source differentiation approaches discussed in this guide, a complementary software application was developed, which can be found on the National Academies Press website (nap.nationalacademies.org) by searching for *ACRP Research Report 255: PFAS Source Differentiation Guide for Airports.* The PFAS Source Differentiation Preliminary Screening Application (PSDA) can help to track an airport's progress with the desktop review efforts described in Chapter 3; it also provides data visualization tools for comparison with broad source categories, as discussed in Section 6.3.

The PSDA is intended to be used in conjunction with the MAPA screening tool, which can be found on the National Academies Press website (nap.nationalacademies.org) by searching for *ACRP Research Report 173: Use and Potential Impacts of AFFF Containing PFASs at Airports*. Application of the MAPA tool allows an airport to identify and rank areas of interest in addressing the potential presence of PFAS at their facilities. Use of the MAPA tool prior to using the PSDA will allow an airport to catalog areas of interest.

The PSDA was developed using Microsoft Excel in order to provide ease of use and access within software widely used at airports. The application does not include macros and thus avoids potential accessibility issues due to security protocols.

The PSDA is structured to engage users on their progress in three distinct desktop review areas:

- On-airport PFAS sources
- Off-airport PFAS sources
- Airport hydrology, geology, and stormwater infrastructure site characteristics

Each of these areas includes a series of questions and statements to help determine the thoroughness with which an airport has explored various lines of evidence and important information related to source differentiation. Based on an airport's response, the PSDA will provide feedback on PFAS source differentiation progress as it relates to desktop review efforts.

The PSDA is not intended to provide a comparison between airports; each airport has unique characteristics that will increase or decrease the applicability or value of each individual question. Furthermore, airport users may rate progress differently depending on each user's perception. The PSDA is intended to provide users with feedback with which to compare their own progress over time. This feedback could be used as a tool for reporting to airport executives, boards, commissions, the public, or other interested parties. The PSDA's utility will be completely dependent on the how the user decides to use the tool and to what extent.

The PSDA allows the user to indicate whether areas are not applicable to their airport. For example, if an airport is in an urban environment and biosolid application from wastewater

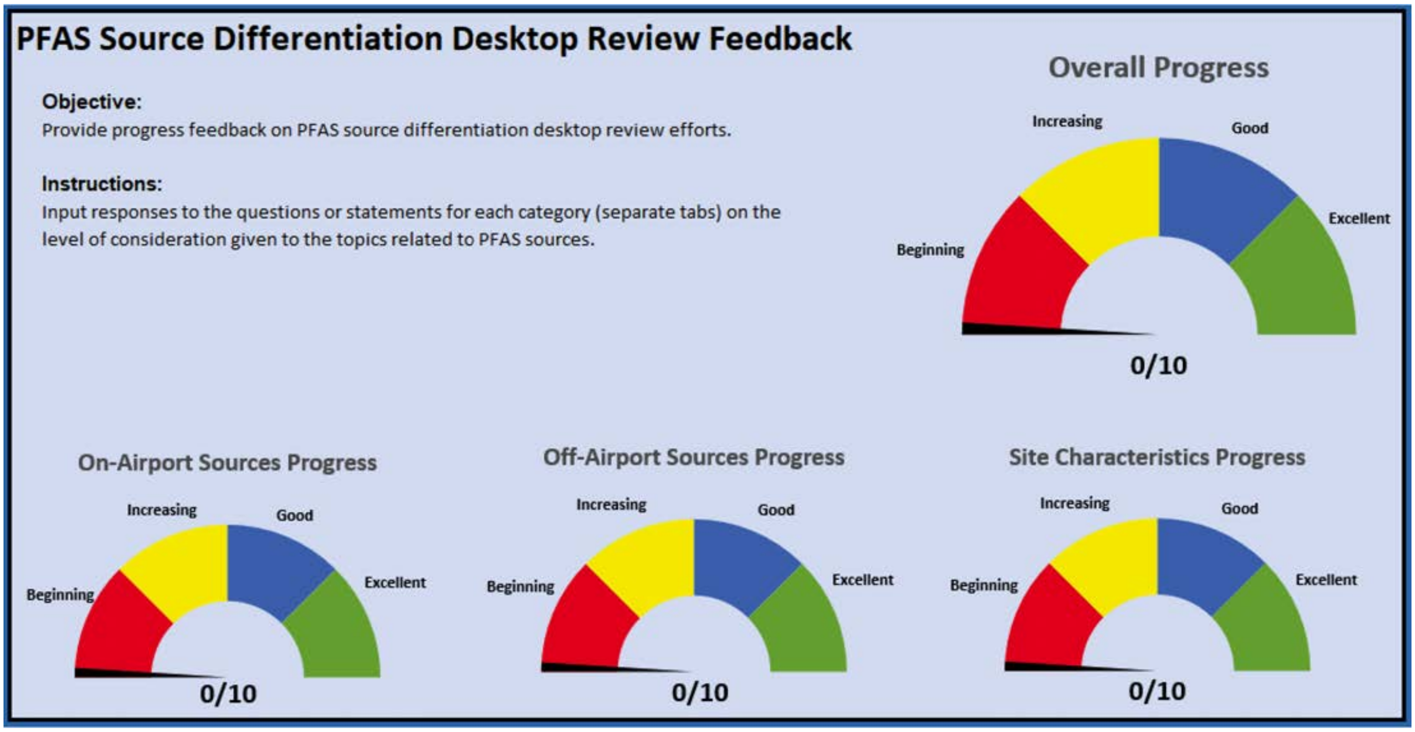


Figure 7-1. PSDA summary progress output.

treatment plants does not occur, questions about biosolids can be designated as not applicable and would not factor into the feedback scheme. Given this flexibility, the tool can be adjusted to provide value to airports of differing size, location, and potential PFAS exposure.

An example output from the PSDA desktop review summary is provide in Figure 7-1. It indicates the progress of the desktop review, with the three categories shown at the bottom and an overall summary in the upper right. Each of the three progress categories is equally weighted to develop the "Overall Progress" feedback.

In addition to the desktop review progress feedback, the PSDA allows the user to input site-specific PFAS data; PFAS compositional data visualization is then developed. This visualization can then be compared to the visualization developed for broad PFAS source categories, as discussed in Section 6.3.

The data visualizations developed within the PSDA are presented as pie charts to allow comparison to the pie charts shown in Figure 6-1. This data visualization was selected because it can be developed with as little as a single sample event. However, the confidence in the lines of evidence generated through any data visualization comparison will increase with greater amounts of PFAS sample data. Results from these comparisons should not be considered definitive regarding PFAS sources, but rather should be weighed against other available information (i.e., the desktop review output) to increase confidence in a lines-of-evidence approach toward source differentiation.

7.2 Desktop Review Progress Application Details

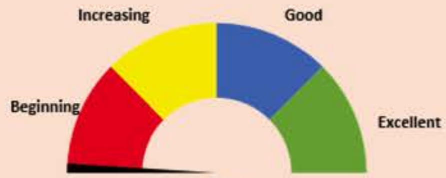
The layout of each area in the PSDA includes a list of considerations, the section of this guide that the user can refer to for additional information, and a place for the user to input comments or notes for each consideration. Figure 7-2 shows the typical layout of a PSDA area.

Potential PFAS Sources at Your Airport

Objective:
Provide topics of consideration to help identify potential off-airport PFAS sources.

Instructions:
Input responses to the questions or statements below on how much consideration has been given to the following topics related to off-airport PFAS sources. For more details on each item, please consult the referenced Guidebook section.

On-Airport Sources Progress



	Have you considered the following ARFF-related potential AFFF use?	Response	Weight	ACRP Guidebook Section	Comments/Notes
1	AFFF use during emergency response (aircraft accident, vehicle fires, etc.)		5	3.1.1	
2	ARFF truck foam proportioning system calibrations		4	3.1.1	
3	ARFF firefighter AFFF training with mobile fire units		4	3.1.1	
4	ARFF firefighter training pits/sites		5	3.1.1	
5	AFFF use during Part 139 annual certification timed response drills		4	3.1.1	
6	Operational testing of ARFF truck foam system		3	3.1.1	
7	Maintenance of ARFF vehicles with AFFF discharge		3	3.1.1	
8	Unintentional release of AFFF including from handling, storage, or other activities		3	3.1.1	

Figure 7-2. PSDA on-airport example.

The list of considerations can assist with creating feedback that is displayed on the progress summary output. Each consideration will allow the user to respond with one of five choices in a drop-down menu. Each response will be given a score. A list of the possible responses along with the score associated with them is given in Table 7-1.

Each of the responses allows for user interpretation. However, general guidelines for each response are as follows:

No consideration: the user has not yet considered this item.
Some consideration: the user has started to review this item but there are additional, readily available resources that have not been reviewed.
Reviewed extensively: the user has reviewed all readily available resources but there are additional follow-up items that could be pursued.
Fully explored: the user has reviewed all known aspects of this item and there are no additional follow-up materials or items that could be pursued.
Not applicable: consideration of this item in the PSDA tool is not applicable to the airport. For instance, if the item relates to adjacent industrial buildings but there are no buildings adjacent to the airport, the user will consider this item not applicable.

The overall feedback score for each area is developed using a weighted average of the response score identified in Table 7-1. The "not applicable" response is not given a score and will not be considered in the overall feedback for each area. Each question will be weighted based on its overall significance to understanding PFAS source differentiation. For example, understanding former ARFF firefighter training sites will have a higher weight than reviewing aircraft hydraulic fluid releases because AFFF use during firefighter training has a higher potential to be a contributing source of PFAS than hydraulic fluid releases. The weighted feedback score for each area is calculated using the following formula.

$$\text{Feedback Score} = \frac{\sum_{i=1}^{n} S_i \times F_{\text{weight},i}}{\sum_{i=1}^{n} 10 \times F_{\text{weight},i}}$$

Where

n = number of responses,
i = instance of response,
S_i = response score, and
$F_{\text{weight},i}$ = weighting factor

The questions for each of the areas in the PSDA, along with their weighting factors, are provided in Tables 7-2, 7-3, and 7-4.

Table 7-1. PSDA responses.

Response	Score
No consideration	0
Some consideration	3
Reviewed extensively	6
Fully explored	10
Not applicable	N/A

Table 7-2. Potential on-airport PFAS sources.

	Question	Weighting Factor
Have you considered the following ARFF-related potential AFFF use?		
1	AFFF use during emergency response	5
2	ARFF truck Part 139 foam proportioning system testing	4
3	ARFF firefighter AFFF training with mobile fire units	4
4	ARFF firefighter training pits/sites	5
5	AFFF use during Part 139 annual certification timed response drills	4
6	Operational testing of ARFF truck foam system	3
7	Maintenance of ARFF vehicles with AFFF discharge	3
8	Unintentional release of AFFF including from handling, storage, or other activities	3
Have you considered the following non-ARFF potential AFFF use?		
9	Hangar fire suppression systems with AFFF	3
10	Fuel farm fire suppression systems with AFFF	3
11	Military ARFF activities	5
Have you considered other sources of relevant PFAS releases?		
12	Aircraft hydraulic fluid releases	1
13	Application of biosolids from wastewater treatment facilities	3
14	On-airport tenant industrial and manufacturing activities with PFAS exposure	2
15	Historical land use at your airport with PFAS exposure (e.g., former landfill, former military)	2
16	Soil stockpiles originating from potential areas of PFAS concern (e.g., former ARFF-use locations)	3
17	Areas where potential PFAS-impacted fill was used for infrastructure development projects	3
Have you reviewed the following sources for information related to potential PFAS use?		
18	Daily airport operational logs	2
19	Part 139 certification inspection records	2
20	ARFF training records	3
21	AFFF purchasing records or SDS files	3
22	Airport records for accident/incident reports	2
23	National Transportation Safety Board accident database	3
24	State-mandated AFFF use notification records	2
25	Environmental spill documentation of AFFF or hydraulic fluids releases	2
26	Site investigation/cleanup documentation of potential PFAS-impacted areas	2
27	Airport development project summary reports (soil movement)	2
28	Airport layout plan property maps	1
29	Available military records	3
30	Property deeds	1
31	Historical imagery	2
32	News archives	2
33	Interviews with current and former airport employees (e.g., ARFF staff)	3
34	Local fire departments regarding current and past AFFF use	2
35	Tenants regarding use of AFFF or PFAS-containing materials	2

Table 7-3. Potential off-airport PFAS sources.

	Question	Weighting Factor
Have you considered the following source categories near your airport?		
1	Industrial and manufacturing facilities with potential PFAS exposure (existing and former)	2
2	Landfills (existing and closed)	2
3	Biosolids application areas	2
4	Refineries and tank farms	2
5	Off-airport AFFF use locations (aircraft accident sites, railroad fires, vehicle/tanker fires)	2
Have you reviewed the following sources for potential off-airport sources?		
6	Toxic Release Inventory	2
7	NPDES permit PFAS water quality monitoring data	3
8	NPDES multi-sector general permit permittee records	2
9	Section 311/312 reporting	2
10	Superfund program	2
11	Air quality permits	1
12	Regulated waste reporting	1
13	State-mandated AFFF use notification records	3
14	Phase 1 environmental site assessment of adjacent areas	2
15	Federal and state environmental databases	3
16	State PFAS awareness sites	3
17	Municipal water supply analytical data	2
18	Wastewater treatment plant water quality and biosolids data	2
19	Septic system inventories	1
20	IRS Active Fuel Terminals and Refinery Location directory	2
21	Inventory of operating and/or closed permitted/unpermitted landfills	2
22	Historical imagery of nearby industries/activities	2
23	News archives about AFFF use in emergency response	2
24	Municipal fire department response records	3
25	Environmental nonprofit organizations	2

Table 7-4. Airport site characteristics.

	Question	Weighting Factor
How well-documented is information regarding site characteristics at your airport?		
1	Groundwater elevations and/or contour maps (hydraulic gradient)	3
2	Groundwater flow direction	3
3	Bedrock units, bedrock competency, confining layers, and bedrock unit extents	3
4	Depositional environment of water-bearing materials	2
5	Porewater distribution/aquifers present	2
6	Primary and secondary permeability/flow pathways	2
7	Soil types and stratigraphy	2
8	Climatological setting (precipitation, prevailing wind direction)	1
9	Manufactured hydraulic conduits created within bedrock or soils (utility corridors, pipe bedding)	2
10	Storm sewer infrastructure and receiving waters	2
Have you considered the following sources for site characteristic information?		
11	Airport environmental documents (e.g., CSM, groundwater monitoring)	3
12	Airport planning documents (e.g., geotech reports, record drawings)	3
13	Subsurface site investigation reports	3
14	Watershed district maps/resources	2
15	The Natural Resources Conservation Service Web Soil Survey	2
16	State or local soil conservation district records and/or soil maps	2
17	State geological surveys	2
18	Stormwater Pollution Prevention Plan for your airport	1
19	Environmental impact statements	2
20	Environmental assessments	2
21	Information request to the responsible government unit	1
22	United States Geological Survey Publications Warehouse	1

The feedback score for each of the three areas (on-airport, off-airport, and site characteristics) are then averaged to develop an Overall Progress score that is displayed on the desktop review summary screen (Figure 7-1).

7.3 PFAS Compositional Analysis Application Details

The compositional analysis application tool in the PSDA allows the user to input site-specific PFAS data for visualization. The list of PFAS compounds utilized in the PSDA includes compounds from the U.S. EPA 2nd Draft Method 1633 list (U.S. EPA 2022) and other PFAS that have been included in other standard analytical methods (45 total PFAS analytes). The user can enter the site-specific PFAS concentration data into the PSDA. The compound name, abbreviation, and CAS Number are provided for reference. Each PFAS compound is separated into one of three families: PFCA, PFSA, or Other. The concentration information for each category of PFAS is aggregated, and a pie chart is developed based on that information. The results can then be used in a variety of ways to support source differentiation efforts, including the following:

- Site-specific results can be compared to compositional analyses for the main source categories (e.g., airports or chrome plating) as described in Chapter 6 and shown in Figure 6-1.

- Results from different sampling locations within or near the site can be compared to help the user to visualize PFAS compositional changes with distance from a presumed source and to identify locations at which differences in composition could be related to contributions from other sources.

Results from these comparisons should not be considered definitive regarding PFAS sources, but rather should be weighed against other available information (i.e., the desktop review output) to increase confidence in a lines-of-evidence approach toward source differentiation. It is also important to note that compositional changes may occur over time and over distance from the same source; the results of this analysis should therefore incorporate consideration of compositional changes that may have occurred.

It should be noted that the compositional analysis includes three families of PFAS compounds that may not be available with all analytical methods. Therefore, the comparative value of output will increase with a greater number of PFAS analytes.

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List of Acronyms

6:2 FTS	6:2 fluorotelomer sulfonate
ADONA	Dodecafluoro-3H-4,8-dioxanoate
AFFF	Aqueous film forming foam
AOF	Adsorbable organic fluorine
ARFF	Aircraft rescue and firefighting
ASTM	American Society for Testing and Materials
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CSM	Conceptual site model
EGLE	Michigan Department of Environment, Great Lakes, and Energy
EPCRA	Emergency Planning and Community Right-to-Know Act of 1986
ESA	Environmental site assessment
F3	Fluorine-free foam
GIS	Geographic information system
HA	Health advisory
HEF	High expansion foam
HRMS	High resolution mass spectrometry
IRS	Internal Revenue Service
ITRC	Interstate Technology and Regulatory Council
LC-MS/MS	Liquid chromatography with tandem mass spectrometry
MAPA	Managing AFFF and PFAS at Airports
MPART	Michigan PFAS Action Response Team
MPCA	Minnesota Pollution Control Agency
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
PCA	Principal component analysis
PFAA	Perfluoroalkyl acids
PFAS	Per- and polyfluorinated alkyl substances
PFBA	Perfluorobutanoic acid
PFBS	Perfluorobutane sulfonate
PFCA	Perfluoroalkyl carboxylates
PFDS	Perfluorodecane sulfonic acid
PFECHS	Perfluoro-4-ethylcyclohexanesulfonate
PFHxA	Perfluorohexanoic acid
PFHxS	Perfluorohexane sulfonate
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonate
PFPeA	Perfluoropentanoic acid
PFSA	Perfluoroakyl sulfonates

POTW	Publicly owned treatment works
PRP	Potentially responsible party
PSDA	PFAS Source Differentiation Preliminary Screening Application
QSM	Quality Systems Manual
SWPPP	Stormwater pollution prevention plan
TAT	Turnaround time
TOF	Total organofluorine
TOP	Total oxidizable precursor
U.S. DOD	United States Department of Defense
U.S. EPA	United States Environmental Protection Agency
UCMR 5	Fifth Unregulated Contaminant Monitoring Rule
USGS	United States Geological Survey
WWTP	Wastewater treatment plant

Appendix A

Table A-1. PFAS analytes in project database.

Abbreviation	Name – Acid/Neutral Form	CAS#	Compound Class
HFPO-DA	Hexafluoropropylene oxide dimer acid	13252-13-6	Other
N-EtFOSAA	N-Ethylperfluorooctanesulfonamidoacetic acid	2991-50-6	Other
N-MeFOSAA	N-Methylperfluorooctanesulfonamidoacetic acid	2355-31-9	Other
PFBS	Perfluorobutanesulfonic acid	375-73-5	PFSA*
PFDA	Perfluorodecanoic acid	335-76-2	PFCA
PFHpA	Perfluoroheptanoic acid	375-85-9	PFCA
PFHxS	Perfluorohexanesulfonic acid	355-46-4	PFSA
PFHxA	Perfluorohexanoic acid	307-24-4	PFCA**
PFNA	Perfluorononanoic acid	375-95-1	PFCA
PFOS	Perfluorooctanesulfonic acid	1763-23-1	PFSA
PFOA	Perfluorooctanoic acid	335-67-1	PFCA
PFTeDA	Perfluorotetradecanoic acid	376-06-7	PFCA
PFTrDA	Perfluorotridecanoic acid	72629-94-8	PFCA
PFHxDA	Perfluoro-n-hexadecanoic acid	67905-19-5	PFCA
PFODA	Perfluoro-n-octadecanoic acid	16517-11-6	PFCA
11 Cl-PF3OUdS	11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid	763051-92-9	Other
9 Cl-PF3ONS	9-chlorohexadecafluoro-3-oxanonane-1-sulfonic acid	756426-58-1	Other
ADONA	4,8-dioxa-3H-perfluorononanoic acid	919005-14-4	Other
PFPeS	Perfluoropentanesulfonic acid	2706-91-4	PFSA
PFHpS	Perfluoroheptanesulfonic acid	375-92-8	PFSA
PFNS	Perfluorononanesulfonic acid	68259-12-1	PFSA
PFDS	Perfluorodecanesulfonic acid	335-77-3	PFSA
4:2 FTS	4:2 fluorotelomersulfonic acid	757124-72-4	Other
6:2 FTS	6:2 fluorotelomersulfonic acid	27619-97-2	Other
8:2 FTS	8:2 fluorotelomersulfonic acid	39108-34-4	Other
10:2 FTS	1H,1H,2H,2H-perfluorododecane sulfonate	120226-60-0	Other
PFBA	Perfluorobutanoic acid	375-22-4	PFCA
PFPeA	Perfluoropentanoic acid	2706-90-3	PFCA
PFUnDA	Perfluoroundecanoic acid	2058-94-8	PFCA
PFDoDA	Perfluorododecanoic acid	307-55-1	PFCA
PFOSA	Perfluorooctanesulfonamide	754-91-6	Other
PFDoS	Perfluorododecanesulfonic acid	79780-39-5	PFSA
N-MeFOSA	N-Methylperfluorooctanesulfonamide	31506-32-8	Other
N-EtFOSA	N-Ethylperfluorooctanesulfonamide	4151-50-2	Other
N-MeFOSE	N-Methylperfluorooctanesulfonamidoethanol	24448-09-7	Other
N-EtFOSE	N-Ethylperfluorooctanesulfonamidoethanol	1691-99-2	Other
3:3 FTCA	2H, 2H, 3H, 3H-perfluorohexanoic acid	356-02-5	Other
5:3 FTCA	2H, 2H, 3H, 3H-perfluorooctanoic acid	914637-49-3	Other
7:3 FTCA	2H, 2H, 3H, 3H-perfluorodecanoic acid	812-70-4	Other
6:2 FTCA	2-perfluorohexyl ethanoic acid	53826-12-3	Other
8:2 FTA	2-perfluorooctyl ethanoic acid	27854-31-5	Other

* PFSA = Perfluoroalkyl sulfonic acid
** PFCA = Perfluoroalkyl carboxylic acid

Table A-2. Comparison of PFAS analytes across various analytical methods.

			U.S. EPA				ATSM
Abbreviation	**Name – Acid/Neutral Form**	**CAS#**	**Method 537.1**	**Method 533**	**Method 8327**	**Draft Method 1633**	**D7968**
HFPO-DA	Hexafluoropropylene oxide dimer acid	13252-13-6	✓	✓	✗	✓	✗
N-EtFOSAA	N-Ethylperfluorooctanesulfonamidoacetic acid	2991-50-6	✓	✗	✓	✓	✗
N-MeFOSAA	N-Methylperfluorooctanesulfonamidoacetic acid	2355-31-9	✓	✗	✓	✓	✗
PFBS	Perfluorobutanesulfonic acid	375-73-5	✓	✓	✓	✓	✓
PFDA	Perfluorodecanoic acid	335-76-2	✓	✓	✓	✓	✓
PFHpA	Perfluoroheptanoic acid	375-85-9	✓	✓	✓	✓	✓
PFHxS	Perfluorohexanesulfonic acid	355-46-4	✓	✓	✓	✓	✓
PFHxA	Perfluorohexanoic acid	307-24-4	✓	✓	✓	✓	✓
PFNA	Perfluorononanoic acid	375-95-1	✓	✓	✓	✓	✓
PFOS	Perfluorooctanesulfonic acid	1763-23-1	✓	✓	✓	✓	✓
PFOA	Perfluorooctanoic acid	335-67-1	✓	✓	✓	✓	✓
PFTeDA	Perfluorotetradecanoic acid	376-06-7	✓	✗	✓	✓	✓
PFTrDA	Perfluorotridecanoic acid	72629-94-8	✓	✗	✓	✓	✓
PFHxDA	Perfluoro-n-hexadecanoic acid	67905-19-5	✗	✗	✗	✗	✗
PFODA	Perfluoro-n-octadecanoic acid	16517-11-6	✗	✗	✗	✗	✗
11 Cl-PF3OUdS	11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid	763051-92-9	✓	✓	✗	✓	✗
9 Cl-PF3ONS	9-chlorohexadecafluoro-3-oxanonane-1-sulfonic acid	756426-58-1	✓	✓	✗	✓	✗
ADONA	4,8-dioxa-3H-perfluorononanoic acid	919005-14-4	✓	✓	✗	✓	✗
PFPeS	Perfluoropentanesulfonic acid	2706-91-4	✗	✓	✓	✓	✗
PFHpS	Perfluoroheptanesulfonic acid	375-92-8	✗	✓	✓	✓	✗
PFNS	Perfluorononanesulfonic acid	68259-12-1	✗	✗	✓	✓	✗
PFDS	Perfluorodecanesulfonic acid	335-77-3	✗	✗	✓	✓	✗
4:2 FTS	4:2 fluorotelomersulfonic acid	757124-72-4	✗	✓	✓	✓	✗
6:2 FTS	6:2 fluorotelomersulfonic acid	27619-97-2	✗	✓	✓	✓	✗
8:2 FTS	8:2 fluorotelomersulfonic acid	39108-34-4	✗	✓	✓	✓	✗

10:2 FTS	1H,1H,2H,2H-perfluorododecane sulfonate	120226-60-0	✗	✗	✗	✗	✗
PFBA	Perfluorobutanoic acid	375-22-4	✗	✓	✓	✓	✓
PFPeA	Perfluoropentanoic acid	2706-90-3	✗	✓	✓	✓	✓
PFUnDA	Perfluoroundecanoic acid	2058-94-8	✓	✓	✓	✓	✓
PFDoDA	Perfluorododecanoic acid	307-55-1	✓	✓	✓	✓	✓
PFOSA	Perfluorooctanesulfonamide	754-91-6	✗	✗	✓	✓	✗
PFDoS	Perfluorododecanesulfonic acid	79780-39-5	✗	✗	✗	✓	✗
N-MeFOSA	N-Methylperfluorooctanesulfonamide	31506-32-8	✗	✗	✗	✓	✗
N-EtFOSA	N-Ethylperfluorooctanesulfonamide	4151-50-2	✗	✗	✗	✓	✗
N-MeFOSE	N-Methylperfluorooctanesulfonamidoethanol	24448-09-7	✗	✗	✗	✓	✗
N-EtFOSE	N-Ethylperfluorooctanesulfonamidoethanol	1691-99-2	✗	✗	✗	✓	✗
3:3 FTCA	2H, 2H, 3H, 3H-perfluorohexanoic acid	356-02-5	✗	✗	✗	✓	✗
5:3 FTCA	2H, 2H, 3H, 3H-perfluorooctanoic acid	914637-49-3	✗	✗	✗	✓	✗
7:3 FTCA	2H, 2H, 3H, 3H-perfluorodecanoic acid	812-70-4	✗	✗	✗	✓	✓
6:2 FTCA	2-perfluorohexyl ethanoic acid	53826-12-3	✗	✗	✗	✗	✓
8:2 FTA	2-perfluorooctyl ethanoic acid	27854-31-5	✗	✗	✗	✗	✓
NFDHA	Perfluoro-3,6-dioxaheptanoic acid	151772-58-6	✗	✓	✗	✓	✗
PFEESA	Perfluoro(2-ethoxyethane)sulfonic acid	113507-82-7	✗	✓	✗	✓	✗
PFMPA	Perfluoro-3-methoxypropanoic acid	377-73-1	✗	✓	✗	✓	✗
PFMBA	Perfluoro-4-methoxybutanoic acid	863090-89-5	✗	✓	✗	✓	✗
PFecHS	Decafluoro-4-(pentafluoroethyl)cyclohexanesulfonate	67584-42-3	✗	✗	✗	✗	✓
8:2 FTUCA	2H-perfluoro-2-decenoic acid	70887-84-2	✗	✗	✗	✗	✓
10:2 FDEA	2-perfluorodecyl ethanoic acid	53826-13-4	✗	✗	✗	✗	✓
6:2 FHUEA	2H-perfluoro-2-octenoic acid	70887-88-6	✗	✗	✗	✗	✓

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
GHSA	Governors Highway Safety Association
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S. DOT	United States Department of Transportation

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