Use and Potential Impacts of AFFF Containing PFASs at Airports

DETAILS

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AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP RESEARCH REPORT 173

Use and Potential Impacts of AFFF Containing PFASs at Airports

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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.

The need for ACRP was identified in *TRB Special Report 272: Airport Research Needs: Cooperative Solutions* in 2003, based on a study sponsored by the Federal Aviation Administration (FAA). ACRP carries out applied research on problems that are shared by airport operating agencies and not being adequately addressed by existing federal research programs. ACRP is modeled after the successful National Cooperative Highway Research Program (NCHRP) and Transit Cooperative Research Program (TCRP). ACRP undertakes research and other technical activities in various airport subject areas, including design, construction, legal, maintenance, operations, safety, policy, planning, human resources, and administration. ACRP provides a forum where airport operators can cooperatively address common operational problems.

ACRP was authorized in December 2003 as part of the Vision 100—Century of Aviation Reauthorization Act. The primary participants in the ACRP are (1) an independent governing board, the ACRP Oversight Committee (AOC), appointed by the Secretary of the U.S. Department of Transportation with representation from airport operating agencies, other stakeholders, and relevant industry organizations such as the Airports Council International-North America (ACI-NA), the American Association of Airport Executives (AAAE), the National Association of State Aviation Officials (NASAO), Airlines for America (A4A), and the Airport Consultants Council (ACC) as vital links to the airport community; (2) TRB as program manager and secretariat for the governing board; and (3) the FAA as program sponsor. In October 2005, the FAA executed a contract with the National Academy of Sciences formally initiating the program.

ACRP benefits from the cooperation and participation of airport professionals, air carriers, shippers, state and local government officials, equipment and service suppliers, other airport users, and research organizations. Each of these participants has different interests and responsibilities, and each is an integral part of this cooperative research effort.

Research problem statements for ACRP are solicited periodically but may be submitted to TRB by anyone at any time. It is the responsibility of the AOC to formulate the research program by identifying the highest priority projects and defining funding levels and expected products.

Once selected, each ACRP project is assigned to an expert panel appointed by TRB. Panels include experienced practitioners and research specialists; heavy emphasis is placed on including airport professionals, the intended users of the research products. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, ACRP project panels serve voluntarily without compensation.

Primary emphasis is placed on disseminating ACRP results to the intended users of the research: airport operating agencies, service providers, and academic institutions. ACRP produces a series of research reports for use by airport operators, local agencies, the FAA, and other interested parties; industry associations may arrange for workshops, training aids, field visits, webinars, and other activities to ensure that results are implemented by airport industry practitioners.

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FOREWORD

By Joseph D. Navarrete
Staff Officer
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ACRP Research Report 173: Use and Potential Impacts of AFFF Containing PFASs at Airports is a comprehensive resource for understanding the potential environmental and health impacts of per- and polyfluoroalkyl substances (PFASs) typically found in aqueous film-forming foams (AFFFs). The report will be of particular interest to airport industry practitioners who wish to learn about the issue, take steps to identify areas of potential concern at their airport, and implement recommended management and remediation practices.

AFFF has been used for extinguishing fires and for firefighter training at airports for decades. The use of AFFF results in the release of PFASs into the environment. Some PFASs are known to be persistent in the natural environment and pose potential human and ecological health risks. Government agencies are developing regulation of these chemicals, and these regulations will likely impact airports. Research was needed to help airports identify potential areas impacted by AFFF use and minimize further potential impacts from future actions.

The research, led by Dillon Consulting Limited, included a review of literature regarding environmental fate and transport and remediation of PFASs, both in North America and in other world regions, with a particular focus on the use of AFFF in airport settings. To gauge the level of awareness and gain a better understanding of management practices, the research team conducted an extensive survey of 167 North American airports. The research team also reached out to subject matter experts, including AFFF manufacturers, emergency response personnel, industry trade organizations, academia, analytical laboratories, and government regulators.

The report features a primer on PFASs that summarizes their composition, structure, and sources, as well as potential environmental and toxicological concerns about PFASs, regulatory issues, and how PFASs may affect airports. The report also provides a discussion of AFFF management in an airport setting and recommended practices to investigate legacy environmental impacts, potential risks, and remediation options.

To help airports identify areas of potential environmental concern, the research team developed the Managing AFFF and PFASs at Airports (MAPA) Screening Tool. The screening tool provides results for the airport as a whole and for individual areas of potential concern. The tool can also be used to foster collaboration among functional departments responsible for management of AFFF and assessment of contamination by PFASs and remediation. The tool can be accessed at www.trb.org/main/blurbs/175866.aspx.

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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 www.trb.org) retains the color versions.

SUMMARY

Use and Potential Impacts of AFFF Containing PFASs at Airports

For decades, aqueous film-forming foam (AFFF) containing per- and polyfluoroalkyl substances (PFASs) has been used at airports across the United States and Canada for extinguishing fires and in training firefighters. While PFASs provide the principal efficacy of AFFF as a firefighting agent against Class B fires, the discharge to the environment of AFFF containing PFASs presents potentially unacceptable human health and ecological risks.

Since the 1990s, data have been collected showing that earlier formulations of AFFF contained some PFASs that are persistent and bioaccumulative. Environmental regulation and guidance have developed in response to ecotoxicological studies, the establishment of standard field sampling techniques, and increased accuracy of laboratory analytical methods. In response to the introduction of U.S. EPA Significant New Use Rules (SNURs) in the United States and pursuant to the Canadian Environmental Protection Act, manufacturers have changed their AFFF formulations so that they are free of perfluorooctane sulfonic acid (PFOS), and manufacturers are in the process of developing formulations that are free of perfluorooctanoic acid (PFOA) (PFOS and PFOA are two of the most prevalent and potentially problematic PFASs.) Although advances have been made in risk management strategies and remediation technologies, research to identify applicable, cost-effective approaches to managing the impacts of AFFF and related PFASs at airports is ongoing.

Under ACRP Project 02-60, a survey was conducted of 167 airports across the United States and Canada. Airport representatives, including emergency responders and environmental managers, were asked 42 questions about the management of AFFF at various life cycle stages at their airport, including procurement, storage, application, and disposal. In addition, the survey asked how airports may have addressed legacy environmental impacts associated with PFASs in environmental media (i.e., soil, groundwater, sediment, surface water) at airports where such environmental assessment and remediation had taken place. The research also included a literature review of peer-reviewed (e.g., scientific journal articles) and non-peer-reviewed (e.g., industry articles) materials and consultation with subject matter and industry experts.

Based on the ACRP Project 02-60 research, this report identifies current regulations and regulatory guidance regarding the management of AFFF at the various life cycle stages and the impacts of PFASs on the environment, the current state of practice at civilian airports in the United States and Canada, and best management practices to help guide airports in mitigating future potential impacts associated with AFFF use and managing historical impacts associated with AFFF application.

At the procurement stage, U.S. and Canadian airports are required to purchase firefighting foam that meets jurisdictional specifications MIL-F-24385 (MIL-SPEC) and CAN/ULC-S560-06, respectively. As a result, alternatives to AFFF containing PFASs are limited.

Moreover, all firefighting foams, even those that do not contain PFASs, have the potential to impact the environment. Providing information on potentially adverse environmental impacts and other environmental considerations will help to foster the responsible purchase, use, and disposal of firefighting foams at airports.

Survey results indicated that storage conditions for these chemicals vary among airports. Storage conditions should, at a minimum, meet the requirements listed on the product sheets provided by suppliers. At many airports, application and disposal of AFFF involve multi-departmental activities. Often, environmental personnel are the most aware of the implications associated with PFASs in AFFF, but they may not be aware of all of the ways that AFFF is tested or used by emergency response and/or operations personnel. For instance, in the survey conducted as part of this research, it was found that firefighting personnel may be aware that they are handling a chemical, but they may also falsely assume that the chemical is "safe" for the environment because historically they have been allowed to discharge/use it broadly. Awareness of methods for collection of discharged AFFF and disposal was not consistent among airports.

Standardized sampling methodologies have been adapted for investigating the impacts of PFASs. Given the ubiquity of PFASs and their ability to stick to many different surfaces, cross-contamination is the largest concern in ensuring that samples collected are representative and will provide meaningful results. Standardized analytical methods have been developed for PFASs in drinking water—reinforcing the need for airports to use accredited laboratories with standardized testing methods for PFASs that will produce reproducible results.

To help airport representatives apply the findings of the ACRP Project 02-60 research, a screening tool (i.e., a macros-enabled Microsoft Excel™ workbook) was developed that allows airports to better integrate best management practices into the AFFF life cycle at their facilities, identify and manage potential risks associated with historical and/or current AFFF use at their site, and prioritize where resources need to be allocated to address concerns regarding AFFF and PFASs.

Best management practices for airports managing AFFF and addressing environmental impacts related to PFASs are presented in Table S-1.

Table S-1. Best management practices for managing AFFF and addressing environmental impacts related to PFASs.

Life Cycle Stage	Recommended Best Management Practice	Description
Procurement: Regulatory Requirements	Use firefighting foam that fulfills regulatory requirements for safety/use.	Meet the requirements of • The Code of Federal Regulations (CFR), Title 14 – Aeronautics and Space, Part 139, Certification of Airports (14 CFR Part 139), in the United States • Canadian Aviation Regulations, Standard 323 Aircraft Fire Fighting at Airports and Aerodromes, Part III Aerodromes, Airports and Heliports, in Canada
	Use short-chain fluorotelomer based AFFF (i.e., carbon chain C_6 and below). Do not use long-chain ($>C_6$) AFFF that may contain or degrade into perfluorooctanoic acid (PFOA), (PFOS), their salts and/or precursors.	Comply with • U.S. EPA Significant New Use Rules (40 CFR 721.9582) • Canadian Environmental Protection Act

Table S-1. (Continued).

Life Cycle Stage	Recommended Best Management Practice	Description
Procurement: AFFF Performance	Confirm that AFFF purchased meets relevant performance standards.	Demonstrate performance and quality meeting the performance standards for AFFF in the United States and Canada as follows: • United States Military Specification (MIL-SPEC): MIL-F-24385 (Fire Extinguishing Agent, Aqueous Film Forming Foam (AFFF) Liquid Concentrate, for Fresh and Seawater) • Underwriters Laboratories Inc. (UL): Foam Equipment and Liquid Concentrates (UL 162) • Standards Council of Canada (SCC): CAN/ULC-S560-06 (Standard for Category 3 AFFF Liquid Concentrates)
Procurement: Environmental Consideration	Review environmental data, where available, from a product's specification.	Choose a foam with the following criteria: • Highest lethal dose (LD50) • Lowest biochemical oxygen demand (BOD) • Lowest chemical oxygen demand (COD) • Highest LC50 • Highest half-maximal effective concentration (EC50)
Procurement: System and Equipment Compatibility	Check compatibility of AFFF.	Check compatibility with • Existing systems and equipment • Previous/existing AFFF type/batch
	Shift toward using 3 percent AFFF concentrates where possible.	AFFF that meets the above specifications comes in 3 percent and 6 percent concentrate formulations. Upgrade equipment to be compatible with lower percentage use, when applicable.
Storage	Use appropriate containers.	Read and follow storage procedures outlined in AFFF concentrate: • Material safety data sheets (SDSs) • Technical data sheets (TDSs)
	Store under appropriate conditions.	Read and follow storage procedures outlined in Material SDS and TDS for the product. Containers for AFFF concentrate storage should be • Sealed • Secured • Stored in appropriate temperature ranges • Not be mixed (with other foam concentrates or brands) • In a designated area • Roofed/sheltered • Use bunded storage methods • Not stacked more than two drums high
Application: Handling	Store the recommended reserves.	Know the current aircraft rescue and firefighting (ARFF) category of the airport and store the recommended reserve quantities as per the FAA (United States) or Transport Canada (Canada) requirements/recommendations.
	Staff awareness of PFASs and AFFF.	Train all staff who could come into contact with AFFF about the human health and environmental implications associated with historical and current AFFF formulations.
	Train staff and follow industry-recommended procedures.	When handling AFFF • Have a Safety Spill Plan in place when transferring AFFF • Read and follow handling procedures outlined in product SDS • Read and follow NFPA 402: Guide for Aircraft Rescue and Fire-Fighting Operations • Wear the appropriate personal protective equipment (PPE) (at a minimum as detailed in the product SDS) • Do not use galvanized pipe and fittings in contact with undiluted concentrate • Limit distance between storage and filling areas • Where possible, have more than one person assisting with moving AFFF containers
Application: Firefighting Training	Training practices.	Firefighting training should • Follow a prescribed training schedule that aligns with the appropriate guidelines and regulations • Involve preparation in advance of training practices (e.g., develop and review safety spill plan in advance, communicate so that personnel are aware of and understand activities in advance)

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Table S-1. (Continued).

Life Cycle Stage	Recommended Best Management Practice	Description
		• Use propane as a fuel source in lieu of flammable hydrocarbons • Take place in an area where water/foam solution can be contained and collected for treatment • Consider using alternative foam products for training exercises
	Use appropriate training facilities.	• Use a regional facility or host live-fire training for multiple airports at one facility • Configure training area to allow collection and disposal of discharged AFFF used during training • Do not discharge to ground (i.e., discharge of AFFF during training should be to an engineered, lined fire training area) • Locate training exercises away from storm drain inlets, drainage facilities, and surface water bodies
Application: System and Equipment Testing	Discharge and collect minimum volumes of AFFF.	• Discharge the minimum volume of AFFF needed to test the system/equipment • Use the same collected samples for multiple tests, where applicable • Develop and employ a Safety Spill Plan • Collect discharge for storage and disposal • Conduct ground pattern tests first with water (ensure set-up), then with the foam solution • Ensure fittings are tight and secure • Maintain equipment in good condition to reduce spillage/waste
Application: Aircraft Hangars	Construct the aircraft hangar following local building code and to mitigate AFFF impacts.	• Read and follow NFPA 402, 403, and 409 • Have piping that connects the foam to the fire suppression system be above ground, over a concrete floor • Provide protection for the aircraft hangar (including electrical and mechanical equipment) potentially exposed to AFFF during discharge tests
Application: Firefighting Training/ Aircraft Rescue	Provided standardized, industry-recommended training.	• Educate and train staff in standardized procedures for safety and environmental concerns of AFFF • Follow industry-recommended practices, e.g., NFPA 403 Section 3.4.3 (2014); NFPA 1003, FAA Advisory Circular No. 150/5210-17C
Application: Emergency Response	Improve communication and response between environmental personnel and firefighting personnel.	• Hazardous waste/spill response team should be nearby to provide preliminary containment and conduct clean-up activities as soon as feasible after emergency has been mitigated • Firefighting team should alert environmental team when deploying, moving, and/or testing AFFF
Application: Discharge	Dispose of foam-water, foam-hydrocarbon, and foam-soil mixtures as appropriate given the local guidelines, legislation, and regulations.	• Personnel handling AFFF should wear appropriate PPE • Record AFFF types, quantities, and disposal method/destination • Dispose of discharged AFFF at an authorized, licensed location
Disposal: Removal from Equipment or Systems	Transfer by pump to containment vessel.	• Personnel handling AFFF should wear appropriate PPE • Containment vessel should have secondary containment during removal/transfer process • Flush/clean out equipment thoroughly, retaining rinse water

Table S-1. (Continued).

Life Cycle Stage	Recommended Best Management Practice	Description
Disposal: Removal from Equipment or Systems	Disposal.	• Dispose of discharged AFFF at an authorized, licensed location • In the United States, meet the requirements of the Code of Federal Regulations (CFR), Title 14 – Aeronautics and Space, Part 139, Certification of Airports (14 CFR Part 139), 139.317 Aircraft Rescue and Firefighting: Equipment and Agents. Follow FAA Guidance Documents (Advisory Circulars and Cert Alerts); align with the targets of the U.S. EPA 2010/2015 PFOA Stewardship Program • In Canada, meet the requirements of the Canadian Aviation Regulations, Standard 323 Aircraft Fire Fighting at Airports and Aerodromes and comply with Part III Aerodromes, Airports and Heliports of the Regulations. Section 323.08 of the Standard, Extinguishing Agents and Equipment • In Canada, comply with Perfluorooctane Sulfonate and Its Salts and Certain Other Compounds Regulations (2008), which prohibits the manufacture, use, sale, offer for sale, and import of PFOS and products containing PFOS
Legacy: Sampling for PFASs	Use standardized field procedures, adapted for PFASs.	• Avoid using polytetrafluoroethylene (PTFE), glass, and/or metals in sampling materials • Follow U.S. EPA Method 537 or modified U.S. EPA Method 537 – "Determination of selected perfluorinated alkyl acids in drinking water by solid phase extraction and liquid chromatography/tandem mass spectrometry (LC-MS/MS)" with respect to guidance for sample collection as appropriate for the sample media under investigation • Follow Transport Canada's Perfluorochemical Sampling and Analysis Guidance • Follow United Nations Environment Programme (UNEP) Chemical Branch "PFAS analysis in water for the Global Monitoring Plan of the Stockholm Convention – set-up and guidelines for monitoring"
	Avoid cross-contamination.	• Avoid using PTFE, aluminum foil, glass, and/or metal in sampling materials and containers • Verify drilling/hydroexcavation water is free of PFASs • Verify field equipment is cleaned in between sampling locations using water free of PFASs • Avoid wearing water resistant, waterproof, or stain-treated clothing during field programs • Avoid using waterproof fieldbooks/paper during field programs • Frequently change disposable, single-use gloves (e.g., nitrile or latex) • Do not bring food on-site in any paper packaging (e.g., fast food) • Field personnel should wash hands after eating and prior to donning PPE and engaging in sample collection • Field personnel should avoid directly contacting samples after touching their footwear (e.g., tying shoelaces)
Legacy: Analysis of PFASs	Avoid suspended particulate matter in aqueous samples.	• Groundwater sampling should follow the field procedures established for low-flow purging (with adaptations to address the cross-contamination concerns identified above) • Surface water samples should be collected avoiding suspended and/or particulate matter in retrieved water samples
	Sampling frequency.	Sampling programs should assess seasonal considerations and be conducted more than once to assess whether site conditions are changing (e.g., precursors transforming/degrading to PFOS, PFOA).
	Quality assurance/quality control.	• Use laboratory-supplied water free of PFASs • Use laboratory-supplied sample containers free of PFASs • Use appropriate QA/QC samples: field duplicates, and equipment and field reagent blanks

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Table S-1. (Continued).

Life Cycle Stage	Recommended Best Management Practice	Description
	Use an accredited laboratory.	In the United States, use a laboratory that is accredited by one (or more) of the following: • U.S. Department of Defense Environmental Laboratory Accreditation Program (DoD ELAP) (http://www.denix.osd.mil/edqw/Accreditation/AccreditedLabs.cfm) • American Association for Laboratory Accreditation (A2LA) (https://www.a2la.org/dirsearchnew/newsearch.cfm) • Perry Johnson Laboratory Accreditation, Inc. (PJLA) (http://www.pjlabs.com/search-accredited-labs) • ANSI-ASQ National Accreditation Board (ANAB) (http://search.anab.org/search-accredited-companies.aspx) • Laboratory Accreditation Bureau (L-A-B) (http://search.l-a-b.com/) In Canada, use a laboratory that is accredited by one (or more) of the following • SCC (https://www.scc.ca/en/accreditation/product-process-and-service-certification/directory-of-accredited-clients) • Canadian Association for Laboratory Accreditation Inc. (CALA) (http://www.caladirectory.ca/)
	Use standardized methodologies.	• Check that your commercial laboratory is using suitable standard methodology to carry out analyses of PFASs • Contact the analytical laboratory prior to sampling to confirm that PFASs are included in their standard analysis and confirm the sampling requirements • Confirm that your commercial laboratory reports PFOS values that include both branched and linear isomers • Consider precursors' influence in environmental quality assessment and discuss available precursor analyses with laboratory • Quality assurance and quality control flags should be reviewed with the commercial laboratory prior to accepting or rejecting the results
Legacy: Risk Management	Identify source areas at the airport.	As part of the development of a conceptual site model (CSM), identify: • AFFF storage areas (i.e., where the potential for leaks and spills existed) • Areas where AFFF was applied as part of an emergency response • Firefighting training areas, burn pits, or other areas where AFFF may have been discharged as part of training • Areas where AFFF was discharged as part of foam testing • Areas where AFFF was loaded or removed from ARFF vehicles during vehicle maintenance • Historical disposal areas (e.g., where expired or contaminated AFFF concentrate was disposed to the environment or where AFFF foam was directed following release [including lagoons and retention ponds]) • Use MAPA Screening Tool to identify areas of potential environmental concern on or near the airport
	Identify and evaluate exposure pathways at the airport.	As part of the development of a CSM, identify: • Human health—dermal contact and/or ingestion, potable water, fish consumption • Ecological—ecological soil contact, groundwater to surface water • Lateral migration pathways (e.g., surface runoff) • Vertical migration (e.g., infiltration/percolation)
Legacy: Remediation	Identify receptors at the airport.	As part of the development of a CSM, identify: • Surface water bodies • Fish • Birds • Terrestrial animals • Invertebrates • Human receptors

Table S-1. (Continued).

Life Cycle Stage	Recommended Best Management Practice	Description
	Adopt risk management strategies that intercept the exposure pathway between source term and receptor.	Where feasible, • Eliminate direct contact to soil impacted by PFASs and limit infiltration (and potential groundwater migration) by covering a portion of the site with pavement • Eliminate surface water runoff to prevent surface water from being impacted by sediment containing PFASs • Require workers to don appropriate PPE when working with AFFF or media impacted by PFASs • Prohibit potable groundwater or surface water use by providing an alternate water supply should a potable source be suspected of being impacted by PFASs • Install erosion and sediment controls in areas where soils may be impacted by PFASs and disturbance is planned
	Develop decision model to support the choice of short-term and long-term remediation strategies.	Consider • Which PFASs are present and their physicochemical properties • Remedial objectives • Hydrogeological conditions • Off-site and on-site risks at present and in the future • Acceptable time frames for remediation • Technology acceptance and stakeholder involvement • Costs for remediation • Acceptable impacts on day-to-day operations
	Soil remediation techniques.	• High-temperature incineration (>1100°C) • Landfill disposal at a facility that is appropriately designed to treat and handle PFAS-impacted soils immobilization/stabilization (e.g., amine-modified clay sorbents)
	Groundwater.	• Pump and treat (e.g., using activated carbon, ion exchange resin, coagulation, membranes) • Permeable reactive barrier. *-Note that activated carbon has been shown to be ineffective for removing short-chain PFASs*
	Discharged AFFF.	• Collect and contain discharged foam • Pretreatment may be required prior to acceptance at a wastewater treatment facility • If no suitable wastewater treatment is available, high-temperature incineration (i.e., > 1100°C)

CHAPTER 1

Introduction and Purpose

1.1 Understanding the Problem

Aqueous film-forming foam (AFFF) has been used for extinguishing fires and training firefighters at airports for decades. AFFF formulations most frequently include surfactants of the class of chemicals called per- and polyfluoroalkyl substances (PFASs) that improve fire knock-down capabilities. The historical use of AFFF is likely to have resulted in the release of PFASs into the environment. Some PFASs exhibit chemical, physical, and toxicological properties that are problematic. These problematic properties include being extremely persistent in the natural environment; potentially presenting human and ecological health risks; bioaccumulating and biomagnifying; and exhibiting physicochemical properties that challenge traditional handling, cleaning, and decontaminating methods. An increase in regulatory attention to PFASs has led to a rapidly evolving regulatory landscape that could impact airports. As a result, airports that have stored and/or used AFFF face operational considerations relative to the existing storage, use, testing, and/or disposal of AFFF containing PFASs. In addition, legacy impacts have the potential to significantly affect capital improvement projects should impacts of PFASs be encountered.

1.2 Project Objectives

The overall objective of this research was to develop an easy-to-understand reference document for airport personnel on what is known and not known about PFASs and their use in AFFF at airports and to develop an accompanying screening tool for use by operators of commercial service and general aviation airports of varying sizes to understand, diagnose, and improve management practices for AFFF and PFASs.

Specific project objectives were the following:

- Understand what airports know about AFFF and PFASs.
- Identify what practices have been and are being employed by airports to store, handle, remove, and dispose of AFFF.
- Identify current research and knowledge regarding the chemistry, fate and transport, and toxicology of PFASs.
- Understand the current regulatory environment related to PFASs.
- Identify the currently available AFFF alternatives (including those AFFFs containing PFASs and those not containing PFASs).
- Facilitate an airport's understanding of where AFFF and PFASs may represent an area of potential environmental concern and help prioritize future action.
- Evaluate innovative approaches to sampling of PFASs and thereby advancing the state of the practice.
- Identify and document advances in remediation technologies in the United States, Canada, and other jurisdictions across the world.

- Identify areas for future research.
- Develop a screening tool that could be used to assist airports with the identification of areas of potential environmental concern (APECs) on or near the airport.
- Develop an easily understood reference guidance document for airport personnel.

1.3 Report Organization

The remainder of this research report is organized into Chapters 2 through 7:

- Chapter 2 is a primer on PFASs at airports that discusses the nature of PFASs, including their physical, chemical, biological, and toxicological effects, as well as properties related to their fate and transport in the environment.
- Chapter 3 presents the research methodology for ACRP Project 02-60, describing the literature review, airport survey, and outreach to industry and subject matter experts that provides the basis for identifying AFFF management practices discussed in Chapter 4.
- Chapter 4 presents suggested best management practices at key AFFF life cycle stages, including procurement, storage, application, and disposal of AFFF that contains PFASs.
- Chapter 5 addresses legacy environmental impacts of AFFF containing PFASs, including considerations for sampling, laboratory analysis, risk management, and remediation options for assessing and addressing the impacts of PFASs on the environment.
- Chapter 6 presents a screening tool that allows airport representatives to identify potential sources of PFASs at airports (i.e., sources associated with airport operations past or present or activities associated with airport tenants on airport property).
- Chapter 7 provides recommendations for further research related to AFFF containing PFASs at airports.

A list of abbreviations, acronyms, initialisms, and symbols used in this research report and a glossary are also provided.

1.4 How to Use This Document

The purpose of this research report and accompanying risk screening tool is to help airport representatives understand the potential implications of the use of AFFF containing PFASs on human health and the environment; provide guidance on identifying, understanding, and mitigating the potential risks associated with AFFF use; identify best management practices for managing AFFF during airport operations; and identify best management practices for addressing legacy environmental impacts. This research report has been developed as a tool to encourage and enable collaboration among key stakeholders involved in management of AFFF procurement, storage, use, and disposal at the airport and the environmental implications of PFASs associated with historical AFFF releases to the environment.

Used alone, this research report can serve as a roadmap for airports interested in appropriately managing AFFF and addressing any impacts of PFASs. The report is designed to inform airport personnel about what is known and not known about PFASs and their use in AFFF at airports. By using the accompanying screening tool in conjunction with this report, airport personnel will be better able to integrate best management practices into the AFFF life cycle at their facilities, identify and manage potential risks associated with historical and/or current AFFF use at their site, and prioritize where resources need to be allocated to address concerns regarding AFFF and PFASs.

CHAPTER 2

Primer—Background on PFASs

PFASs belong to a family of chemicals that are in a variety of products found at airports. The predominant "source" of these compounds at an airport is AFFF, used in firefighting, but these compounds can also be associated with commercial, industrial, or manufacturing applications of airport tenants. The impact of PFASs on environmental media (i.e., soil, groundwater, sediment, surface water) may be the result of historical activities at airports and the surrounding vicinity because PFASs do not break down easily in the environment. Elevated concentrations of PFASs found in the environment and human populations have led to increased investigation and regulation of these compounds.

This chapter provides background information on PFASs, answering the following fundamental questions:

- What are PFASs?
- Where did/do PFASs come from?
- Why and how do PFASs pose a concern?
- What are the regulatory requirements regarding PFASs?
- How might PFASs affect an airport?

2.1 What Are PFASs?

PFASs are a large group of related, human-made, fluorinated organic chemicals (i.e., chemicals that contain fluorine and carbon atoms bonded together) that have unique properties due to their chemical structure and composition. As described in subsequent sections, many PFASs exhibit high degrees of chemical and thermal stability that make them useful in industrial and manufacturing applications. The chemical and thermal stability of many PFASs is what enables AFFF to have better firefighting performance; however, these same properties also contribute to why some PFASs have negative impacts to human health and the environment.

2.1.1 Chemical Composition

PFASs are organic chemicals that contain fluorine atoms bonded to a chain of carbon atoms. The carbon-fluorine bond is one of the strongest organic bonds in nature, and this strong bond contributes to the stability and persistence of some PFASs. Of particular interest and concern are perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA).

2.1.2 Chemical Structure

PFASs are generally composed of a perfluorinated carbon "tail" (i.e., carbon and fluorine) and a functional group "head." The compounds tend to be dual-natured, as the "head" and the

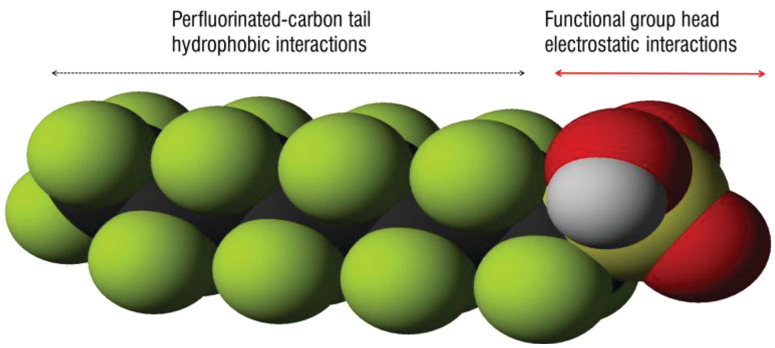


Figure 2-1. Structure of a perfluoroalkyl compound: the PFOS anion.

"tail" prefer different interactions (see Figure 2-1). The perfluorinated carbon tail tends to be both hydrophobic (water insoluble) and oleophobic (oil insoluble); the functional group head is more hydrophilic (water soluble). The solution chemistry (pH and ionic strength) affects the ability of PFASs to interact or bind with a surface by changing the electrostatic interactions between the head and the surface. Larger compounds can degrade or transform to smaller compounds that are more stable in the environment. Both PFOS and PFOA, for example, can be found in the environment as stable compounds resulting from the degradation of "parent" compounds, as well as being manufactured for a particular industrial application. PFASs found in AFFF can be cationic, zwitterionic, and anionic, resulting in very different fate and transport behaviors in the environment (*1*).

In the past, PFASs were often inappropriately referred to as "PFCs" (perfluorinated compounds), but this term can also be understood as perfluorocarbons, which do not contain functional groups (i.e., the "head" shown in Figure 2-1) and consist solely of the carbon-fluorine "tail," and therefore have properties and behaviors that are different from other types of PFASs.

For the purpose of this report, PFASs can be referred to as "long-chain" and "short-chain." Long-chain refers to

- Perfluoroalkyl carboxylic acids (PFCAs) with eight or more perfluorinated carbons.
- Perfluoroalkyl sulfonic acids (PFSAs) with six or more perfluorinated carbons.

The definition of long-chain is different for PFCAs and PFSAs because a PFSA with a given number of carbons has a greater tendency to bioconcentrate and/or bioaccumulate than a PFCA with the same number of carbon atoms. Short-chain PFASs are PFCA compounds that have fewer than eight carbons and PFSAs that have fewer than six carbon molecules. Please note that in much of this report, short-chain PFASs are referred to as C_6 or less because more recent AFFF formulations do not contain PFSAs. These more recent formulations include

- Perfluorobutanoic acid (PFBA), with four carbons.
- Perfluorohexanoic acid (PFHxA) with six carbons.

Table 2-1 provides the standard adopted nomenclature and hierarchy for PFASs. Given the confusion and varying acronyms (e.g., PFCs), this table has been provided to improve dialogue and understanding of terms among researchers, regulators, consultants, and stakeholders. Acronyms for subgroups of PFASs that are referred to in this document, and are more commonly known, are provided. It should be noted that the conjugate base forms (e.g., carboxylates and sulfonates) of the compounds are the forms typically found in the environment, even though in Table 2.1, these forms are referred to as acids.

Table 2-1. Example PFASs.

Type	Sub-Type	Individual Chemical Name and Acronym
Perfluoroalkyl acids (PFAAs)	Perfluoroalkyl carboxylic acids (PFCAs)	Perfluorobutanoic acid—PFBA Perfluoropentanoic acid—PFPeA Perfluorohexanoic acid—PFHxA Perfluoroheptanoic acid—PFHpA Perfluorooctanoic acid—PFOA Perfluorononanoic acid—PFNA Perfluorodecanoic acid—PFDA Perfluoroundecanoic acid—PFUnA Perfluorododecanoic acid—PFDoA Perfluorotridecanoic acid—PFTrDA Perfluorohexadecanoic acid—PFHxDA Perfluorooctadecanoic acid—PFOcDA
	Perfluoroalkyl sulfonic acids (PFSAs)	Perfluorobutane sulfonic acid—PFBS Perfluoropentane sulfonic acid—PFPeS Perfluorohexane sulfonic acid—PFHxS Perfluoroheptane sulfonic acid—PFHpS Perfluorooctane sulfonic acid—PFOS Perfluorononane sulfonic acid—PFNS
Perfluoroalkyl sulfamido substances (FASAs) *Precursor to PFSAs*	Perfluoroalkyl sulfamido substances (FASAs) *Precursor to PFSAs*	N-Ethyl-perfluorooctane sulfonamido ethanol—N-EtFOSE N-Methyl-perfluorooctane sulfonamido ethanol—N-MeFOSE N-Ethyl-perfluorooctane sulfonamido acetic acid—N-Et-PFOSA-AcOH N-Methyl-perfluorooctane sulfonamido acetic acid—N-Me-PFOSA-AcOH Perfluorooctane sulfonamide—PFOSA
Fluorotelomer alcohols (FTOHs) *Precursor to PFCAs*	Fluorotelomer alcohols (FTOHs) *Precursor to PFCAs*	6:2 Fluorotelomer alcohol—6:2 FTOH 8:2 Fluorotelomer alcohol—8:2 FTOH
Fluorotelomer sulfonic acids (FTSs) *Precursor to PFCAs and PFSAs*	Fluorotelomer sulfonic acids (FTSs) *Precursor to PFCAs and PFSAs*	6:2 Fluorotelomer sulfonic acid—6:2 FTS 8:2 Fluorotelomer sulfonic acid—8:2 FTS

2.2 Where Did/Do PFASs Come From?

PFASs were developed in the 1960s and adopted in AFFF formulations in the 1970s. In the airport industry, PFASs are known to have been used in AFFF for firefighting and associated training, industrial components related to aviation and aerospace, metal plating operations, biocides, and construction products. In addition, PFASs have been used in textiles, leather goods, and cooking utensils. Brief descriptions of product formulation and use are provided in the subsections below, with an emphasis on aviation-related sources.

2.2.1 Firefighting

In accordance with federal regulations (as detailed in Section 4.2), AFFF is used in airport operations as a fire-extinguishing agent to prevent, extinguish, or control Class B fires (i.e., fires of flammable and combustible liquids such as crude oil, gasoline, and fuel oils). The presence of PFASs in AFFF generates foam that retains water and separates fuel from flame, ultimately resulting in dramatic, fast knockdown of Class B fires.

Historical AFFF formulations were made with fluorocarbon surfactants containing PFOS as the predominant active ingredient. Increasing concern regarding the effects of PFOS-based AFFF on human health and the environment led users to alternatives that contained long-chain, telomer-based fluorochemicals containing eight carbons or more. Subsequently, in some cases, it was found that the breakdown of these long-chain fluorochemicals in the environment could produce PFOA and other PFASs of concern. Since 2006, both the United States and Canada have taken steps to phase out the production and use of C_8-based fluorotelomers. Consequently, AFFF manufacturers have shifted toward using shorter chain (i.e., $\leq C_6$, having six or fewer carbon molecules) C_6 and C_4 perfluoroalkylated chemicals. C_6-based fluorotelomers are most commonly and widely used. Limited data are available on how these compounds behave in the environment and the potential risks they pose to both the environment and human health.

PFASs at an airport may be related to the following firefighting equipment and materials:

- Past and ongoing firefighting, training, and maintenance activities. These can lead to groundwater and soil contamination by PFASs due to uncontained release of firefighting foam.
- Firefighting equipment, including protective clothing for firefighters. These can be surface treated with side-chain fluorinated polymers or made from fluoropolymers such as woven, porous polytetrafluoroethylene (PTFE) and its copolymers.
- Testing firefighting systems (e.g., deluge system, roof turrets). This activity is often an overlooked source of PFASs.

2.2.2 Industrial Components in Aviation and Aerospace

Fluoropolymers such as PTFE (e.g., Teflon™) are used extensively in various equipment components (e.g., semiconductors, wiring, tubing, piping, seals, gaskets, and cables). In addition, the salts of sulfonated PFASs (primarily PFOS) have been used as additives with a content of about or less than 0.1 percent in hydraulic fluids/lubricants to prevent evaporation, fires, and corrosion (*2*).

2.2.3 Metal Plating Operations

Although metal plating operations may not be directly associated with the aviation industry, they are one of the most important ongoing users of products containing PFASs and are typically situated within industrial zones located near larger airport facilities. Fluorinated surfactants (i.e., PFOS and derivatives) are used in metal plating, and are considered to be essential for use as mist suppressants in the metal plating industry (*3, 4*). The use of PFOS in the European Union (EU) for chromium plating was estimated as 10,000 kg/year (*5*). There is potential for residual concentrations of other PFASs in the surfactants used for metal plating.

2.2.4 Biocides

Non-polymeric PFASs have been used as active ingredients in some plant growth regulators and herbicides (*6*) and as inert ingredients in pesticide formulations in the United States (e.g., ant baits) (*7*).

2.2.5 Construction Products

Fluoropolymers, such as PTFE and polyvinyl fluoride (PVDF), are commonly used in paints, acting as dispersion agents and leveling agents, as well as improving gloss and antistatic properties. Fluoropolymers and fluorotelomers have also been used as fire- or weather-resistant coating in various construction-related applications (*8*).

2.3 Why and How Do PFASs Pose a Concern?

Some PFASs present potential risks to human health and the environment. Many PFASs are very persistent (i.e., do not break down readily).They bioaccumulate (i.e., accumulate in living tissue) and/or biomagnify (i.e., increase in concentration as they move up the food chain) in the environment. The following paragraphs provide an overview of PFASs, detailing environmental and toxicological concerns associated with PFASs, their fate and transport properties, and environmental factors that affect transport.

2.3.1 Environmental and Toxicological Concerns

PFASs have been widely used throughout the world, and some types of PFASs (including PFOS and PFOA) are persistent in the environment. In the late 1990s, the U.S. EPA received information from 3M that PFOS was widespread in the blood of the general population, which raised concerns regarding persistence, bioaccumulation, and toxicity (*9, 10*). The results provided by 3M on PFOS impacts to human health and ecology suggested that the prevalence of these compounds, combined with their increasing ubiquity in the global environment, presented potential human health and ecological risks.

In July 2006, a preliminary ecological screening assessment report by Environment Canada concluded that PFOS, its salts, and its precursors are entering the environment at concentrations that have or may have an immediate or long-term harmful effect on the environment or its biological diversity (*11*). Studies evaluating the relative toxicity of the complex mixture of PFASs typically in the AFFF used at airports (a mixture consisting not just of PFOA and PFOS, but including other PFASs as well) are ongoing. Since multiple PFASs are typically found together in both human and wildlife environments, their cumulative risks and potential interactions are also being considered in ongoing research. Specific documented environmental and toxicological concerns are the following:

- Per- and polyfluorinated compounds have the potential to bioaccumulate and biomagnify in wildlife.
- Per- and polyfluorinated compounds are readily absorbed after oral exposure and accumulate primarily in the serum, kidney, and liver.
- Toxicological studies on animals indicate potential developmental, reproductive, and systemic effects.

PFOS, its salts, and its precursors meet the criteria for persistence under the Stockholm Convention, the Canadian Environmental Protection Act (CEPA) and the U.S. EPA.

2.3.2 Fate and Transport in the Environment

The movement of PFASs and their persistence in the environment is a function of their structure (*12*). Part of the molecule prefers to associate with water and part of the molecule does not; thus these compounds travel along interfaces (e.g., water-air, water-soil, and water-lipid interfaces), smearing themselves along soil particles at the water table interface. In natural waters, the predominant forms of PFCAs and PFSAs will be their anionic forms; the predominance of these forms is due to the low dissociation constants of these compounds. However, at low pH, both PFCAs and PFSAs can exist in water in their fully protonated (acid) forms.

Depending on compound properties, manufacturing procedures, and use and disposal patterns, PFASs and their precursors may enter the environment by various pathways, such as direct discharge to waste (*4, 13–16*) and air particulate matter (*17–20*), as well as wash-off or direct use in the environment (*2, 21–24*) and inappropriate disposal of wastes containing PFASs (*25–31*).

Emissions into the environment can be from both direct and indirect sources (*13, 32–34*). Direct sources include emissions during the manufacture, use, and disposal of products that contain PFASs or their derivatives as ingredients, unreacted raw materials (residuals), or unintended by-products (impurities). Indirect sources refer to the formation of PFCAs and PFSAs from degradation of precursors (i.e., parent compounds).

PFCAs and PFSAs are among the more stable compound groups categorized as PFASs and include PFOA and PFOS. PFOA has been in manufactured AFFF and is also formed as a recalcitrant degradation by-product in AFFF. The perfluorinated carbon tail of these compounds is known to be very resistant to degradation, a property attributed to the carbon-fluorine bond. PFOS is considered to be persistent—the environmental half-life for PFOS (greater than 41 years) (*35*) exceeds the half-life criteria for persistence as defined by the Persistence and Bioaccumulation Regulations of the United Nations (UN) Stockholm Convention on Persistent Organic Pollutants (POPs) in 2001 (*36*), and the Canadian Environmental Protection Act, CEPA 1999 (*37, 38*). Under typical groundwater conditions (i.e., pH 6–8.5), PFOA and PFOS are water soluble and can migrate readily from soil to groundwater, where they can be transported long distances (*39, 40*).

Different PFASs, many with different chemical structures, are often used and present in a mixture (e.g., AFFF). As a result of these chemical structure differences, release of these mixtures may result in distribution patterns of PFASs in the environment that are both source- and site-specific:

- PFASs with longer perfluorinated carbon tails have a greater tendency to bioaccumulate than short-chain PFASs. There are limited studies available that have evaluated the behavior of short-chain PFASs in the environment and/or the potential risks they pose to human health or the environment (*71*).
- Short-chain PFASs are more likely to be found in aqueous phases (i.e., water), whereas long-chain PFASs are more likely to be sorbed to solid matrices.
- Larger and more hydrophobic molecules such as PFHxA or perfluorohexane sulfonic acid (PFHxS) can displace shorter PFASs (e.g., PFBA) from sorption sites.
- Short-chain PFASs may be displaced by increased flow. Short-chain PFASs have been shown to wash out in flow-through adsorption column experiments (*41*).

Specific fate and transport considerations include the following:

- PFASs (particularly PFOS and PFOA) do not readily degrade in the environment to constituents that are not PFASs.
- Although limited studies have been conducted, the scientific literature suggests that sulfonated compounds bind more with soil than do carboxylated compounds.
- Perfluoroalkyl acids (PFAAs) (a subgroup of PFASs that includes PFOS and PFOA) precursors account for 41 to 100 percent of the total concentration of PFASs in archived AFFF formulations (on a molar basis) (*12*).
- Precursors degrade and/or transform to intermediate compounds and PFAAs in the environment.

2.3.3 Environmental Factors That Affect Transport

Groundwater geochemistry and soil properties can affect the ability of PFASs to attach to surfaces. Sorption of these compounds can be influenced by different soil types that contain reactive mineral surfaces and organic carbon (e.g., peaty soils or organic-rich fragments in sand). An increase of sorption of PFASs, such as PFOS to sediment, has been noted with increasing organic matter, decreasing pH, and increasing calcium ions (Ca^{2}+) (*42*). However, in soils that have negatively charged surfaces (e.g., most clays), it has been found that pH, ionic strength, and/or calcium concentrations have minimal effect on sorption of PFOS to the mineral surface (*43*). Precursors are likely to have different physical and chemical properties to their degradatory products. Cationic or zwitterionic precursors may bind to clay minerals through ion exchange.

The fate and transport of PFASs in the environment is very complex and influenced by many factors. The following box identifies factors that affect the mobility of PFASs in the environment, generally, in order of increasing mobility.

The complexity of these compounds and their mobilization in the environment may be confounded by other, unidentified factors (e.g., co-contaminants, synergistic effects). Research into the fate and transport of PFASs is ongoing.

Increased Mobility of PFASs (↑)

- Concentrations observed in bedrock (fractured)
- Elevated concentrations at surface (potential for human health risks, leaching)
- Elevated concentrations at greater depths (indicates pathway to groundwater)
- Ongoing source (e.g., unlined lagoon)
- Petroleum hydrocarbon (PHC) co-contaminants present
- Large water table fluctuation (larger "smear" zone)
- Greater groundwater flow
- Greater infiltration
- Large particle size (if high concentrations—leaching)
- Small particle size (silt—increased sorption—diffusive release)‡
- Small particle size (clay—increased sorption)‡
- High f^{oc} (increased sorption)‡
- Particle reactivity (negatively charged, mineral surfaces increased sorption)‡
- Increased salinity (increases sorption/decreases PFOS solubility)‡
- Increased pH (decreases sorption/increases PFOS solubility)‡

‡Increased sorption leads to decreased mobility, decreased leaching, "mass storage."
Lighter shading indicates system chemical factors that affect the mobility of PFASs.
Darker shading indicates system physical factors that affect the mobility of PFASs.

2.4 What Are the Regulatory Requirements Regarding PFASs?

The regulatory environment related to PFASs is rapidly changing. Improved analytical testing technologies and methodologies have resulted in the ability to detect these substances at low concentrations that new research suggests may have human health or environmental significance. The development of regulations and guidelines for the protection of human health and the environment has followed and continues to evolve.

Between the years 2000 and 2015, countries including the United States, Canada, the United Kingdom (UK), Australia, Norway, the Netherlands, Germany, and Sweden introduced regulations and guidelines to phase out and limit the use of PFOS, PFOA, and their precursors. In 2004, the UN Stockholm Convention on POPs listed the first 12 POPs and added PFOS, one of the most common compounds of PFASs, and its 96 precursors to Annex A (Elimination). Chemicals in Annex A are destined for elimination with specific, time-limited exemptions.

In 2009, PFOS was added to Annex B (Restriction) of the Stockholm Convention. PFOS was banned in countries in the EU on 27 June 2008 (noting, however, that this prohibition is subject to some time-unlimited exceptions relating to certain applications in the photolithographic and photographic industries and chromium plating and hydraulic fluids in the aviation industry). In the EU, firefighting foam containing PFOS and sold on the market prior to 27 December 2006 could have been used until 27 June 2011.

The regulatory frameworks for PFASs of the United States, Canada, EU countries, and Australia are summarized in the sections that follow. Please note that the regulatory requirements for each country are subject to change, especially in the rapidly evolving regulatory environment relating to PFASs. Please refer to the regulatory authority having jurisdiction for the most up-to-date requirements.

2.4.1 United States of America

The U.S. EPA issued the "Long-Chain Perfluorinated Chemicals (PFCs) Action Plan" in 2009 for perfluoroalkyl sulfonates (long-chain PFASs containing sulfonated functional groups, e.g., PFHxS, PFOS, their salts and precursors) and long-chain perfluoroalkyl carboxylates (long-chain PFASs containing carboxylic acid functional groups, e.g., PFOA, other higher homologues, and their salts and precursors).

Since 2009, the U.S. EPA has conducted two screening reviews (in 2013 and 2015). In September 2013, U.S. EPA published a Significant New Use Rule (SNUR) that focused on the use of long-chain perfluoroalkyl carboxylates in carpets. U.S. EPA amended the SNUR (40 CFR 721.9582) on PFASs (1) to add PFASs for which the Toxic Substances Control Act (TSCA) new chemical review process had been completed, but which were not yet being produced or imported and (2) to designate (for all listed PFASs) processing as a significant new use. In January 2015, U.S. EPA proposed a SNUR under TSCA that requires manufacturers (including importers) of long-chain perfluoroalkyl carboxylates to notify the U.S. EPA at least 90 days prior to starting or resuming use of these chemicals in any products. The notification timeframe would allow U.S. EPA to evaluate the new use and, if necessary, take action to prohibit or limit the activity.

In 2009, the U.S. EPA's Office of Water established a provisional health advisory of 0.2 μg/L for PFOS and 0.4 μg/L for PFOA while assessing the potential risk from short-term exposure of these chemicals through drinking water. These values were revised in 2016 to 0.07 μg/L for both compounds, respectively, for chronic exposure (protective over a lifetime) (*44*). The new 2016 health advisory values supersede the 2009 provisional health advisory values. The health advisories are based on the U.S. EPA's assessment of the latest peer-reviewed scientific literature and provide non-enforceable and non-regulatory guidance to state agencies and other public health officials so that they can take appropriate actions.

The U.S. EPA's Office of Water derived reference doses (RfDs) of 2×10^{-5} mg/kg/day in its Health Effects Support Documents for PFOA and PFOS to support the health advisories. Using these RfDs and the standard regional screening level equations (https://www.epa.gov/risk/regional-screening-levels-rsls), risk-based residential soil-screening levels of 1.3 mg/kg can be calculated for PFOA and PFOS. Risk-based industrial soil-screening levels for a generic composite worker of 16.4 mg/kg can also be calculated. Site-specific soil-screening levels for other exposure scenarios and receptors (e.g., recreator, worker) can also be calculated. Risk-based screening levels for perfluorobutane sulfonic acid (PFBS) can also be calculated based on a published RfD by EPA on the same website.

At the time of this writing, several states have established drinking water and groundwater guidelines, as follows:

- Maine developed a maximum exposure guideline for PFOA in drinking water of 0.1 µg/L.
- Michigan has established human noncancer values for drinking and non-drinking water uses for both PFOS (0.011 µg/L and 0.012 µg/L, respectively) and PFOA (0.042 µg/L and 12 µg/L, respectively) (*45*).
- Minnesota has also established a chronic health risk limit of 0.3 µg/L for both PFOS and PFOA, and 7 µg/L for both PFBS and PFBA in drinking water (*46*). Minnesota has established well advisory guidelines of 1.0 µg/L for PFBA, perfluoropentanoic acid (PFPeA), and PFHxA, and 0.6 µg/L for PFBS and PFHxS.
- New Jersey has established a preliminary health-based guidance value of 0.04 µg/L for PFOA in drinking water. The guidance level is the first phase of an ongoing process to establish a drinking water standard for this contaminant and will be adjusted as the science regarding PFOA is developed (*47*).
- New Jersey has established a human-health-based interim specific groundwater quality criterion for PFOS and perfluorononanoic acid (PFNA) of 0.040 µg/L and 0.010 µg/L in groundwater, respectively (*48, 49*).
- In 2006, North Carolina established an interim maximum allowable concentration (IMAC) of 2 µg/L for PFOA in groundwater (*50*).
- In 2010, the North Carolina Secretary's Science Advisory Board (NCSAB) on Toxic Air Pollutants recommended that the IMAC for PFOA in groundwater be reduced to 1 µg/L based on a review of the toxicological literature and discussions with scientists conducting research on the health effects associated with exposure to PFOA. At the time of this writing, the NCSAB's recommendation was still pending review by the North Carolina Division of Water Quality (*51*).
- In 2016, the Vermont Department of Health derived a drinking water health advisory of 0.02 µg/L applicable to the sum of PFOA and PFOS.
- In September 2016, California EPA's Office of Environmental Health Hazard Assessment issued a Notice of Intent to List PFOA and PFOS as known to the state to cause reproductive toxicity under the *Safe Drinking Water and Toxic Enforcement Act* of 1986 (*52*). If listed, warning requirements under the new regulatory scheme would be triggered within 1 year from the date of the Office of Environmental Health Hazard Assessment's (OEHHA's) listing.

The guideline values are summarized in Table 2-2.

Additionally, six PFASs are considered under the U.S. EPA's Third Unregulated Contaminant Monitoring Rule (UCMR 3) (see Table 2-3). While it is not necessarily applicable to airport managers, the 1996 Safe Drinking Water Act (SDWA) amendments require that once every 5 years U.S. EPA issue a new list of no more than 30 unregulated contaminants to be monitored by public water systems. U.S. EPA uses the UCMR to collect data on contaminants that are

Table 2-2. Drinking water and well advisory guidelines in the United States.

Agency	PFOA (µg/L)	PFOS (µg/L)	PFBS (µg/L)	PFBA (µg/L)	PFNA (µg/L)	PFPeA (µg/L)	PFHxA (µg/L)	PFHxS (µg/L)
U.S. EPA	0.07*	0.07*	NC	NC	NC	NC	NC	NC
Maine (maximum exposure in drinking water guideline)	0.1	NC	NC	NC	NC	NC	NC	NC
Michigan (Health limits, drinking water)	0.42	0.011	NC	NC	NC	NC	NC	NC
Michigan (Health limits, non-drinking water use)	12	0.012	NC	NC	NC	NC	NC	NC
Minnesota (well advisory guidelines)	NC	NC	0.6	1.0	NC	1.0	1.0	0.6
Minnesota (chronic health risk limits, drinking water)	0.3	0.3	7.0	7.0	NC	NC	NC	NC
New Jersey (interim health-based values)	0.04	NC	NC	NC	0.010	NC	NC	NC
North Carolina (IMAC)	2.0	NC	NC	NC	NC	NC	NC	NC
Vermont (Health Department, drinking water)	0.02**	0.02**	NC	NC	NC	NC	NC	NC

NC denotes "no criteria."
** Combined concentration of PFOA and PFOS are not to exceed 0.07 µg/L.*
***Combined concentration of PFOA and PFOS are not to exceed 0.02 µg/L.*

Table 2-3. PFASs on UCMR 3 assessment monitoring (List 1 contaminants).

Contaminant	Minimum Reporting Level (µg/L)	Sampling Points	Analytical Methods
Perfluorooctanesulfonic acid (PFOS)	0.04	EPTDS	EPA 537 Rev 1.1
Perfluorooctanoic acid (PFOA)	0.02	EPTDS	EPA 537 Rev 1.1
Perfluorononanoic acid (PFNA)	0.02	EPTDS	EPA 537 Rev 1.1
Perfluorohexane sulfonic acid (PFHxS)	0.03	EPTDS	EPA 537 Rev 1.1
Perfluoroheptanoic acid (PFHpA)	0.01	EPTDS	EPA 537 Rev 1.1
Perfluorobutanesulfonic acid (PFBS)	0.09	EPTDS	EPA 537 Rev 1.1

EPTDS denotes "entry points to the distribution system."

suspected to be present in drinking water and do not have health-based standards set under the SDWA. U.S. EPA pays for the analysis of all samples from systems serving 10,000 or fewer people. If airport operators do not themselves participate in the program, they should be aware that nearby systems may be monitoring these compounds.

2.4.2 Canada

The regulatory environment for PFASs (such as PFOS and PFOA) in Canada is in development. Canadian federal guidelines that protect the human health exposure pathways for potable groundwater use and direct soil contact have been developed for federal custodian sites (*53*). Environment Canada has developed proposed final federal environmental quality guidelines to help assess the significance of PFOS concentrations in the environment (*54*). These proposed final guideline values are based on studies that directly link laboratory exposure to adverse impacts in animals and have been developed for soil, groundwater, surface water, fish tissue, wildlife diet, and bird eggs. Concentrations above the draft guideline values indicate an increased likelihood that adverse effects in the environment may occur; however, PFOS concentrations above the guideline values do not necessarily indicate adverse effects.

In August 2010, Health Canada issued provisional drinking water guidance values for PFOA and PFOS. Based on the available scientific literature and reviews conducted by other jurisdictions, Health Canada revised their 2011 values in 2016, establishing drinking water screening values of 0.0006 mg/L (0.6 μg/L) for PFOS; 0.2 μg/L for PFOA; 15 μg/L for PFBS; 30 μg/L for PFBA; 0.6 μg/L for PFHxS; and 0.2 μg/L for PFPeA, PFHxA, perfluoroheptanoic acid (PFHpA), and PFNA based on lifetime exposure. Environment Canada has developed Canadian Federal Environmental Quality Guidelines for PFOS in aquatic life (water), fish tissue, wildlife diets, and bird eggs (see Table 2-4).

Proposed final guidelines have been developed for screening for soil exposure pathways (see Table 2-5) and groundwater exposure pathways (see Table 2-6) for PFOS and were most recently updated in February 2017. In 2016, British Columbia promulgated amendments to the BC Contaminated Site Regulations, which will become effective November 1, 2017, that include regulatory criteria for PFOS, PFOA, and PFBS based on toxicity, persistence in the environment, and relevance to contaminate sites in British Columbia. In addition, guidelines are currently in development in Ontario.

2.4.3 European Union Countries

The directive on "Environmental Quality Standards" (EQSD) sets environmental quality standards for certain priority hazardous substances for the EU. The EQSD presented in the document for PFOS were derived by the National Institute for Public Health and the Environment (RIVM) in the Netherlands.

RIVM has derived scientific environmental risk limits for PFOS in fresh and marine surface waters. RIVM (*55*) provides maximum permissible concentration (MPC) values for both

Table 2-4. Federal Environmental Quality Guidelines for PFOS (Canada).

Water (μg/L)	Fish Tissue (μg/g wet weight)	Wildlife Diets (μg/g wet weight food)		Bird Egg (μg/g wet weight)
		Mammalian	Avian	
6	8.3	4600	8200	1.9

Table 2-5. Federal soil quality guidelines for PFOS.*

Land Use/Pathway	Agricultural (mg/kg)	Residential/ Parkland (mg/kg)	Commercial (mg/kg)	Industrial (mg/kg)
Final Soil Guideline	0.01	0.01	0.14 [1] 0.21 [2]	0.14 [1] 0.21 [2]
Soil Contact (SQG_{SC})	11	11	61	61
Soil Ingestion (SQG_{1C})	2.2	2.2	NR	NR
Soil Ingestion—secondary and tertiary consumers (SQG_{2C} , SQG_{3C})	0.01	0.01	NR	NR
Agricultural (Livestock watering)	12 [1] 9 [2]	NR	NR	NR
Protection of Freshwater Life (SQG_{FL})	0.14 [1] 0.21 [2]			
Off-site migration (SQG_{OM-E})	NR	NR	0.14	0.14

NR denotes "not required."
**Federal Environmental Quality Guidelines for PFOS, Environment and Climate Change Canada, February 2017.*
[1] *Coarse-grained soil*
[2] *Fine-grained soil*

Table 2-6. Federal groundwater quality guidelines for PFOS.*

Exposure Pathway	Coarse (mg/L)	Fine (mg/L)
Final Groundwater Guideline ($FGWQG_{FINAL}$)[1]	0.068	0.068
Groundwater Contact ($FGWQG_{GC}$) by Soil-Dependent Organisms	2	2
Protection of Freshwater Life ($FGWQG_{FL}$)[2]	0.068	0.068
Protection of Marine Life ($FGWQG_{ML}$)	NC	NC
Protection of Livestock Watering ($FGWQG_{LW}$)	NC	NC
Protection of Irrigation Water ($FGWQG_{IR}$)	NC	NC
Management Considerations ($FGWQG_{M}$)—Solubility	370	370

NC denotes "not calculated."
**Federal Environmental Quality Guidelines for PFOS, Environment and Climate Change Canada, February 2017.*
[1] *The federal groundwater quality guideline-final ($FGWQG_{FINAL}$) is the lowest of the pathway-specific guidelines while also taking the solubility into account.*
[2] *$FGWQG_{FL}$ is the concentration in groundwater that is expected to protect against potential impacts on freshwater life from PFOS originating in soil that may enter groundwater and subsequently discharge to a surface water body. This pathway may be applicable under any land use category, where a surface water body sustaining aquatic life is present (i.e., within 10 kilometers of the site). Where the distance to the nearest surface water body is greater than 10 kilometers, application of the pathway should be evaluated on a case-by-case basis by considering the site-specific conditions.*

Table 2-7. EU maximum allowable drinking water concentrations.

Agency	PFOA (µg/L)	PFOS (µg/L)
UK HPA	0.3	0.3
DEPA*	0.3	0.1
Germany Department of Environmental Protection	0.1 (sum of PFOA and PFOS)	

**Where PFOS, PFOA, and Perfluorooctane sulfonamide (PFOSA) occur in the drinking water at the same time, the total concentration/limit value must be < 1 ug/L.*

environmental and human health, with the value for human health based on consumption of fish and shellfish. The human health value represents the lowest MPC in freshwater at 0.65 ng/L. Table 2-7 presents maximum acceptable concentrations of PFOA and PFOS in drinking water as developed by the UK Health Protection Agency (HPA), the Danish Ministry of the Environment (DEPA) (*56*), and the Department of Environmental Protection in Germany.

DEPA has also derived health-based soil quality criteria:

- PFOS: 0.39 mg/kg
- PFOSA: 0.39 mg/kg
- PFOA (and salts, e.g., Ammonium pentadecafluorooctanoate [APFO]): 1.3 mg/kg

In the case that PFOS, PFOA, and PFOSA occur in the soil together at the same time, the concentration/limit value must be < 1 mg/kg.

2.4.4 Australia

In Australia, regulations on the use, release, and disposal of PFASs and any criteria for these chemicals is primarily a state and territory responsibility. However, interim national guidance on human health reference values for PFASs for use in site investigations has been derived by the Environmental Health Standing Committee (enHealth) of the Australian Health Protection Principal Committee and have been made available as of June 2016 (*57*). (See Table 2-8.)

Additionally, the Government of Western Australia has produced a Contaminated Sites Guideline document containing interim screening levels for soil, sediment, surface water, and groundwater (*58*). (See Table 2-9.) The purpose of the Contaminated Sites Guideline document is to provide guidance on the assessment and management of PFASs within the applicable legislative framework.

Table 2-8. Recommended enHealth interim values.

Toxicity Reference Value	PFOS/PFHxS	PFOA
Tolerable Daily Intake (µg/kg/d)	0.15	1.5
Drinking Water Quality Guideline (µg/L)	0.5	5
Recreational Water Quality Guideline (µg/L)	5	50

Table 2-9. Western Australia interim screening levels for PFOS and PFOA in environmental media.

Exposure Scenario	PFOS	PFOA
Soil		
Human Health Residential (mg/kg)	4	–
Human Health Industrial/Commercial (mg/kg)	100	–
Surface Water and Groundwater		
Drinking Water (µg/L)	0.5	–
Non-Potable and Recreational Uses (µg/L)	5	–
Ecological—Freshwater (µg/L)	0.00023	19
	0.13	220
	2.0 31	632 (90% species protection) 1,824 (80% species protection)

2.5 How Might PFASs Affect an Airport?

Use of AFFF (containing PFASs) at airports has the potential to impact the environmental media on, or in, the vicinity of airports. PFASs may impact airport operations and environmental management. The primary impacts to operations would be related to firefighting activities—specifically, how airports procure, store, handle, apply, remove, and dispose of AFFF. With regard to environmental management, PFASs will have a potentially significant impact on how environmental media are investigated and remediated. Similarly, media impacted by PFASs that require special handling may be encountered as capital projects are undertaken. The following sections discuss these considerations.

2.5.1 Known Practices of AFFF Use

AFFF is used for fire suppression. Its role is to cool the fire and coat the fuel, preventing fuel from contacting oxygen and suppressing further combustion. In the mid-1960s, the U.S. Navy developed AFFF, which was observed to have dramatic "fire knockdown" capabilities, an important factor in crash rescue firefighting. AFFF solutions are mixed with water at the point of use to create the desired mixture strength. The application mixture is typically shown on the container of AFFF concentrate or in the product manufacturer's directions. The foam forms spontaneously upon ejection of the concentrate/water mixture from a nozzle.

Environmental release of PFASs related to AFFF use has historically resulted from emergency response, testing, emergency activation of fire suppression systems in hangars, leaks from storage tanks and/or supply lines, and firefighter training exercises. Additionally, storage tanks or supply lines previously containing PFASs could still contribute residual amounts. Best practices for managing release of PFASs into the environment include the following:

- Up-to-date document and inventory management and personnel training.
- Spill containment during refilling of storage containers and foam tests.
- Fire training activities with an environmentally benign type of foam (e.g., no PFASs).
- Engineered containment systems in hangars, firefighter training areas (FFTAs), and tarmac (e.g., storm sewer) that capture and direct any discharged AFFF.

2.5.2 Potential Sources of PFASs

Potential sources for PFASs at an airport facility are mostly linked to past use of AFFF and could include the following:

- Firefighting training areas where AFFFs were used.
- Firefighting equipment maintenance areas (e.g., from foam tests).
- Disposal areas.
- Treatment lagoons.
- Impacted soils.
- Drainage and wastewater systems used to contain discharged fire-extinguishing materials.
- Storage areas for AFFF.
- Tanks, vehicles, equipment, and distribution systems that were used to store or apply AFFF, and then were not adequately rinsed and may have become a continuous source.

2.5.3 Environmental Considerations

As discussed previously, releases to the environment of small amounts of AFFF containing PFASs could significantly impact environmental media, wildlife, and, potentially, human populations. Responses to environmental impacts of PFASs that present unacceptable human health or ecological risks will be shaped by regulations. Capital projects may be affected by impacts of PFASs on soil and groundwater because if, in the course of a capital project, PFASs are found in these media, care may be required (potentially at significant cost) to handle and properly dispose of the soil and groundwater impacted by PFASs (e.g., dewatering).

2.5.4 Human Health Considerations

Best management practices protect not only the environment from exposure, but also work to protect workers and individuals that may come into contact with AFFF containing PFASs at airports. Firefighters, in particular, are an occupationally exposed population. PFASs in firefighting products have been measured in the blood of firefighters at concentrations above those in the average population (*59–62*). Special consideration must be given to ensuring contaminated sites are cleaned up. Preventative measures should be put into place to limit occupational exposure to AFFF containing PFASs and to monitor worker's health.

CHAPTER 3

Research Methodology

3.1 Overview

The research methodology for ACRP Project 02-60 was developed based on the following understanding:

- The level of awareness and knowledge associated with AFFF and PFASs varies greatly among (and within) airports.
- Management practices associated with AFFF procurement, storage, application, and disposal vary greatly among airports.
- Despite PFASs being characterized as an "emerging contaminant," there has been much study and research on the effects associated with PFASs in the environment.
- Regulations associated with PFASs in the environment are being promulgated more frequently and becoming more stringent.
- Manufacturers of AFFF have changed their formulations in response to regulatory requirements due to concerns associated with the environmental effects of PFASs in the environment. Most notably, manufacturers have removed PFOS-based AFFF and then PFOA and other "long-chain" PFASs from their formulations.
- Many airports that have identified issues related to PFASs that are associated with AFFF use or release are unsure of how best to respond, and some have been pursuing guidance on how to manage their liabilities (understanding that regulatory action could potentially lead to expensive assessment and remediation programs).
- Effective, state-of-the-practice sampling and laboratory analytical approaches for PFASs have been developed and adopted by federal government departments in both the United States and Canada.
- Traditional remediation approaches (e.g., "excavation and disposal" and "pump and treat") have been successfully applied in the field, but are typically limited in their effectiveness (or cost-effectiveness) to address the impacts of PFASs.

The research plan included three principal data-gathering approaches: literature review, airport survey, and consultation with subject matter and industry experts. The following sections summarize the research methodology associated with each of these approaches.

3.2 Literature Review

A literature review was conducted of peer-reviewed (e.g., scientific journal articles) and non-peer-reviewed research (e.g., industry articles) available via academic search engines, online references and searches, and documents otherwise available to the research team. Recognizing that new findings regarding environmental fate and transport and remediation of PFASs are being published at an accelerated rate (*10, 55–61*), the research team monitored scientific journals and industry publications throughout the research. In addition, the research team identified other resources (e.g., conference proceedings) by attending conferences with key subject matter topics, including AFFF, firefighting, PFASs, AFFF alternatives, analysis of PFASs, and remediation technologies for PFASs. Specific efforts targeted jurisdictions that have been relatively (i.e., compared to North America) proactive—such as Norway, Sweden, and Australia—in understanding the chemistry and fate and transport of PFASs and in developing remediation solutions and AFFF alternatives.

3.3 Airport Survey

A survey was designed to effectively canvas a broad segment of the North American civilian airports that are required to have firefighting equipment (and, thus, use AFFF) to understand how these airports manage the procurement, storage, use, and disposal of AFFF, and any practices related to impacts of PFASs on the environment.

Pursuant to Title 14, Code of Federal Regulations Part 139 (i.e., specifically, Part 139 Airport Certification Status List) and the Canadian Aviation Regulations (CARs) 303, 580 airports (540 airports in the United States and 40 in Canada, including commercial service and general aviation airports) were identified to provide a representative, initial sample population pool that included a broad range of firefighting and emergency response services, management practices, and airport classes. In order to provide a 95-percent confidence level with a margin of error of +/− 5 percent, a net survey sample size of 223 was targeted. Designed to place an emphasis on airports with greater aircraft rescue and firefighting (ARFF) facilities (e.g., larger storage requirements, more infrastructure and, therefore, it is assumed, more need and use of AFFF), the net sample set included all of the airports in ARFF Categories E, D, and C (including the Canadian airports, which were recategorized to "match" their U.S. category counterparts) and proportional numbers from Categories B and A to produce a total net sample set of 225 airports (199 U.S. airports and 26 Canadian airports). General aviation airports that elected to apply for a Part 139 certificate and thus are required to provide firefighting capabilities pursuant to their Part 139 certification (and were listed on the Part 139 Airport Certification Status List) were categorized among the ARFF indices as appropriate.

As detailed in Appendix A of this report, 167 airports across the United States (149) and Canada (18) completed survey interviews between December 2015 and March 2016. The survey questionnaire was vetted by select airports and the ACRP Project 02-60 panel and contained 42 questions, 16 of which were open-ended; the average interview length was 21 minutes. As indicated in Table 3-1, the overall response rate was 74 percent, and all ARFF categories had response

Table 3-1. Distribution of responses by airport size category.

	Unduplicated Valid Sample	Completed Interviews	Percent of Sample
Category A	48	40	83
Category B	29	22	76
Category C	90	69	77
Category D	28	19	68
Category E	30	17	57
Total	225	167	74

rates greater than 50 percent. The margin of error for the survey, given the population and sample sizes, is ± 6.7 percent at the 95-percent confidence level.

Data collected from the survey (including open-ended answers) were coded (as detailed in Attachment B of Appendix A) and used to assess the extent of AFFF management and use across a statistically representative cross-section of civilian airports and identify current industry management practices.

3.4 Subject Matter and Industry Expert Outreach

To supplement the information on current AFFF management practices obtained through the industry survey, the research team also solicited subject matter and industry expertise related to AFFF; airport firefighting and ARFF classification; regulations associated with PFASs; environmental fate, transport, and remediation of PFASs; and laboratory analyses of PFASs. Specifically, the research team reached out to manufacturers of AFFF and alternative products; industry trade organizations; airports, including airport emergency response personnel; academics specializing in the science of PFASs; commercial analytical laboratories; and representatives of government involved in the regulation of PFASs and policy development. The research also sought input from the ACRP Project 02-60 panel. Additionally, the screening tool framework was reviewed by the ACRP Project 02-60 panel, and subsequent beta testing of the screening tool was vetted by three airports.

CHAPTER 4

AFFF Management Within Airport Operations

4.1 Overview

AFFF is used in airport operations as a fire-extinguishing agent to prevent, extinguish, or control Class B fires, i.e., fires of flammable and combustible liquids such as crude oil, gasoline, and fuel oils. AFFF generates foam that retains water, separates fuel from flame, and ultimately results in dramatic, fast knockdown of Class B fires. Fluorocarbon surfactants and specifically PFASs—a large group of related human-made fluorinated organic chemicals—are key ingredients in AFFF.

As indicated previously, some PFASs used in AFFF have been shown to exhibit multiple problematic chemical, physical, and toxicological properties. The problematic properties have largely been attributed to "long-chain" PFASs, i.e., PFCAs with eight or more carbons (including PFOA) and PFSAs with six or more carbons (including PFOS). In the past, AFFF formulations were made with PFOS as the predominant active ingredient. Early alternatives to PFOS-based AFFF contained long-chain, telomer-based fluorochemicals that in some cases could breakdown to PFOA. Like PFOS, PFOA has been observed to be persistent in the environment. Consequently, AFFF manufacturers have shifted toward using short-chain (i.e., $\leq C_6$, having six or fewer carbon molecules) C_6 and C_4 perfluoroalkylated chemicals (*7*). Currently, the most common and widely used short-chain PFASs in AFFF are the C_6-based fluorotelomers.

While current AFFF formulations are believed to be potentially less problematic to human health and the environment than PFOS-based formulations, much remains unknown about the short-chain PFASs used in AFFF. Short-chain PFASs can be as environmentally persistent as long-chain substances or have persistent degradation products. A switch to short-chain and other fluorinated alternatives may not reduce the quantity of PFASs in the environment (*70*). In addition, because some of the short-chain PFASs are less effective than their long-chain counterparts, greater quantities of short-chain PFASs may be required to provide the same performance. Potential risks to human health and the environment may result from contact with or release into the environment of current AFFF formulations. Consequently, it is important for users of AFFF, such as airports, to develop best practices for managing the use of AFFF that mitigate potential impacts to human health and the environment.

This chapter discusses management practices of AFFF at airports in North America related to procurement, storage, application (i.e., maintenance, use/testing, and training), and disposal (i.e., discharge to environment, containment, and treatment/off-site disposal). (See Figure 4-1.) Specifically, this chapter describes the following:

- Legislation, regulations, and/or guidance relevant to AFFF. Guidance from firefighting foam manufacturers is also identified.

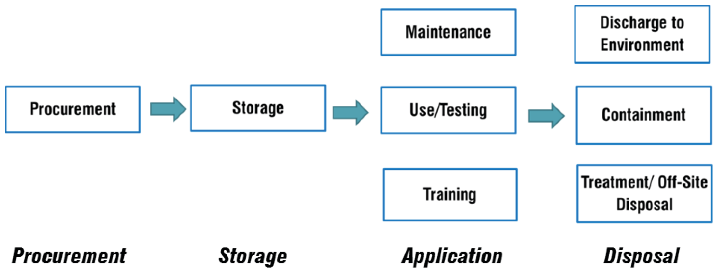


Figure 4-1. AFFF life cycle stages.

- The state of the practice of AFFF procurement, storage, application, and disposal at airports in North America based, in part, on a survey completed by 167 airports across the United States and Canada. Further detail on the survey is provided in Appendix A.
- Best management practices for North American airports related to procurement, storage, application, and disposal of firefighting foams.

4.2 Procurement

Airports procure AFFF in the form of a liquid concentrate that, when mixed with water in the correct proportions and with the correct equipment, produces a foam solution. AFFF is procured for use in firefighting and fire suppression at civilian airports in the United States and Canada, pursuant to the requirements detailed in Section 4.2.1. The selection of firefighting foam is based on numerous factors, including compliance with governmental quality or performance specifications, cost, availability, compatibility with existing stock and systems, and environmental considerations.

The following sections identify quality and performance-based procurement criteria for evaluating firefighting foams used in airport operations, describe AFFF alternatives acceptable for use in the United States and Canada, and identify best practices for AFFF procurement.

4.2.1 Procurement Criteria

Quality and performance-based criteria for AFFF are established, in part, through standards established in the United States and Canada by federal agencies responsible for civil aviation (i.e., the FAA and Transport Canada, respectively). Additional considerations affecting the procurement of AFFF at airports are associated with performance, compatibility with existing firefighting equipment and systems, availability, and cost.

In North America, FAA and Transport Canada regulations reference the following standards related to aircraft rescue and firefighting at airports:

- **United States Military Specification (MIL-SPEC)**—MIL-F-24385 (Fire Extinguishing Agent, Aqueous Film Forming Foam (AFFF) Liquid Concentrate, for Fresh and Seawater). MIL-F-24385 is specific to AFFF and includes performance tests on the foam concentrate itself. It is a performance specification as well as a procurement specification for the U.S. military and federal government.
- **Underwriters Laboratories Inc. (UL)**—Foam Equipment and Liquid Concentrates (UL 162). UL 162 tests foam concentrates and equipment, evaluating specific foam concentrate/ proportioner/discharge device combinations.
- **Standards Council of Canada**—CAN/ULC-S560-06 (Standard for Category 3 AFFF Liquid Concentrates).

In addition, the FAA cites standards by the National Fire Protection Association (NFPA). These standards provide guidance on ARFF services at airports. Standards referenced include the following:

- NFPA 11: Standard for Low-, Medium-, and High-Expansion Foam.
- NFPA 18: Standard on Wetting Agents.
- NFPA 403: Standard for Aircraft Rescue and Fire-Fighting Services at Airports.
- NFPA 412: Standard for Evaluating Aircraft Rescue and Fire-Fighting Foam Fire Equipment.
- NFPA 1003: Standards for Professional Qualifications for Airport Fire Fighters.

NFPA 403 defines the minimum requirements for ARFF services at airports. It should be noted, however, that the Code of Federal Regulations (CFR), Title 14 – Aeronautics and Space, Part 139, Certification of Airports takes precedence over the NFPA 403 standard, which in some areas exceeds FAA requirements.

Unlike the United States, Canada does not have a fire protection association that specifically provides standards for firefighting foam, aircraft rescue, and firefighting at airports. Rather, Transport Canada references NFPA 412: Standard for Evaluating Aircraft Rescue and Fire-Fighting Foam Fire Equipment as a standard to be followed by Canadian airports for rescue vehicles.

4.2.2 Environmental Considerations

As outlined in Chapter 2 of this report, releases of firefighting foam to the environment pose potential impacts to environmental media, wildlife, and human populations. Different firefighting foams have different chemical compositions, with varying properties (*1, 71*). A product manufacturer's safety data sheet (SDS) may contain sections that provide toxicological, human health, and ecological information. If this information is not presented in the SDS, it can be requested from a product manufacturer. The indicator values presented on a SDS can be compared to identify better alternatives or options for an airport facility. For example, within the same species (e.g., rabbit), a higher LD50 or LC50 would be preferred—this value indicates that a greater quantity or concentration of AFFF would be required to harm 50 percent of the rabbit test sample population. Some indicator values (LD50, LC50, and EC50) cannot be compared between species (e.g., rabbit versus guinea pig). Indicators typically found on SDSs are presented in Table 4-1.

4.2.3 Alternatives

AFFF is the most widely used firefighting foam due to its film-forming and fast knock down properties. PFOS (part of the larger group of PFASs) was a key ingredient in AFFF until concerns were identified regarding its environmental persistence, bioaccumulative properties, and toxicity. In 2002, 3M voluntarily stopped production of AFFF that contained and/or degraded into PFOS. Subsequently, regulations in numerous jurisdictions, including North America, were developed to ban all production of PFOS-based products. In 2002, the U.S. EPA published a SNUR under the TSCA restricting the reintroduction into the market of the PFOS chemicals included by 3M in the voluntary phase-out. A 2007 SNUR broadened the scope to 183 chemicals within the class of PFASs. In Canada, as of June 2013, production, supply, and use of AFFF containing PFOS are banned, with some exemptions for military applications.

As discussed, early alternatives to using PFOS-based AFFF were long-chain fluorotelomers, which in some cases can break down to PFOA. Later, it was found that, like PFOS, PFOA is very persistent in the environment. In response, a voluntary global directive by the U.S. EPA—referred to as the U.S. EPA 2010/2015 PFOA Stewardship Program—was introduced calling for a 95-percent reduction of plant emissions and product content of PFOA, PFOA precursors, and

Table 4-1. Environmental indicators on AFFF product SDSs.

Indicator	Description	Look for
LD50	Lethal dose at 50 percent (LD50) is the amount of an ingested substance that kills 50 percent of a test sample (short-term exposure).	Same species (e.g., species are both rabbit), higher values.
LC50	Lethal concentration at 50 percent (LC50) is the lethal concentration required to kill 50 percent of the population (longer-term exposure).	Same species, higher values.
EC50	Half maximal effective concentration (EC50) is the concentration of a substance that gives half-maximal response. Used as a measure of the substance's potency.	Same species, higher values.
BOD	Biochemical oxygen demand (BOD) is the amount of dissolved oxygen needed by aerobic biological organisms to break down organic material present in a given water sample at a certain temperature over a specific time period.	Lower values.
COD	Chemical oxygen demand (COD) is the amount of dissolved oxygen needed by chemicals to break down organic material present in a given water sample at a certain temperature over a specific time period.	Lower values.

related homologue materials by 2010, and a 100-percent reduction (i.e., elimination) by 2015. In 2010, Environment Canada also published the decision to regulate PFOA (C_8), its salts, and its precursors. These chemicals are now listed in the List of Toxic Substances Managed Under CEPA (Schedule 1). As of the publication of this report, amendments to include PFOA have been proposed for Environment Canada's Prohibition of Certain Toxic Substances Regulations, 2012.

The implementation of regulations banning the production of PFOS and the voluntary stewardship program have brought about substantial research and development into alternative firefighting foams that do not breakdown into PFOS, PFOA, or other types of PFASs.

Alternatives are described in two categories, fluorinated foams and fluorine-free foams. While fluorine-free foams are described as alternatives and are being used in some applications in Europe and Australia, there are currently no fluorine-free foams that meet specifications for use in emergency response at North American airports. All AFFFs contain fluorocarbon surfactants. The most widely used alternative for North American airports continues to be AFFF that contains fluorocarbon surfactants that are manufactured using telomerization and are referred to as short-chain fluorotelomers. While persistent in the environment, PFCA chemicals with fewer than eight carbons and PFSA compounds with fewer than six carbons are generally believed to be less toxic and less bioaccumulative in wildlife and humans, although limited toxicological data are available. AFFF containing these short-chain PFASs can still degrade to other PFASs in the environment. The use of these compounds has persisted as testing has shown that, for a given application rate, no alternative foam agent can equal the performance of AFFF for airport applications (*72*).

Appendix B describes AFFF alternatives in further detail, identifies their advantages and disadvantages, and lists properties of available products in the marketplace. The following sections identify the currently acceptable AFFF alternatives available in the United States and Canada.

4.2.3.1 Acceptable Alternatives Available in the United States

In the United States, the FAA issues operating certificates to airports that comply with certain operational and safety standards. The regulatory requirements related to firefighting at airports, as overseen by the FAA, are found in CFR, Title 14—Aeronautics and Space, Part 139, Certification of Airports (14 CFR Part 139) and, specifically, 14 CFR Part 139, 139.317 Aircraft rescue and firefighting: Equipment and agents. The FAA also issues guidance documents and resources such as Advisory Circulars and CertAlerts to provide further guidance for airports on how to comply with 14 CFR Part 139. Up-to-date information can be found on the FAA website under Airports.

The most recent Advisory Circular on Aircraft Fire Extinguishing Agents, AC 150/5210-6D, states that foam concentrates must meet the performance test requirements of the MIL-SPEC, MIL-F-24385, to comply with 14 CFR Part 139. Further guidance by the FAA on the procurement of AFFF notes that

- Any foam purchased since July 2006 must be on the United States Department of Defense Qualified Products Database (QPD) list indicating that the foam meets the MIL-SPEC requirements. The QPD serves as the official repository for qualification information regarding producers and manufacturers and is accessible to the public at http://qpldocs.dla.mil/.
- AFFF in concentrations lower than 3 percent is not acceptable for the use at airports. AFFF is available in 1-, 3-, or 6-percent concentrates. The percentages refer to the percentage of concentrate mixed with fresh water or seawater by a proportioning nozzle to create a foam solution. The 1-percent concentrate should not be used in ARFF applications because of the difficulty in consistently providing an accurate mixture.

Firefighting performance is an important, if not the primary, procurement consideration for AFFF. In addition to understanding the standards used to evaluate and certify firefighting foams, the FAA suggests that airport managers request proof of tests on performance and quality by a recognized testing laboratory (e.g., UL) from prospective firefighting foam concentrate suppliers.

System and equipment compatibility is also an important consideration in the procurement of firefighting foams. Guidance by the NFPA on firefighting foams suggests that

- The type of foam concentrate used should be a type that has been indicated as suitable for the system and equipment that will be used.
- Converting to use of a different type of foam concentrate requires consultation with the equipment manufacturer.
- Flushing of the system is required prior to using a new foam concentrate.
- Recalibration and resetting proportioning equipment may also be required.

Regulations in the United States do not currently prohibit the purchase of AFFF containing long-chain fluorocarbon surfactants (i.e., C_8 or longer); however, there are regulations that prohibit the manufacture and import of this material. Existing stock of foams containing PFASs that may break down into PFOS or PFOA still exists and may still be used in the United States. A product's adherence to the U.S. EPA 2010/2015 PFOA Stewardship Program can often be found in the manufacturer's product information sheet, indicating that the foam concentrate formulation contains C_6 or short-chain fluorochemicals rather than the long-chain fluorochemicals.

4.2.3.2 Acceptable Alternatives Available in the Canada

In Canada, Transport Canada administers the CARs, which require airports to have a safety management system in place and comply with airport safety standards and security requirements, including firefighting capabilities. Per Transport Canada's CAR Standard 323—Aircraft Fire Fighting at Airports and Aerodromes, operators of "designated airports," where the total of the number of passengers that are enplaned and the number of passengers that are deplaned is more than 180,000 per year, are to provide aircraft firefighting service with both the principal and the complementary extinguishing agents.

The regulatory requirements related to firefighting at airports are guided by CARS Part III—Aerodromes, Airports and Heliports, Standard 323—Aircraft Fire Fighting at Airports and Aerodromes. Information specific to firefighting foams is provided in Standard 323, Section 323.08—Extinguishing Agents and Equipment. Section 323.08 requires the following of foams provided as principal extinguishing agents: "AFFF shall meet the latest relevant performance specifications of CAN/ULC-S560."

As it relates to system and equipment compatibility, Transport Canada requires that the principal extinguishing agents for aircraft firefighting service be foams suitable for the type of equipment used.

Civilian airports in Canada can no longer purchase PFOS-based AFFF in accordance with the Perfluorooctane Sulfonate and Its Salts and Certain Other Compounds Regulations (2008), which prohibit the manufacture, use, sale, offer for sale, and import of PFOS and products containing PFOS. Environment Canada has proposed amendments to existing regulations that would prohibit PFOA and products containing PFOA (e.g., possibly including AFFF formulations containing PFOA and/or its precursors).

4.2.4 State of the Practice

In the survey of North American airports, about two-thirds of the respondents (65.7 percent) indicated that the most important procurement criterion for the acquisition of AFFF was complying with government regulations. In the United States, most respondents specifically highlighted the need for the AFFF purchased to be in compliance with the MIL-SPEC and meet FAA requirements. Canadian respondents identified Transport Canada guidelines as the defining regulations. Other important criteria mentioned included cost or price, the use of an external purchasing agency or organization, the availability of sufficient quantities, and the use of a required list of vendors.

For many airports, cost influences procurement decisions. Once foam compatibility and compliance with regulations is known, many airports seek bids from a variety of suppliers. For a handful of respondents, procurement is based on municipal procurement policies and may involve selecting suppliers from a pre-approved vendor list, obtaining a minimum number of bids from suppliers, and/or working with a supplier under contract. Some Canadian airports specifically made mention of a joint procurement process for major airports and bulk buying AFFF from suppliers.

Procurement decisions were also said to be made based on the required quantities and the amount a supplier could sell. In both the United States and Canada, certain quantities of firefighting foam must be held at an airport by law, driving the procurement of new foams when existing stocks are consumed or disposed.

When asked about alternative formulations of AFFF, roughly a quarter of respondents indicated that they were aware of alternative formulations, but most respondents who were aware of alternatives were unable to name specific formulations or products. As noted, some respondents indicated that procurement and the consideration of alternatives was the responsibility of others. In general, however, the survey indicated that AFFF alternatives were rarely used, principally because alternatives were not compliant with government regulations.

4.2.5 Best Management Practices

Table 4-2 identifies the best management practices associated with procurement of AFFF. Consideration of these practices will allow an airport to make an informed decision on what type of AFFF will meet its current and future needs.

Table 4-2. Best management practices associated with procurement of AFFF.

Area	Best Management Practice	Rationale
Legislation and Regulations	❑ Comply with legislation, regulation, and/or guidance in the United States	• To meet the requirements of the Code of Federal Regulations (CFR), Title 14 – Aeronautics and Space, Part 139, Certification of Airports (14 CFR Part 139), 139.317 Aircraft rescue and firefighting: Equipment and agents. To follow FAA Guidance Documents (Advisory Circulars and Cert Alerts). To align with the targets of the U.S. EPA 2010/2015 PFOA Stewardship Program.
	❑ Comply with legislation and regulations in Canada	• To meet the requirements of the CARs, Standard 323 Aircraft Fire Fighting at Airports and Aerodromes, which identifies the requirements to comply with Part III Aerodromes, Airports and Heliports. Section 323.08 of the Standard, Extinguishing Agents and Equipment. • Comply with *Perfluorooctane Sulfonate and Its Salts and Certain Other Compounds Regulations* (2008), which prohibits the manufacture, use, sale, offer for sale, and import of PFOS and products containing PFOS.
AFFF Performance	❑ Meet firefighting foam performance standards in the United States ❑ Use foam that is a 3-percent or 6-percent concentrate.	• FAA requires that AFFF meets the requirements of the MIL-SPEC, MIL-F-24385. Qualified AFFF products are listed on the QPD, found at http://qpldocs.dla.mil/. • As suggested by the FAA, foam concentrate must be either a 3-percent or 6-percent concentrate. Foam concentrate at 1 percent should not be used because of the difficulty in consistently providing an accurate mixture without the use of a computer-controlled system. In addition, there is no room for error when using a foam concentrate at a low percentage; if a discharge is on the lean side, effectively, plain water will be applied to the fire. Further information on the selection of 3-percent and 6-percent foam is included under "System and Equipment Compatibility."
	❑ Meet firefighting foam performance standards in Canada	• As per the CARs, Standard 323 Aircraft Fire Fighting at Airports and Aerodromes, AFFF purchased must meet the latest relevant performance standards of CAN/ULC-S560.
	❑ Request proof of tests on performance and quality from prospective firefighting foam concentrate suppliers.	• To confirm that the foam purchased meets the relevant performance standards required for the country.
Environmental Considerations	❑ Do not purchase PFOS-based AFFF	• All new production has been banned in the United States and Canada, and the sale (and purchase) of PFOS-based AFFF is prohibited in Canada.
	❑ Do not use AFFF that has >= C_8 fluorotelomers	• To align with the targets of the U.S. EPA 2010/2015 PFOA Stewardship Program and to be in compliance in advance of the incumbent Environment Canada regulations that would ban the use of >= C_8 fluorotelomers that can break down to PFOA.
	❑ Select AFFF that contains C_6-based fluorotelomers where available (Information can be found in a product's manufacturing sheet.)	• While persistent in the environment, PFCAs with fewer than eight carbons, such as perfluorohexanoic acid (PFHxA), and PFSAs with fewer than six carbons, such as perfluorobutane sulfonic acid (PFBS), are believed to be generally less toxic and less bioaccumulative in wildlife and humans.
	❑ Review environmental data, where available, from a product's specification. If available, choose a foam with the following criteria: • Highest lethal dose – Lowest BOD – Lowest COD – Highest LC50	• Some firefighting foams can have greater environmental impact based on the physicochemical properties of the firefighting foam product. • It is important for those working with the products to understand the type of potential impacts a product may have so it can be dealt with accordingly.

Table 4-2. (Continued).

Area	Best Management Practice	Rationale
System and Equipment Compatibility	❑ Determine the compatibility of foam with existing systems and equipment. Use the type of device required for the foam concentrate. ❑ Check the compatibility of any new foam with the previous foam type/batch	• Based on the foam concentrate, different equipment or systems may be required (i.e., an aspirating vs. non-aspirating device). In addition, different equipment may only be compatible with a foam concentrate of a certain percentage. Older equipment may only be compatible with 6-percent foam. • The type of foam concentrate should be compatible with the system and equipment to avoid coagulation concerns. Recalibration and resetting proportioning equipment may also be required. • Consult with the equipment manufacturer prior to using a different type of foam concentrate in the equipment. • Flushing of the system is required prior to using a new foam concentrate.
	❑ Select 3-percent foam concentrates, when system and equipment compatibility allows. ❑ Look to upgrading firefighting equipment to be compatible with the use of less foam concentrate, when applicable	• 3-percent foams require half of the volume of concentrate to produce the same amount of foam, making them more cost-effective, reducing on-site storage requirements, and requiring less product in ARFF vehicles. • Newer equipment is compatible with 3-percent foam concentrate, which requires the use of less foam concentrate as an input.

4.3 Storage

Proper storage of AFFF concentrates used for firefighting purposes alleviates the likelihood of accidental releases, spills, or concentrate contamination and prolongs the shelf life of the product. At most airports, AFFF is stored within ARFF vehicles (i.e., in the vehicle's designated foam tanks), on-site in the manufacturer's containers, in on-site storage tanks, and/or within hangar deluge systems.

The following sections identify legislative requirements governing AFFF storage, the current state of the practice, and best management practices associated with AFFF storage.

4.3.1 Regulations Dictating Firefighting Foam Reserves Capacity

The FAA and Transport Canada dictate how much AFFF airports need to store in reserve. Reserve storage requirements vary by the size of the airport and the type of aircraft the airport services. In the United States, the FAA requires an on-airport reserve firefighting foam supply either in a single container, storage tank, or storage area that has capacity sufficient to fill all vehicles with at least twice their assigned capacity (i.e., bunded storage). Transport Canada's guidance related to firefighting foam reserves is included in Standard 323.08. It requires that a sufficient quantity of foam concentrate is held in reserve to allow four complete discharges (i.e., assuming that at the proper concentrate-to-water ratio [or percentage], there is enough concentrate on hand to empty the total water volume available within the ARFF vehicles four times). The amount held in reserve can be considered to include the volume carried on the ARFF vehicles.

4.3.2 State of the Practice

The following sections describe the state of the practice associated with key storage considerations: storage areas and type of containers.

4.3.2.1 Storage Areas

Survey respondents characterized storage areas for firefighting foams to be as follows:

Most Likely Storage Areas	Least Likely Storage Areas
• Enclosed • Covered • Have a cement or concrete floor	• Have double containment • Underground storage tanks • Have an earth or gravel floor

The survey responses suggested that enclosed storage was substantially more common in the United States (95.3 percent) than in Canada (77.8 percent). While double containment for storage was not common, responses showed that larger airports were more likely than smaller ones to use double containment. The two countries also differed in the quantity of AFFF storage areas that have an earth or gravel floor. In the United States, virtually none (99.3 percent) of the respondents have such floors, whereas approximately 6 percent of Canadian airports reported storing their AFFF in storage areas with earthen or gravel floors.

4.3.2.2 Containers

Regulations in the United States and Canada do not dictate how foam concentrates should be stored. On-site storage of firefighting foams at North American airports is often in tanks or in the manufacturer's containers. Guidance on conditions for storage reserves and general storage of foam concentrates can be found in a foam concentrate manufacturer's product information sheets such as an SDS and/or a technical data sheet. Additional guidance on storage conditions, storage containers, and mixing, among other things, can be found within the standards used to accredit firefighting foams (i.e., NFPA, MIL-SPEC, and UL).

Manufacturers of foam concentrates suggest storing the product in its original shipping container or in tanks or other containers that have been designed for foam concentrate storage. Above-ground storage tanks designed specifically for foam concentrate storage are produced and sold by a number of manufacturers, including select AFFF manufacturers. Recommended construction materials for storage containers include stainless steel (Type 304L or 316), high-density cross-linked polyethylene, or reinforced fiberglass polyester with a vinyl ester resin. Manufacturers of storage tanks for foam concentrates suggest that above-ground storage tanks be placed on a level surface.

Conditions

To avoid evaporation, foam concentrate storage should be in a container that is sealed to prevent the free exchange of air. The recommended storage environment should be within the temperature range listed in the product manufacturers' information sheet. Storage temperatures for AFFF concentrates are generally listed as being between 2°C to 49°C (36°F to 120°F). If stored in the correct environment, following manufacturer's guidelines and not otherwise contaminated, AFFF concentrates can reportedly last between 20 and 25 years.

Mixing

Mixing of different foam concentrates is not recommended. However, on a case-by-case basis and in consultation with the manufacturer, mixing may be acceptable. Current guidance regarding mixing includes the following:

- Different types of foam concentrates (e.g., AFFF and fluoroprotein based) should not be mixed. Different brands of the same type of concentrate should not be mixed unless data are provided by the manufacturer to, and accepted by, the authority having jurisdiction (e.g., FAA, Transport Canada) to prove that they are compatible under NFPA 11.

- In the United States, MIL-F-24385F qualified product should not be mixed with other foam concentrates that are not qualified.
- In Canada, foam concentrates of different types or from different manufacturers should not be mixed except where it has been established that they are completely interchangeable and compatible (CAR Standard 323, Section 323.08).

4.3.3 Best Management Practices

Table 4-3 identifies the best management practices associated with the storage of AFFF. Proper storage following these practices can reduce the likelihood of accidental releases, spills, or concentrate contamination and prolongs the shelf life of the AFFF.

Table 4-3. Best management practices associated with the storage of AFFF at airports.

Area	Best Management Practice	Rationale
Storage Containers	❑ Store in specific types of containers: • Original shipping container • 55-gallon drums/plastic barrels • Above-ground storage tanks (double walled)	• To allow for product integrity and shelf life to be maintained and to minimize the risk for leaks and spills.
	❑ Read and follow the storage procedures outlined in SDSs and TDSs for the product	• To meet product manufacturers' recommendations for storage.
	❑ Use containers with recommended materials: • Double-walled stainless steel (Type 304L or 316) • High-density cross-linked polyethylene (XLPE) • Reinforced fiberglass polyester with a vinyl ester resin	• Recommended composition of storage containers are inert, so the product will not change nor will the concentrate be contaminated.
	❑ Label storage containers and storage tanks to identify the type of foam concentrate and concentration.	• To prevent mixing of foams of different brands and/or concentration and prevent inappropriate use or disposal.
Storage Conditions	❑ Store under storage conditions as described in a manufacturer's product information sheet: • Sealed • Secured • Temperature (ranges) • Mixing (do not mix foam concentrates or brands)	• To meet product manufacturers' recommendations for storage, to allow for product integrity and shelf life to be maintained, and to alleviate the risk for leaks and spills.
	❑ Store in a storage facility/environment that is • In an area designated for the storage of these chemicals • Roofed/sheltered • Rack system in place when totes are used	• The designated storage area provides an area where foam concentrates are stored away from incompatible materials (as outlined in a product's SDS). A designated area should also allow the recommended storage conditions to exist and for storage to be away from any potential hazards (e.g., electrical). • Roofed/sheltered areas are to avoid weather damage (rain, snow) that could compromise the integrity of the product.
	❑ Make use of other bunded storage methods: • Secondary containment (e.g., drums sit on top of a tote)	• In the event of a leak or spill the product would be contained until remedial action can take place.
	❑ Store on level ground with a hard surface (e.g., concrete, asphalt)	• In the event of leak or spill, to reduce the risk of the product permeating the ground surface.
Reserves	❑ Follow the recommended reserve quantities to be stored	• The FAA requires that an on-airport reserve of firefighting foam have the capacity sufficient to fill all vehicles with at least twice their assigned capacity. Transport Canada requires that the amount of foam concentrate held in reserve should allow for four complete discharges with the required quantity of water.

4.4 Application

AFFF is applied as an extinguishing agent for Class B fires (i.e., fires of flammable and combustible liquids such as crude oil, gasoline, and fuel oils). The application of AFFF serves to

- Coat a pool of flammable or combustible liquid, acting as a barrier to prevent oxygen from fueling the fire.
- Form an aqueous film of the water/concentrate after the foam has dissipated on the fire surface that suppresses fuel vapor and seals the fuel surface.
- Provide additional fire suppression through the water in the foam providing a cooling effect.

The following sections describe applications where AFFF is used, handled, or tested; the current state of the practice with regard to AFFF application at airports; and best management practices associated with AFFF application.

4.4.1 Firefighting Foam Application in Airport Operations

AFFF is used in airport operations for the primary purposes of preventing, extinguishing, and controlling fires involving flammable liquids. The application of AFFF occurs during aircraft rescue situations, training, testing, and/or as a result of a discharge from deluge systems in aircraft hangars. In addition, for the purposes of this report, application also refers to handling of AFFF concentrate, including the periodic removal and replacement of AFFF concentrate from vehicles during maintenance. Please note that this report does not address how AFFF should be deployed to prevent, extinguish, or control a fire. Guidance on how to deploy AFFF for these purposes should be sought from airport emergency response personnel.

4.4.1.1 Aircraft Rescue

Aircraft rescue is the firefighting action taken to prevent, control, or extinguish fire involving, or adjacent to, an aircraft (FAA 2004). Federal law in both the United States (14 CFR 139) and Canada (CAR Subpart 3 —Aircraft Rescue and Fire Fighting at Airports and Aerodromes) requires that all airports operating regularly scheduled commercial flights have firefighting capabilities appropriate for the aircraft serviced.

In the United States, 14 CFR Part 139 establishes the minimum firefighting capability to respond to aircraft rescue situations. The different types, quantities, and flow rates of AFFF are described for ARFF Category A to E airports. The FAA requires airports to meet 14 CFR Part 139, but encourages them to provide greater ARFF capability, consistent with NFPA Standard 403: Aircraft Rescue and Fire-Fighting Services at Airports.

In Canada, the CARs (Section 303.05) define critical categories for firefighting based on aircraft length and maximum fuselage width and the number of passenger and aircraft movements. The critical category determines the minimum aircraft firefighting service that must be provided by operators of designated airports or participating airports. Specific quantities of water, extinguishing agents, and the minimum number of ARFF vehicles necessary to provide a discharge capacity of foam related to the category of firefighting are provided in Section 303.09 of the regulations. Further, as per Standard 323.08, the quantity of foam concentrate on board ARFF vehicles should be sufficient to produce foam for at least two full loads of the required quantity of water specified in Section 303.09 of the CARs.

4.4.1.2 Training

AFFF is most commonly used for training purposes at airports, specifically during live-fire drill training. In the United States, the FAA requires that following initial ARFF training, all airport firefighting personnel who are involved in firefighting complete at least one live-fire firefighting drill every 12 consecutive calendar months. As per Advisory Circular 150/5210-17C, live-fire drills involve a pit fire with an aircraft mock-up using enough fuel to simulate the type of conditions that could be encountered during a rescue situation at that airport. If training of airport firefighting personnel who are involved in firefighting does not occur within the 12-month period, an airport will be considered out of compliance with 14 CFR 139. While not required by 14 CFR 139, FAA recommends that airports also follow NFPA 1003: Standards for Professional Qualifications for Airport Fire Fighters.

The FAA's Advisory Circular 150/5220-17B: Aircraft Rescue and Fire Fighting Training Facility provides guidance for airports on the design, construction, and operation of ARFF training facilities. Some facilities are located on airport properties due to convenience for training.

Transport Canada requires live-fire drill training to be provided to all aircraft firefighting personnel every 12 months. The required training involves a live-fire drill to simulate a realistic firefighting situation that could be encountered on a typical aircraft at an airport. During these drills, fire-extinguishing equipment that will be used in the event of an accident includes the use of firefighting foams.

Where training is conducted, if at all, varies by airport. Many airports have designated firefighting training areas. If training is not conducted in a designated training area or the designated training area is not an engineered system designed to contain discharged AFFF and fuel, AFFF discharge may result in PFASs being released into the environment.

4.4.1.3 Testing

AFFF has the potential to be released to the environment during testing of an AFFF mixture and equipment. In the United States and Canada, testing of firefighting foam equipment on ARFF vehicles is done in accordance to NFPA 412: Standard for Evaluating Aircraft Rescue and Fire-Fighting Foam Equipment. Transport Canada, per Standard 322.08, requires the NFPA tests to determine that the correct discharge rate is being delivered and the required foam physical characteristics are being met.

In addition to performance testing done by manufacturers on foam concentrates, NFPA 412: Standard for Evaluating Aircraft Rescue and Fire-Fighting Foam Equipment states that ARFF vehicles should be tested on a schedule set out by the authority having jurisdiction (e.g., FAA, Transport Canada) in the following criteria areas: expansion ratio, drainage 25 percent, and proportioning and distribution pattern. Tests for these criteria involve allowing a foam solution to discharge from a hoseline or turret.

Methods for testing these criteria include the following:

- Expansion ratio, drainage 25 percent, and proportioning:
  - Selecting foam samples representative of the foam produced by the nozzle as it would be applied to a fire.
  - Collecting foam samples through a foam sampling apparatus or foam collector, where a foam nozzle is aimed into a collector so that discharge is collected in a 1,000 mL graduated cylinder.
  - Observing the level of accumulation at timed intervals and the total weight of the foam sample and performing calculations to analyze the results.
- Distribution pattern:
  - Ground sweep nozzle and hand line nozzle tests:
    - Discharging from ground sweep nozzles and hand line foam nozzles onto a paved surface for a period of 30 seconds.

    - Plotting the outline of the effective foam pattern.
    - Establishing, measuring, and recording straight stream and fully dispersed nozzle settings.
  - Turret ground pattern tests:
    - Preparing a foam solution with the type of foam concentrate to be used during actual emergencies with the proportioner set for normal firefighting operations.
    - Performing discharge tests to establish foam patterns produced and the maximum range attainable by a turret nozzle for a period of 30 seconds.
    - Recording and analyzing results.

Further details on performance criteria, test methods, and calculations are available in NFPA 412.

4.4.1.4 Handling

Handling of AFFF may occur during an emergency response incident, training, testing, or vehicle maintenance. Procedures for safe handling apply not just to firefighting personnel. Due to the potential for spills and leaks, airport personnel responsible for handling AFFF need to exercise caution and practice safe handling procedures. Procedures for safe handling of foam concentrates are included in the manufacturer's product SDSs. Examples of these procedures from a manufacturer's SDSs include the following:

- Limit all unnecessary personal contact.
- Wear protective clothing when risk of exposure occurs.
- Handle in a well-ventilated area.
- Avoid contact with incompatible materials.
- Wash hands with soap and water after handling.

4.4.1.5 Aircraft Hangars

Fixed fire protection systems use AFFF to extinguish Class B fires that could occur in facilities that house aircraft. Most fire protection systems for aircraft hangars are designed in accordance with NFPA 409: Standard on Aircraft Hangars. In the United States, requirements for adherence to NFPA 409, or specific sections of NFPA 409 as it relates to aircraft hangars, are contained in the International Building Code. In Canada, local building code requirements are followed and often reference NFPA 409. There are no specific requirements by the FAA or Transport Canada related to fire suppression and the use of firefighting foams in aircraft hangars.

NFPA 409 considers four aircraft hangar groups classified on the basis of aircraft access door height, single fire area, and, in some cases, the aircraft that they store. The aircraft hangar classification determines the appropriate fire protection systems. Aircraft hangars housing larger aircraft (Group I and II) have several options for protection systems, including a fixed foam–water deluge system, whereas Group III hangars do not usually require any fixed protection system, and Group IV hangars can use an automatic water sprinkler (meeting specific criteria), or high- or low-foam expansion systems. The following application rates are required for fixed foam systems in hangars:

- Group I: 0.20 gpm per sq ft for AFFF
- Group II and IV: 0.10 gpm per sq ft for AFFF

Firefighting foam can be intentionally released from an aircraft hangar fire protection system in the event of a fire, or it can be released due to human error, mechanical malfunction, or electrical malfunction. A release may also occur during periodic testing of a deluge system.

Trench drainage systems should be designed in a hangar system to collect and contain fuel to prevent fire hazards, but can also assist with the containment of AFFF and other discharge for subsequent treatment. Per NFPA 409, trench drainage systems, in addition to sufficient floor pitch to allow liquids to flow into drain inlets and be collected, are to be a part of the aircraft hangar design. Curbs, ramps, drains, or appropriate sloping of the floor at all openings of the hangar are also suggested to prevent any releases of liquids. Trench drainage systems are meant to have oil separators and a bypass around each separator to allow for emergency direct disposal of water and flammable liquid when the foam-water systems are in use in the event of a fire. The flammable liquids are then meant to be discharged to a tank, cistern, or sump away from any potential exposure.

4.4.2 State of the Practice

While these events may be infrequent, close to three-quarters of the responding North American airports surveyed have used AFFF for actual firefighting purposes. The extent to which AFFF has been used for these purposes varies by airport size, with the largest airports having the highest frequency of use and the smallest airports having the lowest.

The more common use of AFFF at airports was found to be training and testing. Most airports have held firefighting training on their premises at some point in time, and the majority used AFFF in the training exercises. Of the 167 North American airports that completed the survey, 97.6 percent indicated that they conduct foam tests of both the AFFF mixture and equipment. The majority of respondents indicated that these tests are conducted every 6 to 12 months (54.6 percent); the second largest group of respondents indicated that they conduct their tests every 4 to 6 months (33.1 percent). The survey also suggested that the testing frequency increased with increasing airport size.

When handling AFFF, staff and trainees wear various types of protective equipment. Almost all respondents outfit those handling AFFF with work gloves and eye protection; strong majorities provide safety boots, turnout gear, and fire-retardant clothing. Substantially fewer respondents reported use of nitrile or other one-time-use gloves.

The survey also indicated that equipment testing of deluge systems in airport hangars occurred infrequently, with only 7 percent of responding airports indicating that such testing is conducted.

4.4.3 Best Management Practices

Table 4-4 identifies the best management practices associated with the application of AFFF at airports.

4.5 Disposal

Given the potential environmental implications associated with PFASs (as documented in Chapters 2 and 5 of this report), proper disposal of AFFF and/or AFFF concentrate is required. The unique properties of PFASs, however, present challenges in disposing of AFFF in an environmentally responsible manner. Moreover, traditional disposal methods suitable for other waste streams may not be effective.

Regardless of waste stream or application scenario, AFFF and/or AFFF concentrate should not be directly discharged or deposited to the environment. The only exception is when AFFF is being used in an emergency response. The following sections discuss various disposal considerations, the state of the practice as determined from the industry survey conducted as part of this research, and best management practices.

Table 4-4. Best management practices for the application of AFFF at airports.

Area	Best Management Practice	Rationale
Handling	❑ Follow industry-recommended practices: • NFPA 402: Guide for Aircraft Rescue and Fire-Fighting Operations • Have a safety spill plan in place when transferring containers/testing equipment and systems	• So that industry-recommended operational procedures are followed to provide the basis for airport representatives to respond to an aircraft emergency in the minimum possible time and employ rescue and firefighting techniques effectively.
	❑ Provide personnel training: • Staff is educated in safety and environmental concerns • Staff is trained in standardized procedures designed for safety and environmental concerns • Have two or more people available to move containers with AFFF ❑ Require personnel to wear PPE: • Includes but not limited to work gloves, eye protection, safety boots, and protection from contact with skin	• To promote awareness of the potential impacts to human health and the environment if the product is mishandled and to provide an understanding of mitigation measures. • To minimize any potential health hazards during the handling of the foam concentrate.
	❑ Read and follow the handling procedures outlined in SDS and TDS for the product (e.g., work in a ventilated area/avoid inhalation). ❑ Never use galvanized pipe and fittings in contact with undiluted concentrate.	• To meet product manufacturer's recommendation that may be specific to the product. • A galvanized pipe and fittings would be at risk of corrosion upon contact with foam concentrate.
	❑ When applicable, limit the distance travelled between storage areas and filling areas.	• Limiting the transportation of foam concentrate when not stored in fixed tanks minimizes the potential risk of leaks and spills during handling and transport.
Aircraft Rescue	❑ Follow industry-recommended practices • NFPA 402: Guide for Aircraft Rescue and Fire-Fighting Operations.	• Fire control is often an essential condition to provide protection for the occupants in an aircraft rescue event. Following industry-recommended operational procedures provides the basis for airport representatives to respond to an aircraft emergency in the minimum possible time and employ rescue and firefighting techniques effectively.
	❑ Provide personnel training: • Staff is educated in safety and environmental concerns. • ARFF personnel possess a sound knowledge of fire behavior, as per NFPA 403 Section E.4.3 (2014). • Staff is trained in standardized procedures designed for safety and environmental concerns. • Hazardous waste/spill response team nearby to carry out clean-up activities after the emergency has been mitigated.	• Responding to an emergency response incident safely should be the first priority; however, having environmental response teams ready and mobilized following the emergency can contribute to reducing the potential environmental impacts by containing and establishing a perimeter to help control the extent of environmental impacts.
	❑ Require personnel to wear appropriate PPE: • Including but not limited to: nitrile or latex gloves, eye protection, safety boots, and protection from contact with skin.	• To minimize any potential health hazards during response activities.
Training	❑ Implement training that follows industry-recommended practices • FAA Advisory Circular No. 150/5210-17C. • NFPA 1003: Standard for Airport Fire Fighter Professional Qualifications. • Staff is educated in safety and environmental concerns. • Staff is trained in standardized procedures designed for safety and environmental concerns.	• To promote awareness of the potential impacts to human health and the environment when the product is released during training exercises and an understanding of mitigation measures.

Table 4-4. (Continued).

Area	Best Management Practice	Rationale
	❑ Follow a defined training schedule as defined by the authority having jurisdiction.	• In the United States, each Part 139 Certificate holder must ensure all ARFF personnel participate in at least one live-fire drill every 12 consecutive calendar months. • Transport Canada requires live-fire drill training to be provided to all aircraft firefighting personnel every 12 months.
	❑ Use a regional training facility or host live-fire training for multiple airports at one location.	• To reduce the potential environmental impact for individual airports and lower the frequency of firefighting foam use for training activities.
	❑ Require personnel to wear appropriate PPE: • Including but not limited to: nitrile or latex gloves, eye protection, safety boots, and protection from contact with skin.	• To minimize any potential health hazards during the handling of the foam concentrate.
	❑ Prepare for training exercises: • Safety spill plan in place when transferring containers/testing equipment and systems.	• In the event of a leak or spill as a result of preparing for training exercises, a plan is in place for rapid response and containment.
	❑ Training locations: • Conduct training in an area where AFFF water/foam solution can be contained and collected for treatment (e.g., bermed). • Configure training area with a sump to allow collection and disposal of material used during training. • Do not discharge to ground. • Consider constructing a lined fire training pit. • Locate training exercises away from storm drain inlets, drainage facilities, or water bodies.	• To prevent migration of the discharged firefighting foam to locations where it cannot be collected and properly disposed of.
	❑ Make use of alternative foam products for training exercises.	• Other international jurisdictions (e.g., Norway, Australia) make use of training foams that do not contain fluorine but have similar foaming properties for certain training exercises (e.g., equipment and/or live-fire testing). These fluorine-free foams are considered to present the lowest environmental impact.
	❑ Optimizing firefighting program (e.g., equipment, training, procedures)	• Differences in foam concentrate characteristics can be adjusted for by changing firefighting procedures
Equipment and System Testing	❑ Follow industry-recommended best practices: • NFPA 412: Standard for Evaluating Aircraft Rescue and Fire-Fighting Foam Equipment ❑ Discharge the minimum required to test the system/equipment: • Use the same collected samples for multiple tests, where applicable. • Collect discharge for storage and disposal. • Put a safety spill plan in place. • Maintain equipment in good condition to reduce spillage (e.g., ensure fittings are tight).	• To limit the amount of foam solution discharged during testing. NFPA 412 states that the portions of drained solutions used in drainage tests can be used for the "foam solution sample" for other tests.
	❑ Conduct ground pattern tests first with water, then with the foam solution.	• To minimize unnecessary discharge of foam solution by using water in advance of testing when adjustments are being made on equipment and systems.

(continued on next page)

Table 4-4. (Continued).

Area	Best Management Practice	Rationale
Aircraft Hangers	❑ Construct the aircraft hangar following local building code: • NFPA 409: Standard on Aircraft Hangars.	• Local building codes often reference NFPA 409, which contains the minimum requirements for proper construction of aircraft hangars and for fire protection at aircraft hangars.
	❑ Design deluge (foam) testing systems with the following characteristics: • Away from storm drain inlets, drainage facilities, or water bodies. • Discharge AFFF waste to a sanitary sewer (industrial wastewater permitting may be required). • AFFF waste should not be discharged to storm drains or water bodies. • Paved with concrete or asphalt or stabilized with aggregate base. • Bermed to contain AFFF and to prevent run-on. • Configure discharge area with a sump to allow collection and disposal of AFFF.	• To mitigate the potential effects of AFFF discharge in the event of a testing exercise or an incident in an aircraft hangar.
	❑ Discharge the minimum required to test the system/equipment. • Have a safety spill plan in place ❑ Have piping that connects the foam to the fire suppression system be above ground over a concrete floor.	• To limit the amount of foam solution discharged during testing. • In the unlikely event that a pipe burst, above-ground piping would provide for more rapid leak detection and spill response.
	❑ Provide protection for the aircraft hangar, including electrical and mechanical equipment exposed to possible damage during discharge tests. • Sandbags or similar means.	• To prevent migration of the discharged firefighting foam to other locations in the aircraft hangar and to protect the mechanical and electrical equipment.

4.5.1 Disposal

The means by which an airport disposes of AFFF or AFFF concentrate can vary based on the nature of activity resulting in waste for disposal, the nature of the material being disposed (e.g., aspirated residual AFFF, AFFF concentrate, and wastewater containing AFFF or PFASs as a result of vehicle or equipment system maintenance), an airport's waste management facilities and associated capacity, and applicable regulations. Given the stringent and evolving regulatory standards surrounding PFASs, please note that proper disposal is not to be predicated on the volume of material to be disposed (i.e., even very small quantities of material discharged into the environment could have significant human health and environmental impacts and result in significant costs to address).

4.5.1.1 Discharge Disposal

Discharged AFFF will likely result in residual foam. Uncontrolled releases pf AFFF to land and surface water can occur in the event of an accidental discharge or a fire emergency; where possible, residual foam (or, if washed down, residual AFFF wastewater) should be contained so that the amount directly released to the environment is minimized.

Generally, in accordance with the manufacturer's SDSs, 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). Such facilities, however, vary widely in their ability to address the impacts of PFASs effectively, if at all (i.e., many studies have shown no removal of PFASs via wastewater treatment), depending on the treatment train. Prior to disposal (to the extent practicable, recognizing that weather conditions may drive runoff), airports should check with the local wastewater facility to confirm its ability to treat wastewater containing PFASs. At some airports, residual AFFF/AFFF wastewater is directed to stormwater drains that may not be directed to a treatment facility. In addition, airports need to coordinate with federal, state/province, and local authorities and other waste service managers to understand the applicable requirements and available disposal options.

In the event that hydrocarbon fuels are mixed with the foam solution, a fuel-water separator can be used to allow for the AFFF/AFFF wastewater solution to be disposed of separately from the fuel. Prior to discharge, waste should be evaluated to determine whether flammable materials are still present at hazardous concentrations and to review the applicability of sewer restrictions (*73*).

4.5.1.2 Removal from Equipment or Systems

Testing and/or maintenance may require the removal of AFFF concentrate from ARFF vehicles, equipment, and systems. Removal of AFFF from vehicles, equipment, or systems may also be required in the event that an airport switches to a different type of foam concentrate. Flushing during removal or testing generates wastewater that contains AFFF.

4.5.1.3 Disposal of AFFF Stockpiles

AFFF has a long shelf life. This means that legacy AFFF containing PFOS or long-chain fluorocarbon surfactants still exists in U.S. and Canadian inventories. The manufacture and import of new PFOS-based products is banned in the United States; however, existing stocks may still be used if they were manufactured or imported into the United States prior to the rules taking effect in 2002 (*74*). While there is no explicit regulation barring the discharge of wastewater containing AFFF, in the United States it can be regulated under the Clean Water Act that regulates pollutant discharges into water. In Canada, the Perfluorooctane Sulfonate and Its Salts and Certain Other Compounds Regulations indicated that PFOS-containing AFFF should not be used or otherwise released to the environment as PFOS has been identified as posing a risk to the environment. Consequently, PFOS-containing AFFF should be disposed of at an authorized waste management facility. Prior to the proper disposal of AFFF, provincial/territorial authorities should be contacted.

4.5.2 State of the Practice

Two-thirds of the responding North American airports indicated that AFFF discharged during testing is disposed of onto the ground. The remaining third of respondents discharge AFFF into an engineered containment system. For the one-third of respondents who used engineered containment systems, the type of system most widely used was a small or non-permanent vessel, and the next most widely used system was testing in a designated area such as a containment basin or training pit. Survey results regarding AFFF discharge during training activities were similar, with the majority of respondents (80 percent) indicating that AFFF was discharged directly onto the ground during training exercises. The remaining 20 percent responded that AFFF was discharged during training exercises into engineered containment systems.

According to the survey, most respondents remove AFFF concentrate from firefighting equipment or systems for maintenance by draining or pumping AFFF into containers (e.g., a training pit, a holding tank, drums, barrels, and totes) for temporary storage of AFFF and then reuse it.

4.5.3 Best Management Practices

Table 4-5 identifies the best management practices associated with the disposal of AFFF stockpiles or following use at airports.

Table 4-5. Best management practices for disposal of AFFF at airports.

Area	Best Management Practice	Rationale
Discharge Disposal	❑ Dispose of foam-water solutions: • Wastewater treatment, appropriate pretreatment steps taken. ❑ Dispose of foam-hydrocarbon solutions: • Use fuel-water separator. ❑ Dispose of foam-soil mixtures.	• Industry guidance in the United States recommendations for disposal of PFOS-based AFFF concentrate is by incineration at a facility capable of handling the waste. • Authorized disposal facilities can only dispose of waste for which they have been issued a certificate of approval or which meet their operating permits and are regulated by Province/Territory in Canada.
	❑ Record all disposal.	• Recording what has been disposed of, in what volumes, and where provides a record of an airport's disposal.
Removal from Equipment or Systems	❑ Removal to containment vessel: • Transfer by pump to containment vessel. • Containment vessel should have secondary containment (e.g., underlying tote) during removal process.	• In the event of a leak or spill, the product would be contained until remedial action can take place.
	❑ Practice proper handling protocol: • Flush/clean out equipment thoroughly, retaining rinse water. • Staff handling AFFF transfer should wear appropriate PPE.	• To minimize any potential health hazards during the handling of the foam concentrate.
	❑ Dispose of removed foam concentrate at an authorized location.	• The ability to dispose of unused foam concentrate may differ by jurisdiction. Disposal should occur at an authorized location that handles hazardous waste.
Disposal of AFFF Stockpiles	❑ Comply with legislation, regulation, and/or guidance in the United States.	• Industry guidance in the United States recommendations for disposal of PFOS-based AFFF concentrate is by incineration at a facility capable of handling the waste.
	❑ Comply with legislation, regulation, and/or guidance in Canada.	• Authorized disposal facilities can only dispose of waste for which they have been issued a certificate of approval or which meet their operating permits and are regulated by Province/Territory in Canada.

CHAPTER 5

Addressing Legacy Environmental Impacts

5.1 Overview

As indicated in Chapter 2 of this report, AFFF has been used for decades at airports in the United States and Canada to extinguish fires. PFASs, principal active ingredients in AFFF, are considered an emerging contaminant in the environmental industry. Some PFASs are ubiquitous in the environment and exhibit properties that could pose a potential human health or ecological risk to sensitive receptors at low concentrations. Historical use, training, testing, maintenance, and disposal practices may have resulted in a release of PFASs into the environment. This chapter discusses how to address environmental impacts associated with past releases or applications of AFFF into the environment. Specifically, this chapter describes the following:

- Best practices for sampling environmental media for PFASs so that representative samples are obtained. Key information for evaluating whether there is a potential unacceptable human health or ecological risk involves identifying whether PFASs are present in environmental media (i.e., soil, sediment, groundwater, and surface water) and at what concentration.
- Current, commercially available laboratory analytical methods for PFASs that are necessary to achieve analytical detection limits appropriate for comparing concentrations to stringent regulatory criteria. Analytical approaches under development and not yet commercially available in the United States or Canada are also identified.
- Risk management considerations specific to the impacts of PFASs, including key factors in developing the conceptual site model (CSM) and strategies to manage potentially unacceptable risks.
- State-of-the-practice remediation technologies and approaches that have demonstrated some success (or are generally believed to hold promise) in field-scale remediation of PFASs in soil and groundwater. Emerging technologies and approaches under review and development are also identified.

5.2 Sampling of PFASs

5.2.1 General Challenges with Sampling of PFASs

Traditional, standardized environmental sampling protocols provide effective means to collect representative samples from various environmental media for most contaminants. However, as described in Chapter 2, the chemical and physical properties of some PFASs offer unique challenges in obtaining concentrations of PFASs representative of field conditions. For example, the fact that compounds containing PFASs stratify in water as they migrate to the air-water interface means that groundwater samples need to be taken from the surface of the water table and laboratory analytical methods must involve vigorous shaking of water samples before a subsample is removed and injected into laboratory instrumentation. PFASs are also likely to "stick" to suspended particles in water or to a filter if samples are filtered to retain the "dissolved" fraction of the water sample. In addition, the ubiquity of PFASs in the environment from sources such as clothing (e.g., Gore-Tex™) or sampling equipment (e.g., PTFE or Teflon™) could contaminate samples, resulting in measured concentrations that are greater than the actual concentrations in the environmental media being evaluated.

In order to obtain representative samples, specific sample collection protocols are recommended when a site is to be investigated for PFASs. These protocols include avoiding the use of glass or metals, as some PFASs bind to these materials. Contact with materials that may contain PFASs such as PTFE (i.e., Teflon™) should also be avoided, and samples should be collected using polyethylene or polypropylene containers and equipment. Additional guidance on conducting sampling programs for PFASs can be found in the following:

- U.S. EPA Method 537. Determination of Selected Perfluorinated Alkyl Acids in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry (LC-MS/MS).
- Transport Canada's Perfluorochemical Sampling and Analysis Guidance.
- United Nations Environment Programme (UNEP) Chemicals Branch's PFAS Analysis in Water for the Global Monitoring Plan of the Stockholm Convention: Set-Up and Guidelines for Monitoring.

The following sections discuss best practices for sampling soil, sediment, groundwater, and surface water for PFASs and reducing the likelihood for cross-contamination. Also discussed are quality assurance and quality control considerations and innovative approaches to sampling for PFASs.

5.2.2 PFASs—Sampling Challenges and Mitigation

5.2.2.1 Cross-Contamination

Cross-contamination occurs when samples collected in the field are impacted by chemicals from sources other than the media being sampled. Cross-contamination can result in a detectable concentration where no PFASs are present or a concentration that is biased high relative to what is present in the environment. The potential for cross-contamination is significant given the ubiquity and environmental persistence of some PFASs and the very low detection limits and regulatory criteria associated with many PFASs. General practices recommended to eliminate the likelihood of cross-contamination regardless of media are presented below.

Sampling Equipment and Sample Containers

The use of glass or metals should be avoided because compounds containing PFASs bind to these materials. Samples should be collected using polyethylene or polypropylene containers and equipment. Contact with materials that may contain PFASs such as PTFE should also be avoided (e.g., Teflon™ tubing, Teflon™ bailers, and sticky labels and adhesive tape used during sample collection and storage). Use of aluminum foil should also be avoided, as some PFAAs could be transferred from the aluminum foil to the sample.

Drilling Water/Hydroexcavation

Potential sources of PFASs (other than what is in the environmental media being investigated) should be considered and removed during sampling field programs to avoid cross-contamination. For example, if water is necessary to obtain a soil sample (e.g., drilling or hydroexcavation), it is important to confirm that the water does not contain PFASs that could impact the samples or, worse, impact the study area.

Field Equipment Decontamination

Field equipment that is used at multiple sampling locations (e.g., flow-through cells, field meters, and interface probes) requires proper decontamination between uses at different sampling locations. Decontamination should be conducted with rinsate that is free of PFASs (i.e., water that is free of PFASs) and detergents. Water that is free of PFASs can be obtained from a laboratory. Where impacts of PFASs are known to be present, field decontamination of each piece of field equipment should be conducted prior to use, at least twice between sampling locations, and before leaving the site.

Personal Protective Equipment and Field Clothing

Personal protective equipment and field clothing commonly worn during field investigations may represent potential sources of PFASs that could cross-contaminate samples collected in the field. The following practices are recommended:

- Field clothing to be worn on-site should be restricted to clothing made of natural fibers (e.g., cotton). Synthetic fibers and/or clothing that is water resistant, waterproof, or stain-treated should not be worn during the field program.
- Field personnel should avoid documenting field notes on waterproof field books/paper as the coated paper may contain PFASs. Acceptable field documentation alternatives include field tablets, other electronic data entry interfaces, or uncoated paper.
- Most safety footwear is made from leather and synthetic fibers that have been treated to provide some degree of waterproofing/increased durability and may represent a trace source of some PFASs. For the health and safety of field personnel, the protection afforded by the footwear must be maintained. Field staff should avoid directly contacting samples after touching their footwear (e.g., tying shoelaces).
- Field personnel should frequently replace gloves (using disposable single-use gloves and having multiple changes per location) to mitigate the potential for cross-contamination. At a minimum, sampling gloves should be replaced after contact with equipment and prior to contact with sample bottles or containers of water that are free of PFASs. Gloves should be nitrile or latex; regular canvas or leather work gloves should not be used for sample collection or for personal protection when handling AFFF or media impacted by PFASs.

Food Packaging

For health and safety reasons, food and beverages should not be consumed during field activities except during a designated break in a designated clean area. However, due to the historical use of some PFASs in food packaging, field personnel must be particularly careful when sampling for PFASs. The following practices are recommended for field personnel (and visitors to the area):

- Do not bring food on-site in any paper packaging (i.e., do not bring any fast food to the site that uses any form of paper wrapping like sandwiches with paper wrap or coffee in paper cups).
- Avoid products such as aluminum foil, coated papers, and coated textiles.
- Wash hands after eating and prior to engaging in sample collection, and wear appropriate gloves (e.g., nitrile) for sample collection.

Specific Best Practices for Sampling Aqueous Media

In order to alleviate the potential for cross-contamination, the following practices, specific to aqueous media sampling, are recommended:

- A well condition survey should be completed *after* groundwater purging and sampling has been completed to help mitigate the possibility of cross-contamination of groundwater samples. (Please note that this practice is atypical for groundwater sampling programs, which usually have static water levels, and which include monitoring well depths as one of the first steps.)

- Aqueous samples should be collected directly into bottles prepared by a laboratory to be free of PFASs. High-density polyethylene (HDPE) tubing connected to a peristaltic pump (where feasible) with silicon tubing should be used for the groundwater sampling program.

5.2.2.2 Suspended Particulate Matter in Aqueous Samples

The adsorptive properties of some PFASs relative to field filtration and their ability to "stick" to particles in the water column can make quantifying PFASs in aqueous matrices challenging. To avoid suspended particulate matter and solids during groundwater sampling, procedures for compounds with PFASs in groundwater should follow the field procedures established for low-flow purging and sampling, as described in the two documents listed below, with adaptations to address the sampling concerns specific to PFASs (e.g., cross-contamination and no materials containing PTFE):

- Low Stress (low flow) Purging and Sampling Procedure for the Collection of Groundwater Samples from Monitoring Wells, EQASOP-GW 001 US EPA (2010).
- ASTM D4448-01 (Reapproved 2013)—Standard Guide for Sampling Ground-Water Monitoring Wells.

As with groundwater, surface water samples should be collected in accordance with standard methodologies, avoiding suspended and/or particulate matter in retrieved water samples. As mentioned earlier, the presence of particulate matter in water samples can contribute to measured concentrations that are greater than the actual environmental concentrations and, therefore, not representative of the media (i.e., water) sampled.

Filtration is *not* recommended before laboratory extraction, as the filter may absorb PFASs or may be a source of contamination.

5.2.2.3 Sampling Frequency

AFFF formulations may contain precursors that transform or degrade into other, more stable and recalcitrant PFASs such as PFOS and PFOA. Changes in the concentrations of precursors and these more stable PFASs may occur over time. Consequently, in addition to assessing seasonal considerations, sampling more than once may help to better assess sites where PFASs are transforming and/or identify whether migration is occurring.

5.2.3 Quality Assurance and Quality Control

A quality assurance/quality control (QA/QC) program appropriate for achieving the project's data quality objectives should be adopted for any type of environmental program. Typically, an appropriate QA/QC field sample collection program for field investigations involving PFASs includes (at a minimum) field duplicates and equipment blanks. Brief descriptions of each type of field QA/QC sample important to investigations involving PFASs (as recommended by U.S. EPA Method 537) follow:

- Field duplicate: a duplicate sample taken in the field from the same location as the original sample to ascertain sampling precision. The sample is given another name so it is not identified with any field duplicate, to further test precision.
- Equipment blank: rinsate from the equipment used to take the sample. The purpose of the equipment blank is to assess the effectiveness of the implemented decontamination process and the potential of cross-contamination of samples due to insufficient decontamination of sampling equipment.
- Field reagent blank (FRB): An analyte-free water in a sample bottle that is provided by a laboratory. The FRB is shipped to the sampling site along with the sampling bottles. At the

sampling site, the sampler opens the shipped FRB and pours the preserved reagent water into an empty shipped sample bottle, then seals it and labels it as the FRB. The FRB is shipped back to the laboratory along with the samples and is analyzed to ensure that PFASs were not introduced into the sample during sample collection/handling.

Given the ubiquity of some PFASs, modifications to these standard QA/QC samples should use laboratory-supplied water and sample containers that are free from PFASs and suitable for sampling PFASs.

5.2.4 Innovative Approaches to Sampling PFASs in Water

Innovative sampling approaches are being developed by researchers to address or alleviate concerns associated with cross-contamination, biases, and extraction concerns associated with programs sampling PFASs in water and the lack of real-time characterization tools for PFASs. Two of these approaches, passive sampling and ion-selective electrodes (ISEs), are summarized below. Neither method has been standardized or adopted by the U.S. EPA.

5.2.4.1 Passive Sampling in Water

Passive sampling is an efficient and cost-effective way of measuring contaminants in the environment over a measured period of time and with limited field time. Passive, or diffusive, sampling relies on the unassisted molecular diffusion of gaseous agents (analytes) through a diffusive surface onto an adsorbent. Passive sampling in water for PFOS has been implemented in environmental field assessments in Sweden by the Swedish Environmental Protection Agency. In-situ calibration with the use of reference compounds has not been observed to be successful (*75*); however, certain types of passive sampler (e.g., polar organic chemical integrative sampler or POCIS) may be a suitable tool for biomonitoring of PFASs (*76*).

5.2.4.2 Ion-Selective Electrodes

An ISE is a transducer (or sensor) that converts the activity of a specific ion dissolved in a solution into an electric potential. ISEs fabricated from fluorous materials are used to measure PFOS in drinking and groundwater down to the part-per-trillion level with no sample preparation. Research to evaluate the applicability of this technology for measuring PFOS in soil is ongoing. This would be a rapid screening tool that could provide field results in real time (rather than waiting for laboratory analysis). A universal PFOS anion soil extraction methodology that is broadly applicable to different soil types has not been developed. Research to develop a method to categorize different soil types and develop suitable extraction methods for each soil sample type is ongoing (*77*).

5.3 Analysis of PFASs

Analytical procedures are required to identify concentrations of PFASs that are representative of the environmental media being assessed and consistent with levels of potential concern. As research provides new information on human health and ecotoxicological impacts associated with PFASs and their fate and transformation in the environment, regulations and corresponding analytical methodologies are targeting lower detection limits. Laboratory analytical methods are being developed as the working understanding of the chemicals themselves is growing (*78*). Commercially available analytical methodologies (e.g., the types of analyses that are undertaken by commercial analytical laboratories) are currently not capable of quantifying the full suite of PFASs that exist in soil and groundwater; this is partially due to the lack of available reference standards. Stratification in water samples requires that samples are shaken vigorously in the laboratory prior to analysis. Additionally, significant challenges arise due to the propensity of precursor PFASs to transform into daughter compounds in the environment (e.g., do the laboratory results adequately account for the full mass of PFASs and the associated potential risks, at the site?). Airport managers and operators should be aware of these limitations and identify laboratories that understand these challenges and have procedures in place to address them so that the analytical results are representative and reproducible. The following sections discuss

- Commercially available analytical methods used for analyses of PFASs.
- Key considerations associated with analyses of PFASs.
- Laboratory accreditation for analyses of PFASs.
- Promising analytical methods in development.

5.3.1 Commercially Available Analytical Methodology

The commercially available analytical method for PFASs in drinking water is U.S. EPA Method 537: Determination of Selected Perfluorinated Alkyl Acids in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry (LC-MS/MS), which analyzes a suite of 14 PFAAs (including PFOA and PFOS, shown in Table 5-1) following published

Table 5-1. Common PFASs included in commercial laboratory analysis.

Analyte	Acronym	Chemical Abstract Services Registry Number (CASRN)	Included in US EPA 537 Rev. 1.1	Included in UCMR 3
N-ethyl perfluorooctane sulfonamido acetic acid	N-Et-PFOSA-AcOH	2991-50-6	Y	N
N-methyl perfluorooctane sulfonamido acetic acid	N-Me-PFOSA-AcOH	2355-31-9	Y	N
Perfluorobutanoic acid	PFBA/PFBTA	375-22-4	N	N
Perfluoropentanoic acid	PFPeA	2706-90-3	N	N
Perfluorohexanoic acid	PFHxA	307-24-4	Y	N
Perfluoroheptanoic acid	PFHpA	375-85-9	Y	Y
Perfluorooctanoic acid	PFOA	335-67-1	Y	Y
Perfluorononanoic acid	PFNA	375-95-1	Y	Y
Perfluorodecanoic acid	PFDA	335-76-2	Y	N
Perfluoroundecanoic acid	PFUnA	2058-94-8	Y	N
Perfluorododecanoic acid	PFDoA	307-55-1	Y	N
Perfluorotetradecanoic acid	PFTA	376-06-7	Y	N
Perfluorotridecanoic acid	PFTrDA	72629-94-8	Y	N
Perfluorobutane sulfonic acid	PFBS	375-73-5	Y	Y
Perfluorohexane sulfonic acid	PFHxS	355-46-4	Y	Y
Perfluorooctane sulfonamide	PFOSA	754-91-6	N	N
Perfluorooctane sulfonic acid	PFOS	1763-23-1	Y	Y

methodology. Reporting limits for this methodology range from 0.005 to 0.020 μg/L, i.e., below U.S. EPA's health advisory of 0.07 μg/L for PFOS and PFOA. A drawback to U.S. EPA Method 537 is that it includes a limited range of analytes; this method does not currently report the results for the full range of short-chain PFAAs, many fluorotelomers, or the many other precursor PFASs. Additionally, U.S. EPA Method 537 was developed for the analysis of PFASs in drinking water, which is a relatively clean matrix compared to groundwater and one which will have different extraction requirements than solid matrices (e.g., soil and sediment). In order to fully understand the potential extent of contamination by PFASs in the environment, additional laboratory techniques are being developed to increase the range of analytes for U.S. EPA Method 537 (and similar LC-MS/MS methods) to include up to 39 PFASs (i.e., Modified U.S. EPA Method 537).

U.S. EPA Method 537 outlines areas where deviation from the prescribed procedure is allowable and where the described methodology must be followed (e.g., sample collection and quality control requirements). U.S. EPA Method 537 also describes possible sources of interference and standards to be utilized.

The International Organization for Standardization (ISO) has also developed a method to analyze PFASs based on the same basic principles as U.S. EPA Method 537. The ISO method developed for evaluating PFASs, specifically PFOS and PFOA in unfiltered samples, is ISO 25101:2009—Water Quality—Determination of Perfluorooctanesulfonate (PFOS) and Perfluorooctanoate (PFOA)—Method for Unfiltered Samples Using Solid Phase Extraction and Liquid Chromatography/Mass Spectrometry. Similar to U.S. EPA Method 537, ISO 25101:2009 uses solid phase extraction and solvent elution with analyte determination by LC-MS/MS. The focus of this methodology is linear isomers of PFOS and PFOA, but other isomers (i.e., branch isomers) can be reported separately as non-linear isomers. Further limitations to the ISO method include the following:

- The ISO method may result in unrepresentative results as the materials used in the method may result in contamination of the sample being analyzed (e.g., seals, O-rings, and tubing), ultimately biasing the results high. Likewise results may indicate lower concentrations than what is in the sample due to sorption to glassware or filters (*79*).
- Solid phase extraction methods generate significant amounts of liquid and solid waste, are laborious, and are predisposed to negative and positive artifacts (*1*).

A standardized method has not yet been developed for extracting and analyzing PFASs in soils and sediments. Four methods for the extraction of PFASs from sediments have been described in the scientific literature:

- A wrist-action shaker operated at maximum deflection, extraction by methanol, followed by a graphitized carbon adsorbent clean up (*80*).
- An acetic acid wash, followed by repeated extraction with methanol/1 percent acetic acid in water (90:10, v/v) in a heated sonication bath and subsequent clean up using C_{18} cartridges (*81*).
- Pressurized fluid extraction with acetone/methanol (25:75, v/v) at 100°C followed by headspace solid-phase microextraction (*82*).
- Sonication with acetonitrile/water (60:40, v/v) and ion pairing clean up (*83*).

Different extract clean-up methods can be used, either separately or in combination, depending on the characteristics of the sediment, the extraction solvent, and the concentration level.

Commercial laboratories typically homogenize soil or sediment samples in water that is free of PFASs, conduct a liquid/liquid extraction, and analyze the extraction by isotope dilution LC-MS/MS. Extraction of PFASs from soil and sediment requires the use of a solvent. The resulting extraction liquid (i.e., eluent) is then homogenized by centrifugation prior to LC-MS/MS analysis, as would be done for an aqueous sample. The lack of an available standardized methodology for extracting and analyzing PFASs in soil reinforces the need to use a reliable, accredited analytical laboratory.

The following sections describe key considerations in laboratory analysis for airports or site custodians when discussing an analytical program for PFASs with an analytical laboratory and what to look for in methodology and accreditation.

5.3.2 Key Considerations in Laboratory Analysis

5.3.2.1 Laboratory Standards

Standard reference chemicals have not yet been developed for each of the PFASs in AFFF; therefore, identification, let alone quantitative analysis, is limited to the known and quantifiable PFASs in AFFF. Additionally, even with available reference standards, these results may vary according to the laboratory methods used. Some PFASs (such as PFOS) are observed in AFFF as a mixture of linear and branched isomers. Depending on the calibration method used by the analytical laboratory, there may be bias in instrumental responses between linear and branched PFOS isomers using LC-MS/MS analysis, which is discussed further below.

It is important that a commercial laboratory is using suitable standard methodology to carry out analyses of PFASs. Where no suitable standard methodology exists (e.g., PFASs in soils/sediments), an accredited laboratory facility should be used (as discussed in Section 5.3.3).

5.3.2.2 Branched and Linear Isomers

PFASs exist as both branched and linear isomers. Both versions, together, make up the total concentration of individual PFASs. This analytical concern has come to attention most recently for PFOS, but the problem exists for other PFASs, including PFOA. The analytical laboratory results should include data that addresses both "versions" so that the total concentration reported is representative. If the concentration of only one isomer is reported, the reported value may underrepresent actual concentrations in the field (and potential risk). Reference standards (other than mixed linear/branched standards) are available separately for linear PFOS and PFOA, but not for the branched isomers (*84*). This calibration is important to evaluating whether the total amount of PFOS reported is an accurate representation of a sample. If a laboratory is quantitating using linear standards, this may result in a systematic high bias for PFOS analysis on real samples containing any branched PFOS. This calibration concern is an issue that has been acknowledged by commercial laboratories competent in analysis of PFASs and underlies the need for selecting a reputable laboratory with the appropriate accreditations.

Stable isotope dilution methods have been developed for analyzing PFASs and are an alternate to using standard calibration solutions that run into branched/linear isomer issues, as described above. Stable isotope dilution methods use relative ratios of natural to enriched isotopes to directly evaluate concentration of the target analyte, providing a more usable PFOS value.

It is important to confirm that a commercial laboratory reports PFOS values that include *both* the branched and linear types.

5.3.2.3 Precursors

Both past and current AFFF formulations contain "precursor compounds," or parent compounds that can degrade to more persistent daughter products. Older formulations of AFFF contained long chains (e.g., C_8 or greater), which could break down to PFOA and PFOS. Newer formations contain short-chain PFASs (e.g., C_6 and below), which can still degrade to persistent daughter products (PFHxA and PFBA); however, these daughter products are thought to pose fewer ecotoxicological risks since the daughter products have lower potential for bioaccumulation than the long-chain compounds. A site investigation for PFOS without an analysis for precursor PFASs may not result in a fully representative CSM or accurate understanding of the potential risk posed by PFASs at an airport. Analysis for precursor PFASs is imperative to have a comprehensive understanding of the impact of PFASs. If a site has levels of PFOS and PFOA below the levels recommended by guidelines in the region, it is possible that precursor compounds could degrade to resilient and regulated PFOS and PFOA and cause an exceedance of the level recommended by guidelines and a human health or environmental ecotoxicological risk.

While many precursors are not regulated at this time, airports should be aware of the potential future liability associated with these compounds, i.e., they may become future sources of PFOS or PFOA and/or potentially other (currently) regulated compounds or become regulated themselves. There is no commercially available method for precursor analyses; however, new, commercialized, standardized methods are in development as a response to regulatory drivers and the need to effectively meet new regulations.

5.3.2.4 Quality Assurance and Quality Control

QA/QC programs come from the methodology being used (e.g., prescribed by U.S. EPA Method 537) and from overall laboratory accreditation (discussed further in Section 5.3.3). The laboratory-provided QA/QC information should be carefully reviewed due to the many potential contamination sources. Laboratory-provided information to review can include method and/or matrix interferences notes, recovery of internal and surrogate analyte standards used, adequate calibration, and laboratory duplicate/blank values meeting internal criteria. Other data to evaluate include laboratory-blinded field duplicate sample results, equipment blank results, and field blank results. Values should comply with the pre-ordained QA/QC program that meets the data quality objectives of the field sampling program. QA/QC flags should be reviewed with the commercial laboratory prior to accepting or rejecting the results.

5.3.3 Laboratory Accreditation

In addition to conducting sample analysis for PFASs using standardized methods (where available and applicable), laboratories should be accredited for analyses of PFASs by a reputable accreditation agency. Accreditation implies that a laboratory has established the technical competence to perform specific types of testing and analysis and that their equipment and methods will provide results that are reliable, reproducible, and representative of actual concentrations. Laboratory accreditation is for the testing and calibration for laboratories to "ISO/IEC 17025—General requirements for the competence of testing and calibration laboratories," which is a generic standard applicable to many different analyses. Accreditation/recognition for specialty analyses such as PFOA/PFOA is distinct from laboratory accreditation.

It is recommended that an accredited analytical laboratory be used and that the analytical laboratory be contacted prior to sample submission to confirm that PFASs are included in their standard analysis and to confirm the sampling requirements.

Accreditation bodies, methodologies, and laboratories are described for the United States and Canada in the following subsections.

5.3.3.1 United States of America

In the United States, the following organizations provide accreditation for analyses of PFASs. Links are provided to their webpages, which list accredited laboratories and can be used to find an accredited laboratory across jurisdictions:

- U.S. Department of Defense Environmental Laboratory Accreditation Program (DoD ELAP) (http://www.denix.osd.mil/edqw/Accreditation/AccreditedLabs.cfm)

- American Association for Laboratory Accreditation (A2LA) (https://www.a2la.org/dirsearchnew/newsearch.cfm)
- Perry Johnson Laboratory Accreditation, Inc. (PJLA) (http://www.pjlabs.com/search-accredited-labs)
- ANSI-ASQ National Accreditation Board (ANAB) (http://search.anab.org/search-accredited-companies.aspx)
- Laboratory Accreditation Bureau (L-A-B) (http://search.l-a-b.com/)

5.3.3.2 Canada

In Canada, methodologies to analyze PFASs are accredited under CAN-P-1585: Requirements for the Accreditation of Environmental Testing Laboratories, Program Specialty Area—Environmental Testing (PSA-ET)—December 2008. The organizations listed below provide accreditation for analyses of PFASs. Links are provided to their webpages, which list accredited laboratories and can be used to find an accredited laboratory across jurisdictions:

- Standards Council of Canada (SCC) (https://www.scc.ca/en/accreditation/product-process-and-service-certification/directory-of-accredited-clients)
- Canadian Association for Laboratory Accreditation Inc. (CALA) (http://www.caladirectory.ca/)

5.3.4 Analytical Method Development

As consumer needs and regulatory drivers change, industry continues to modify and develop analytical methods. Changes in laboratory methods have resulted in more PFASs being able to be analyzed (e.g., short-chain PFASs), lower detection limits (i.e., allowing lower concentrations of PFASs to be detected), and better management of potential biases in the analytical procedures (e.g., sample-ware and filter composition). The following sections discuss analytical methods that are under development in academic and research communities.

5.3.4.1 Total Organic Fluorine

There are two methods in development for quantifying total organic fluorine (similar to using total petroleum hydrocarbon analysis). These methods are particle-induced gamma-ray emission (PIGE) and adsorbable organo-fluorine via combustion ion chromatography. These values overcome the analytical challenges posed by the limited availability of reference standards. Further, these methods enable airports and their environmental professionals to evaluate the extent of the impacts of PFASs at a site because organic fluorine is anthropogenic. At a site impacted by AFFF, this is likely to be related directly to the presence of AFFF. The limitation of these methods (similar to the limitation of total petroleum hydrocarbon analysis) is that specific compounds (such as PFOS) are not identified. The PIGE method is currently being commercially developed and is available in the United States, although it is not standardized by the U.S. EPA.

5.3.4.2 Increasing the Number of Identifiable PFASs

Methods are in development to analyze a more comprehensive range of PFASs (*79*). Two promising methods include liquid chromatography/quadrupole time of flight/tandem mass spectrometry (LC-QTOF-MS/MS) and total oxidizable precursor (TOP) assay. LC-QTOF-MS/MS is a semi-quantitative method revealing the empirical formula of multiple PFASs by assessing the accurate mass of the molecular ions of PFASs (*69*). The TOP assay involves a reaction with hydroxyl radicals that reveals precursors with the potential to degrade into more stable fluorochemicals (e.g., PFAAs such as PFOS and PFOA). Concentrations before and after oxidation are compared to determine the concentrations of chain-length-specific PFAA precursors. The TOP assay approach quantifies the sum of PFASs that could be converted to PFAAs in the environment by simulating accelerated environmental degradation, with a slightly expanded range of PFSA and PFCAs quantified. Performing this analysis before and after the sample containing PFASs is partially digested reveals the "hidden mass" of PFAAs that were previously not detectable. The TOP methodology has revealed that for AFFF-impacted sites the existing analytical LC-MS/MS methods are only detecting some 30 percent of the total PFAA mass hidden in PFASs. The TOP assay is now commercially available in the UK, but is not yet commercially available in the United States or Canada. Commercial analytical methods are under development in Canada.

5.4 Risk Management

For airports with a history of AFFF use (and the associated release to the environment of PFASs), potential human health and ecological risks may exist. Airports are challenged to understand whether they have an unacceptable risk and, if so, how to manage that risk. Risk management is employed when unacceptable risks are determined to be present via a human health or ecological risk assessment.

Risk management integrates the site's remedial strategy with technical, political, legal, social, and economic considerations to develop risk reduction and prevention strategies. Risk management effectively manages one or more of the three risk components (i.e., source/contaminants, receptors, and exposure pathways) alleviating or eliminating potential risks to human health and/or the environment. Generally, risk management consists of one or more of the following:

- Administrative controls that limit access or exposure to potential contamination.
- Engineering controls that render potential exposure pathways "inoperable" (or otherwise cuts off the pathway between contamination and receptors).
- Remediation that removes or reduces the mass of contaminant at the site.

The following sections describe how risk management approaches can be applied specifically to sites impacted by PFASs.

5.4.1 Defining Risk

In order for a human health or ecological risk to be present, three conditions must be fulfilled (see Figure 5-1). There must be the following:

- A source/contaminant: A chemical (or group of chemicals) found at a concentration that represents a potential concern to human health or the environment.

Figure 5-1. Principles of risk model.

- A receptor: A human or ecological receptor that would be exposed to the source.
- An exposure pathway: At least one complete exposure pathway through which the receptor(s) would be exposed to the source/contaminant.

As shown in the principles of risk model presented in Figure 5-1, risk management aims to remove one or more of these conditions, eliminating potential risk. As described in the following section, a conceptual site model (CSM) is developed to identify source, pathways, and receptors; better understand the relationship among these elements; and develop a risk management strategy.

5.4.2 Conceptual Site Model

The CSM discussed here is a general representation of the nature and fate and transport of PFASs at an airport facility. A site-specific CSM should be developed as necessary to assess potential and/or actual exposure to PFASs and be reviewed to identify whether data gaps exist. Aligning with the risk model, the CSM consists of three main components: source/contamination, receptors, and pathways (i.e., exposure and migration). Figure 5-2 provides an example of a CSM for an airport, grapahically presenting sources, potential receptors, and exposure pathways.

5.4.2.1 Source/Contamination

AFFF manufactured and imported into the United States and Canada prior to the voluntary phase-out in production in 2002 contained PFASs, including—predominantly—PFOS. While manufacturers have since modified their formulations to eliminate PFOS, AFFF formulations continue to include short-chain PFASs, the toxicological properties of which are not well known. Historical application of AFFF (i.e., via emergency response, testing, and training) to the environment (e.g., soil or surface water) and incidental releases (e.g., spills, leaks, and disposal), therefore, represent a potential source of contamination by PFASs. Specifically, potential sources of contamination by PFASs associated with AFFF may include the following:

- AFFF storage areas (i.e., where the potential for leaks and spills existed).
- Areas where AFFF was applied as part of an emergency response.
- Firefighting training areas, burn pits, or other areas where AFFF may have been discharged as part of training.
- Areas where AFFF was discharged as part of foam testing.
- Areas where AFFF was loaded or removed from ARFF vehicles during vehicle maintenance.
- Historical disposal areas (e.g., where expired or contaminated AFFF concentrate was disposed to the environment or where AFFF foam was directed following release, including lagoons and retention ponds).

As indicated in Chapter 2 of this report, other sources of PFASs may be present at an airport or on adjacent property. Obtaining good quality information about the source/contamination should follow the best management practices for sampling and analysis of PFASs as described Sections 5.2 and 5.3.

5.4.2.2 Pathways

For CSMs, pathways can be categorized as exposure pathways or migration pathways. As described previously, exposure pathways are how contamination moves through the environment from a source to a receptor. Migration pathways are how contamination moves off-site, independent of whether a receptor is present. Table 5-2 identifies exposure pathways and migration pathways for each type of environmental media (i.e., soil, groundwater, surface water, sediment, and air).

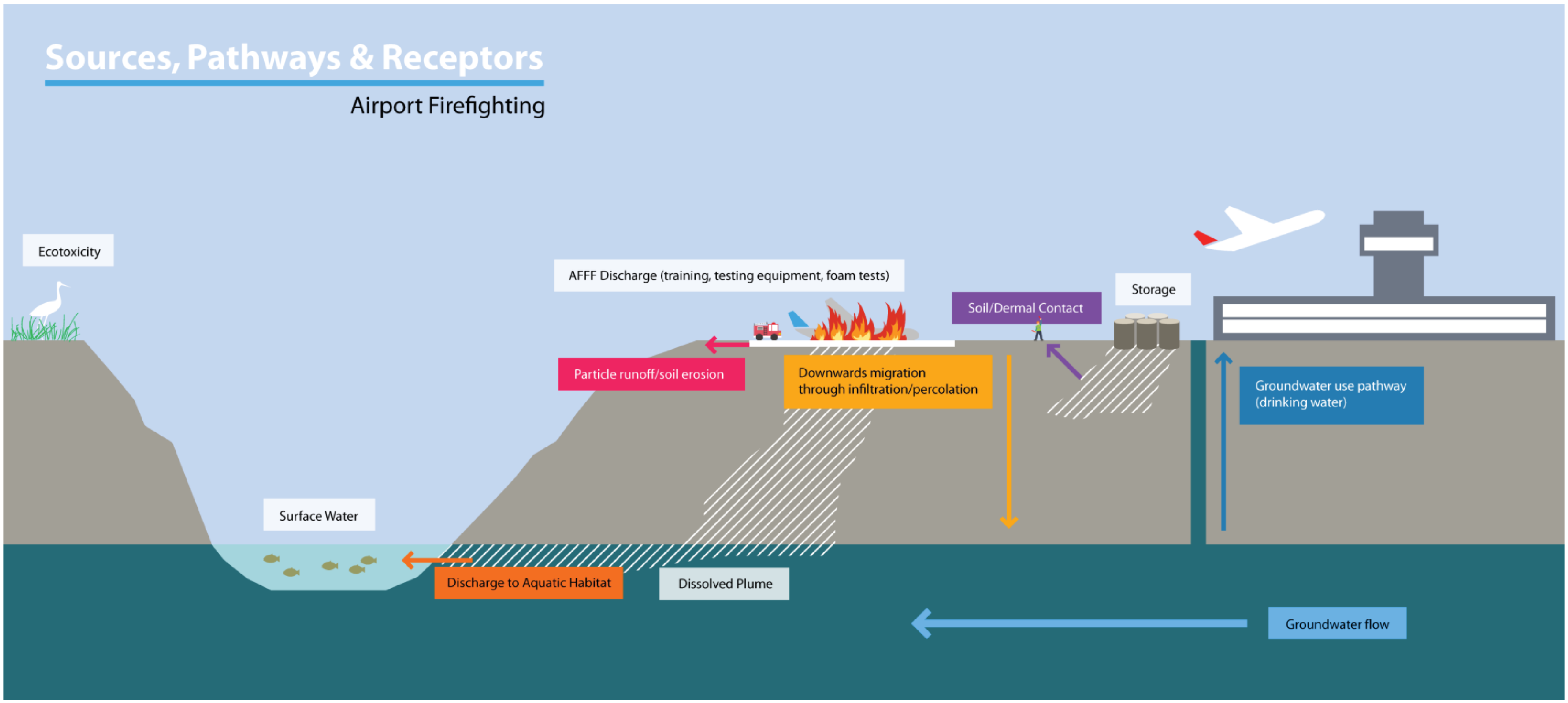


Figure 5-2. Sources, pathways, and receptors in airport firefighting.

Table 5-2. Exposure and migration pathways for AFFF.

Environmental Media	Exposure Pathway	Potential Risk Driver for PFASs?
Soil	Human Health—dermal contact	Yes
	Human Health—ingestion	Yes
	Human Health—soil inhalation	No
	Human Health—vapor inhalation pathway	No
	Ecological Soil Contact	Yes
	Ecological—nutrient and energy cycling	Unknown
	Lateral Migration—surface runoff	Yes
	Vertical Migration—infiltration/percolation	Yes
Groundwater	Human Health—potable/drinking water	Yes
	Human Health—agricultural use—irrigation	Unknown
	Human Health—agricultural use—livestock	Unknown
	Human Health Contact	Yes
	Ecological—protection of aquatic life receptors	Yes
	Lateral Migration—advective/diffusive transport	Yes
Surface Water	Human Health—protection of aquatic life (fish ingestion)	Yes
	Ecological—protection of aquatic life	Yes
	Lateral Migration—advective/diffusive transport	Yes
Sediment	Ecological—aquatic life receptors	Yes
	Migration—sediment transport	Yes
Air	Migration—long-range transport, atmospheric deposition	Yes (on a global scale)

5.4.2.3 Receptors

Receptors can be either humans or ecological flora and fauna (i.e., plant and/or animal) that could be exposed to contamination. Receptors known to be potentially sensitive to PFASs include the following:

- Fish
- Birds
- Terrestrial animals
- Invertebrates
- Humans (exposure to drinking water, dermal contact pathways, consumption of fish)

Some PFASs are known to bioaccumulate and biomagnify in the food chain. This affects receptors at different points along the food chain, e.g., humans consuming fish. Field measurements of PFOS, PFOA, PFHxS, and PFOSA in the Great Lakes food web have suggested that precursors to PFASs metabolize to PFASs that have known ecotoxicological properties (e.g., PFOS, PFOA, PFHxS, PFOSA) (*85*). These results indicate that the risks to some receptors are difficult to quantity without knowledge about the precursors.

5.4.3 Managing Risk Associated with the Impacts of PFASs

The scientific and regulatory communities' understanding of the chemistry, fate, transport, and toxicology of PFASs continues to evolve rapidly. In the midst of this changing regulatory climate, airports are currently challenged to understand what unacceptable risks may be present and what to do about these risks if they are present. Airports need to proactively manage the potential risks associated with current operations (i.e., with respect to AFFF management through the life cycle stages, as detailed in Chapter 4) while considering how best to address potential risks associated with legacy environmental impacts, understanding that historical use of AFFF at airports likely resulted in releases of PFASs to the environment. Risk management strategies for legacy impacts of PFASs in the environment need to consider the CSM, whether there is a current unacceptable risk, whether there is a potential for a future unacceptable risk, and how to eliminate unacceptable risk. Given the recalcitrant nature of some PFASs to remediation, proactively cutting off the exposure pathway between contamination by PFASs and potential receptors may provide a cost-effective means for managing unacceptable or, preemptively, potentially unacceptable risks, where permissible. Some examples are as follows:

- Eliminating direct contact to soil impacted by PFASs and limiting infiltration (and potential groundwater migration) by covering a portion of the site with pavement.
- Eliminating surface water runoff to prevent surface water from being impacted by sediment containing PFASs.
- Requiring workers to don appropriate personal protective equipment (PPE) when working with AFFF or media impacted by PFASs.
- Prohibiting potable groundwater or surface water use by providing an alternate water supply should a potable source be suspected of being impacted by PFASs.
- Installation of erosion and sediment controls in areas where soils that may be impacted by PFASs are planned to be disturbed.

If unacceptable risks cannot be managed by means of cutting off the exposure pathway, remediation may be required. Section 5.5 discusses remediation options that remove or reduce the mass of contamination by PFASs to acceptable levels as defined by regulatory standards.

Finally, airports also need to consider and plan for the potential implications of contamination by PFASs on capital projects. Should soil or groundwater impacted by PFASs be encountered during construction of capital infrastructure projects, the cost to manage the impacted media could be significant and delays to the capital project could be substantial.

5.5 Remediation Options

Remediation of PFASs in environmental media is required if unacceptable risks are present and cannot be appropriately managed without remediation. PFASs, however, have unique properties that are problematic when environmental remediation is required. Those properties that have made many PFASs very useful in a wide range of commercial and industrial applications (e.g., high degrees of chemical and thermal stability) result in challenges relative to remediation. Many PFASs do not readily degrade in the environment (*86*) and are resistant to many forms of remediation. For example, a strong fluorine-carbon bond and low vapor pressure mean that some PFASs (e.g., PFOA and PFOS) are resistant to a number of conventional water treatment technologies, including direct oxidation, biodegradation, air stripping and vapor extraction, and direct photolysis (ultraviolet radiation).

Additionally, PFASs in AFFF are a mixture of compounds, each with variable properties. Different remedial approaches will be successful at varying degrees with each compound and, like environmental remediation in general, a multitude of site-specific factors will greatly affect the effectiveness of any given remedial approach. Moreover, with PFASs, degradation of select precursors if present (or had been historically present) within AFFF can compound the issue by generating additional persistent PFASs (e.g., PFOA and PFOS). Finally, the selection and ultimate effectiveness of remedial approaches may be significantly influenced by co-mingled contaminants as would be the case with the application of AFFF for extinguishing Class B fires.

Given the challenges identified above, development of proven remedial technologies for PFASs has been elusive. Recent publications have discussed some bench-scale success with degradation or destruction using advanced oxidation (*87*), enhanced photochemical (*88*), and irradiation methods (*89*); however, these technologies are often not practical for field-scale implementation (*90*). Traditional methods such as "excavation and disposal" and "pump and treat" have been successfully applied in the field, but maintain the limitations that are typically associated with these methods (and would likely be exasperated by the nature of some PFASs). With excavation and disposal, contamination is just being transferred to another site; with groundwater treatment via "pump and treat," high costs of operation and maintenance are ongoing for long periods of time. Known available and emerging technologies are summarized in Table 5-3.

Like remediation of other recalcitrant and persistent compounds, remediation of PFASs is not likely to be achieved with a single remedial technology; rather, a successful remedial strategy will likely consist of a combination of remedial approaches applied appropriately. Any treatment technology that uses oxidants may release more mobile forms of PFASs that will be subsequently more difficult to remove. Airport operators and their contractors should consider fully the limitations and implications of using degradatory technologies. Further, given that remediation technologies for PFASs are under development, a remediation strategy may involve short-term solutions (e.g., pump and treat or administrative measures) to address known unacceptable risks until appropriate remedial approaches have been developed.

In order to develop appropriate approaches for successful remediation, consideration should be given to developing decision support models to support the choice of short- and long-term remediation strategies for PFASs at sites where AFFF has been applied or otherwise released into the environment (*98*). One such example decision tree, developed by Avinor, considers the following (*98*):

- Which PFASs are present and their physicochemical properties.
- Hydrogeological conditions.
- Off-site and on-site risks at present and in the future.
- Acceptable time frames for remediation.
- Technology acceptance and stakeholder involvement.
- Costs for remediation.
- Acceptable disturbance of day–to-day operations.

The following sections discuss the current state of practice of remedial technologies and approaches that have demonstrated some success (or are generally believed to hold promise) in field-scale remediation of PFASs in soil and groundwater. In addition, Section 5.5.3 identifies limitations that an airport should consider in the disposal of released AFFF and water impacted by AFFF.

5.5.1 Soil

Soil remediation may be required if current concentrations of PFASs pose a potential risk to human and/or ecological health. Remediation may be required to limit contaminant migration (e.g., vertical infiltration to groundwater pathway) and/or remove the impacts from the site (e.g.,

Table 5-3. Summary of available and emerging technologies for PFASs.

Remedy		Status	Technology Details
Source Treatment	In-situ chemical oxidation	Emerging	Lab scale (ScisoR for PFOS/PFOA) (*91*) *It should be noted that this approach can generate short-chain PFASs that are more mobile and are difficult to remove by more traditional remediation approaches (e.g., granulated activated carbon)
Source Treatment	In-situ enhanced bioremediation	N/A	—
Source Treatment	In-situ thermal	N/A	—
Source Treatment	Stabilization	Commercial	Carbon and other commercially available additives (RemBind^{TM} and MatCARE^{TM})
Source Treatment	Soil Removal	Commercial	—
Groundwater Treatment	Sorptive media (granulated activated carbon)	Commercial	High-temperature thermal regeneration required to reuse carbon Sorption to carbon is low/ineffective for short-chain PFASs
Groundwater Treatment	Sorptive media (synthetic media)	Commercial	Commercially available additives include RemBind^{TM} and MatCare^{TM}. PerfluorAd—coagulant (emerging)
Groundwater Treatment	Sorptive media (ion exchange resin)	Commercial	Ion exchange media (*92*, *93*)
Groundwater Treatment	Ultrafiltration	Commercial	Reverse osmosis and nanofiltration
Groundwater Treatment	Sonochemical	Emerging	Investigated at the bench scale for landfill leachate and groundwater (*94*, *95*)
Groundwater Treatment	Air stripping	Commercial	Spray stripper system as part of Pump and Treat for volatile organic compounds. Mobilized volatile PFASs (aerosols, volatilization), moved less volatile PFASs deeper within the soil column (*96*). Found to be ineffective in removing PFASs from landfill leachate adequately prior to land application (*97*)

concentrations of PFASs in soil need to be brought into compliance with applicable guidelines and/or regulations). The following sections describe remediation methodologies that address impacts of PFASs in soil.

5.5.1.1 Excavation

Excavation may be appropriate for removal of PFASs when the substances have not significantly migrated vertically and the objective is contaminant mass removal. Unfortunately, some of the more mobile PFASs can, depending on site conditions, migrate to depths that make excavation cost prohibitive. Upon excavation, there are two main options for disposal of soils impacted by PFASs: incineration and landfill disposal.

Incineration

Off-site, high-temperature incineration (> 1100°C) has proven to be a viable (yet expensive) method for destruction of PFASs. However, incineration facilities must limit the volume of soil and groundwater impacted by PFASs that is introduced into their operations at a given time to avoid operational efficiency issues. This circumstance adds additional complexity to large-scale remediation projects for PFASs.

Landfill Disposal

Given the cost of incineration, off-site disposal at an appropriately engineered landfill may provide a more viable disposal alternative. An appropriate facility must be selected for the disposal of soils containing PFASs, since several PFASs (e.g., PFOS and PFOA) are water soluble and have limited biodegradation potential and, as a result, end up in landfill leachate (*30*). Moreover, biodegradation of precursor PFASs will produce a number of persistent and toxic PFASs (e.g., PFOS and PFOA). Landfills must be designed to prevent migration of PFASs via landfill leachate into the environment. This may require the leachate to be treated with advanced water treatment methods (*29, 30*). Airports disposing of soil impacted by PFASs should verify that the receiving facility is engineered with double liners and leachate collection systems and is appropriately certified to receive soil impacted by PFASs. Airports should also verify that the receiving wastewater treatment plant used to treat leachate is capable of treating PFASs, as many landfills send their leachate off-site for treatment (*99*). Transferring soils (and leachate) impacted by PFASs from a site to a facility that is not designed to contain PFASs (or manage the leachate) could be considered as simply relocating the problem, and, therefore, the best practice is to ensure that the receiving facility is appropriately designed to treat and handle soils impacted by PFASs.

5.5.1.2 Immobilization/Stabilization

Adsorbents (also called sorbents) are materials that have an ability to adsorb substances, resulting in their immobilization and stabilization. Adsorbents that have the potential to treat PFOS and PFOA include organo-clays, clay minerals, and carbon nanotubes. Commercial sorbents containing activated carbon, aluminum hydroxide (amorphous), and other proprietary additives have been explored for their sorbent properties with PFASs. Bench-scale studies have shown that sorbent technology holds promise for field application; however, site-specific conditions would need to be evaluated in order to assess the applicability for implementation. At the field scale, use of amine-modified clay sorbents, as opposed to activated carbon, for treatment of sites impacted by PFASs (*82, 83*) has shown some promise.

5.5.2 Groundwater

Numerous studies have evaluated the suitability of treatment technologies for PFASs in wastewater and drinking water. Unfortunately, these technologies are not always directly applicable to the treatment of contaminated groundwater in-situ. This section describes those technologies that have demonstrated success in field-scale applications and should be considered for the remediation of groundwater and surface water impacted by PFASs, depending on site conditions and project objectives.

5.5.2.1 Pump and Treat

Pump and treat is a common method for cleaning up groundwater impacts where groundwater is pumped from wells to an above-ground treatment facility that removes the contaminants prior to disposal or reuse. Because of the length of time required to "treat" the contaminant mass in groundwater, pump and treat remedial technologies should be viewed as "control" technologies, rather than source removal remedial technologies. Much of the current literature on the successful application of treatment technologies has been shown for water treatment plants. While the principles remain the same (e.g., inlet flow of PFASs in water, PFASs sorb to granulated activated carbon [GAC]/removed by membrane, “treated” effluent), the inlet concentrations, quantity of reactive media required, and time frame to treat groundwater impacted by PFASs may be very different. The following sections discuss pump and treat systems that have been applied for the remediation of PFASs in groundwater.

Activated Carbon

Pumping and ex-situ treatment of groundwater with activated carbon filters has proven to be viable and an appropriate treatment technology, although the efficiency of activated carbon filters has been observed to be variable (*102*). Use of activated carbon has also been shown to be less effective at removing short-chain PFASs (*65, 66*), which must be considered given the overall uncertainty associated with the ecotoxicity, synergistic effects, and environmental fate and transport of PFASs. Activated carbon is commonly used to adsorb contaminants found in water. Activated carbon, which is used in a granulated or powdered form, is an effective adsorbent because it is highly porous and provides a large surface area on which contaminants may adsorb. Several case studies have indicated that GAC is a common and effective (>90 percent removal) treatment for contamination with long-chain PFASs. However, short-chain PFASs have been observed to break through. The efficiency of this method varies based on several factors:

- Target effluent contaminant concentration
- pH
- Water temperature
- Contact time
- Properties of the selected carbon
- Concentration of inorganic substances in the water
- Ambient natural organic matter
- Chlorine concentrations in the water

Dudley et al. (*103*) evaluated powdered activated carbon (PAC) and found that >90 percent removal of PFNA and PFOS was possible but only with unreasonably high adsorbent dosages, unless contact times could be extended to approach adsorption equilibrium. Use of PAC has also been shown to be less effective at removing short-chain PFASs. Modified sorbents other than activated carbon (e.g., amine-treated clays) have also been evaluated at the bench-scale for applications to groundwater.

Coagulation and Activated Carbon

Coagulation-flocculation is a chemical water treatment technique typically applied prior to sedimentation and filtration (e.g., rapid sand filtration) to enhance the ability of a treatment process to remove particles prior to subsequent polishing treatments, such as PAC or GAC. The coagulation process works with chemicals that exhibit a charge (zwitterionic, cationic, and/or anionic), such as PFASs.

A recent study found that a combination of coagulation and adsorption by PAC was effective (>90 percent removal) at removing both PFOS and PFOA from water (*104*). Coagulation alone is not an effective means of removal for long-chain PFASs (e.g., PFNA, PFOS and PFOA) (*65, 105*). Removal of PFOS and PFOA by coagulation works by adsorption of the contaminants onto the surface of the coagulants; anions absorb onto the positive surface of coagulants and flocs and are then removed with sedimentation and filtration. Subsequent to coagulation-flocculation treatments, PAC was shown to have a significantly higher absorption rate and capacity than GAC and higher absorption efficiency for PFOA than PFOS (*104*). The removal ratios for PAC increased with decreasing pH and with increasing coagulant dose, which was consistent with other research results evaluating pH on PAC efficacy for removal of PFASs (*103*).

Ion Exchange Resin

Ion exchange (IX) involves the use of resins (i.e., very small plastic porous beads with a fixed charge) to exchange undesirable ions with hydrogen or hydroxyl. The removal rate is dependent upon a number of factors:

- Initial contaminant concentration
- Competing ion concentration
- Treatment design (e.g., flow rate, resin bead size)
- Resin ion properties

One significant advantage of IX over activated carbon is that IX resins can be regenerated and reused, whereas activated carbon is difficult to regenerate and is typically discarded after a single use.

IX resins, specifically anion exchange treatments, have been investigated in pilot studies for application in pump and treat systems for removing PFASs. The removal of PFOA and PFOS has been reported at a New Jersey drinking water treatment plant using porous anion exchange resin impregnated with iron oxide (*105*). Researchers have noted that the short-chain PFASs were not removed through the documented IX treatment processes (*65*). A possible alternative for removal of PFASs could be a hybrid adsorption/anion exchange treatment approach, in which more strongly adsorbing PFASs are initially removed by activated carbon and the more weakly adsorbing PFASs subsequently removed by anion exchange. The hybrid approach may facilitate resin regeneration, which is more readily accomplished if only PFASs that interact more weakly with the resin need to be removed.

The management of the spent resin (e.g., incineration, landfill, and regeneration) and of the brine (e.g., chemical/biological processes or disposal) must be considered with this technology.

Membranes (Reverse Osmosis, Nanofiltration)

Reverse osmosis (RO) can remove many types of molecules and ions from solutions and is used in both industrial processes and the production of potable water. RO systems have been used for the treatment of PFASs in drinking water. The solute (a compound of PFASs) is retained on the pressurized side of the membrane, and the pure solvent (water) passes through to the other side. Pretreatment is required prior to implementing an RO system to reduce membrane fouling (biological, chemical, and/or physical). RO is effective at removing both long and short-chain compounds, filtering out both precursor materials and short-chain by-products.

Nanofiltration is another form of membrane technology that is pressure-driven and has been shown to be effective in removing PFASs in water treatment systems (*106*). The method is easy to operate and reliable for pollutant removal. High PFOS removal rates have been observed in nanofiltration systems.

RO is thought to provide more desirable performance than nanofiltration. Both systems result in reject water (20 to 25 percent), which must be managed properly to avoid further contamination of surrounding water and ensure compliance with applicable regulations. Additional waste to be considered is membrane disposal.

Given anticipated low total dissolved solids in groundwater, the cost of RO systems may be reasonable for groundwater systems. Low-pressure RO could be applied (operating at <250 psi) for treatment. The use of centralized reject processing/management facilities to serve several local satellite water treatment plants could be considered to minimize capital and operating costs. RO and nanofiltration treatment systems have not yet been implemented at the field scale for remediation of groundwater contaminated by PFASs.

5.5.2.2 Permeable Reactive Barrier

Permeable reactive barriers (PRBs), which essentially are vertical walls (or trenches) created below ground to clean up contaminated groundwater, have been investigated for use in treating groundwater impacted by PFASs. The wall is "permeable," which means that groundwater can flow through it. As the water flows through the wall, the water reacts with the material in the wall and is thereby treated. Concerns with GAC and other reactive media for use in PRBs mirror those mentioned above for pump and treat systems. Concerns with observed breakthrough in column experiments (*41, 107, 108*) have slowed application of PRBs in the field for groundwater impacted by PFASs.

5.5.3 Disposal of Discharged Foam

AFFF containing PFASs that is released (e.g., from incidents, training, and foam tests) requires treatment and should be captured and disposed of carefully. Municipal wastewater treatment systems that receive captured AFFF/AFFF wastewater may not have the appropriate, advanced methods to treat some of the PFASs that would likely be present. Pretreatment (with a viable technology applicable for PFASs in aqueous solutions, as identified in Section 5.5.2) may be required for acceptance at a wastewater treatment facility.

CHAPTER 6

Screening Tool Guidance

6.1 Introduction to the MAPA Screening Tool

6.1.1 Overview

The Managing AFFF and PFASs at Airports (MAPA) Screening Tool has been designed to assist airport managers with the identification of APECs on or near their airport. The identified APECs account for historical and current use of AFFF and other sources of PFASs at an airport facility. The MAPA Screening Tool has been designed to enable users to easily identify

- Whether an airport has APECs that need to be further evaluated.
- The nature of these APECs (i.e., operational versus legacy).
- The relevant or significant characteristics related to AFFF management and the fate and transport of PFASs.
- Relative ranking of each APEC to facilitate evaluation of future action (e.g., allocation of resources or implementation of best management practices).
- Data gaps that need to be filled to characterize individual APECs and develop a CSM.

The MAPA Screening Tool provides airport managers with a sequential and systematic approach to identifying APECs on an airport property. Conceptually, the MAPA Screening Tool works progressively along two sequential phases, or modules, as follows:

- Module 1 focuses on the airport property as a whole and identifies actual or potential sources and/or activities involving AFFF and PFASs. At the airport scale, the potential presence of off-site sources of PFASs and sensitive receptors is also considered.
- Module 2 focuses on the APECs identified in Module 1. The MAPA Screening Tool can be used to evaluate each APEC based on APEC-specific features related to the management of AFFF and impacts of PFASs in the environment. The MAPA Screening Tool will score APECs for further evaluation/action.

To facilitate use of the MAPA Screening Tool, a “Quick Guide” has been provided in Appendix C of this report.

6.1.2 How to Use the Screening Tool

The MAPA Screening Tool has been designed so users can rely on readily available information to complete the screening effort. If information is not known, or otherwise unavailable, the MAPA Screening Tool will flag the missing information as a potential data gap, which then can be applied by the user for future planning. Data from previous environmental site assessments or other intrusive investigations are not required to use the MAPA Screening Tool.

The MAPA Screening Tool has been designed for airport representatives familiar with AFFF management and impacts of PFASs at an airport. As knowledge and responsibilities related to

AFFF and/or PFASs may exist among different departments at an airport, collaboration among the members of different functional departments is beneficial for working with the MAPA Screening Tool to gain a holistic understanding of an airport's level of potential risk. For example, AFFF management through the life cycle stages (i.e., procurement, storage, use, testing, maintenance, and disposal) is typically the responsibility of emergency response personnel, and addressing legacy impacts in the environment (i.e., contamination of soil, groundwater, sediment, and/or surface water with PFASs) is typically the responsibility of the department(s) responsible for environmental issues.

The MAPA Screening Tool also allows the user to consider whether future projects (e.g., capital improvement projects) may be affected. For example, airports impacted with PFASs may face unexpected and costly remediation actions to address impacted soils or groundwater encountered during a capital improvement project (e.g., costs associated with the proper disposal of impacted soil or groundwater, such as dewatering during construction).

6.1.3 MAPA Screening Tool Architecture

The MAPA Screening Tool is a Microsoft Excel™-based tool that walks the user through a series of questions associated with two modules. Module 1 addresses content related to the airport. Module 2 is more specific and asks questions related to each APEC identified in Module 1. The details associated with each module are presented in subsequent sections.

6.1.3.1 How to Use the MAPA Screening Tool in Microsoft Excel™

The MAPA Screening Tool works best when used in Microsoft Excel™ 2010. If Microsoft Excel™ 97 to 2003, or 2007, is being used to run the screening tool, the version of the screening tool that is contained in the file entitled "MAPA Screening Tool Compatibility Version" should be used. If running a more recent version of Microsoft Excel™, use the file entitled "MAPA Screening Tool." When first opening the file, if a security warning appears saying that macros have been disabled, click "Enable content." The workbook contains numerous formulas and macros to make the MAPA Screening Tool user friendly. Users should only edit cell content where prompted; typing in a cell with a formula or other text will adversely impact MAPA's functionality. The MAPA Screening Tool leads the user from one worksheet to the next sequentially, as needed; filling out every worksheet in the screening tool may not be required for every airport.

6.1.3.2 Macros Security

The MAPA Screening Tool consists of multiple worksheets and embedded macros. Macros automate frequently used tasks; the ones used in the MAPA Screening Tool are created with Visual Basic for Applications and have been written by Dillon Consulting Limited specifically for the MAPA Screening Tool. When users first open the MAPA Screening Tool, macros need to be enabled for the program to function and carry out its tasks.

Some macros pose a potential security risk. A person with malicious intent can introduce a destructive macro in a document or file, which can spread a virus on computers. In Microsoft Office Excel™, users can change the macro security settings to control which macros run and under what circumstances when a workbook is opened. The following steps discuss how to enable macros.

When first opening the program, a pop-up window generally provides the user with an option to enable macros. If there is no pop-up window, or if the user has accidentally clicked "do not enable macros," the user should refer to the online instructions provided by Microsoft Office for the appropriate version of Excel™: https://support.office.com/en-us/article/Enable-or-disable-macros-in-Office-files-12b036fd-d140-4e74-b45e-16fed1a7e5c6#__toc311698310.

Typically, these instructions provided by Microsoft Office include the following steps (with variations on naming conventions, e.g., File Tab versus Microsoft Office Button). Microsoft Office provides a disclaimer on the risks associated with running macros from unknown sources. The steps are

- Click the Microsoft Office Button (or File Tab), and then click Excel Options.
- Click Trust Center, click Trust Center Settings, and then click Macro Settings.
- Click the options that you want: Enable All Macros (not recommended, potentially dangerous code can run). Click this option to allow all macros to run. This setting makes your computer vulnerable to potentially malicious code and is not recommended.

6.2 Module 1—Airport Scale Evaluation

Module 1 of the MAPA Screening Tool provides a rapid assessment for users to identify whether they have a potential concern that needs to be explored at their airport. If an APEC is identified, the location and nature of the area (e.g., known release/application, incidental/limited release, or historically contained storage unit) are documented. Module 1 focuses on identification of the following:

- Areas on the airport property, both those associated with airport operations and tenants, where AFFF (containing PFASs) is currently or has historically been stored, used/applied, tested, handled, managed, or disposed.
- Areas on the airport property where there were accidental uncontrolled spills or releases of AFFF.
- Other potential sources of impacts of PFASs (other than AFFF) to the environment on or near the airport property.

Additionally, Module 1 screens for potential sensitive receptors at and in the vicinity of the airport.

Being familiar with the AFFF life cycle (shown in Figure 6-1) at an airport is critical to identifying and understanding APECs. If an airport has never stored, transported, or used AFFF, the airport is unlikely to have a concern associated with AFFF or PFASs, and there will be fewer worksheets to fill out in the MAPA Screening Tool. However, for airports that are/were required to have firefighting services and use AFFF (by their respective federal agency, i.e., FAA or Transport Canada), understanding how AFFF is (and has been) procured, stored, handled, distributed, tested, applied, and disposed of will help to identify APECs at the airport.

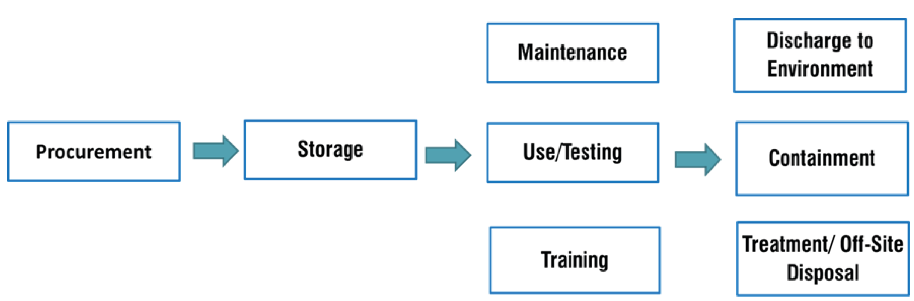


Figure 6-1. AFFF life cycle stages.

APECs will be identified as those areas of the airport that have, or have had, activities that could result in impacts to the environment from AFFF or PFASs. APECs are likely to include (but are not limited to) areas of AFFF storage, firefighting training, and historical emergency response involving AFFF application, as well as equipment and infrastructure used in AFFF application, equipment and system testing areas, and disposal areas.

While AFFF is the primary focus of the MAPA Screening Tool, there are other potential sources of PFASs, as detailed in Section 2.2 that are also considered because they may influence the identification and prioritization of APECs. These sources include the following:

- **Aviation and/or industrial components.** Fluoropolymers such as PTFE are used extensively in various equipment components (e.g., semiconductors, wiring, tubing, piping, seals, gaskets, and cables). In addition, the salts of sulfonated PFASs (primarily PFOS) have been used as additives with a content of about or less than 0.1 percent in hydraulic fluids/lubricants to prevent evaporation, fires, and corrosion.
- **Metal plating operations.** Although metal plating operations may not be directly associated with the aviation industry, such operations are one of the most important ongoing uses of products containing PFASs and are typically situated within industrial zones that may be located near larger airport facilities. An ammonium salt of PFOS is used in metal plating. There is potential for residual concentrations of other PFASs in the PFOS products used for metal plating, as they are not always 100-percent chemically pure.
- **Herbicide/pesticide application.** Non-polymeric PFASs have been used as active ingredients in some plant growth regulators and herbicides and as inert ingredients in pesticide formulations (e.g., ant baits).

APECs can result from tenant activities (possibly similar to those described above) or be located off-site. If any of these activities/sources of PFASs are known to have occurred on or in the vicinity of the airport property, the user of the MAPA Screening Tool should include this information, to the extent known, to gain a more holistic understanding of potential sources that could affect concentrations of PFASs in various media on or near the airport. Although site-specific, off-site impacts of AFFF and PFASs may affect resources and sensitive receptors on the airport property.

The MAPA Screening Tool includes questions for users that have been designed to ascertain whether potential sources of AFFF (and PFASs) reflect ongoing, active operations or legacy issues, or both.

The outcomes of Module 1 include the following:

- Identification of whether PFASs may be a concern.
- An understanding of the AFFF life cycle at the airport.
- Information necessary to develop a geo-referenced, geographic-information-system (GIS)-enabled map of the airport property that depicts identified AFFF sources, release sites, other APECs (both on and off the airport property), and locations of potential sensitive receptors (e.g., potable wells, surface water bodies, and wetlands).
- Categorization of APECs as operational (i.e., related to airport operations and therefore the potential risk to human health and the environment can be proactively managed) or legacy (i.e., impacts of PFASs are present in the environment and need to be managed "reactively").

The balance of this section walks the user through each step (i.e., worksheet) of Module 1.

6.2.1 Entering Module 1 Information

The first worksheet of the MAPA Screening Tool, called the Introductory Worksheet, collects basic information about the airport and the users involved in completing the MAPA Screening

Tool process. This information will be incorporated into a cover page for the document produced as a result of completing MAPA. Users should complete the fields to the best of their knowledge.

Following the Introductory Worksheet, Module 1 consists of four worksheets (it may not be necessary to fill out all four worksheets for each airport):

- Module 1 Overview Questions
- Module 1 APECs
- Module 1 Sensitive Receptors
- Module 1 Summary

Details on input are described in the following.

6.2.1.1 Module 1 Overview Questions Worksheet

After the Introductory Worksheet, users begin the MAPA Screening Tool on the second worksheet of the screening tool, Module 1 Overview Questions, which consists of two tables: (1) APECs and (2) Potential Sensitive Receptors (see Figure 6-2). On this worksheet, users will identify on-site and off-site APECs and sensitive receptors. The table cells have been shaded to categorize data:

- Information associated with on-site APECs will be entered in cells colored blue.
- Information associated with off-site APECs will be entered in cells colored green.
- Information associated with sensitive receptors will be entered in cells colored gray, white, and red.

The user will be directed to the other input worksheets from Module 1 Overview Questions.

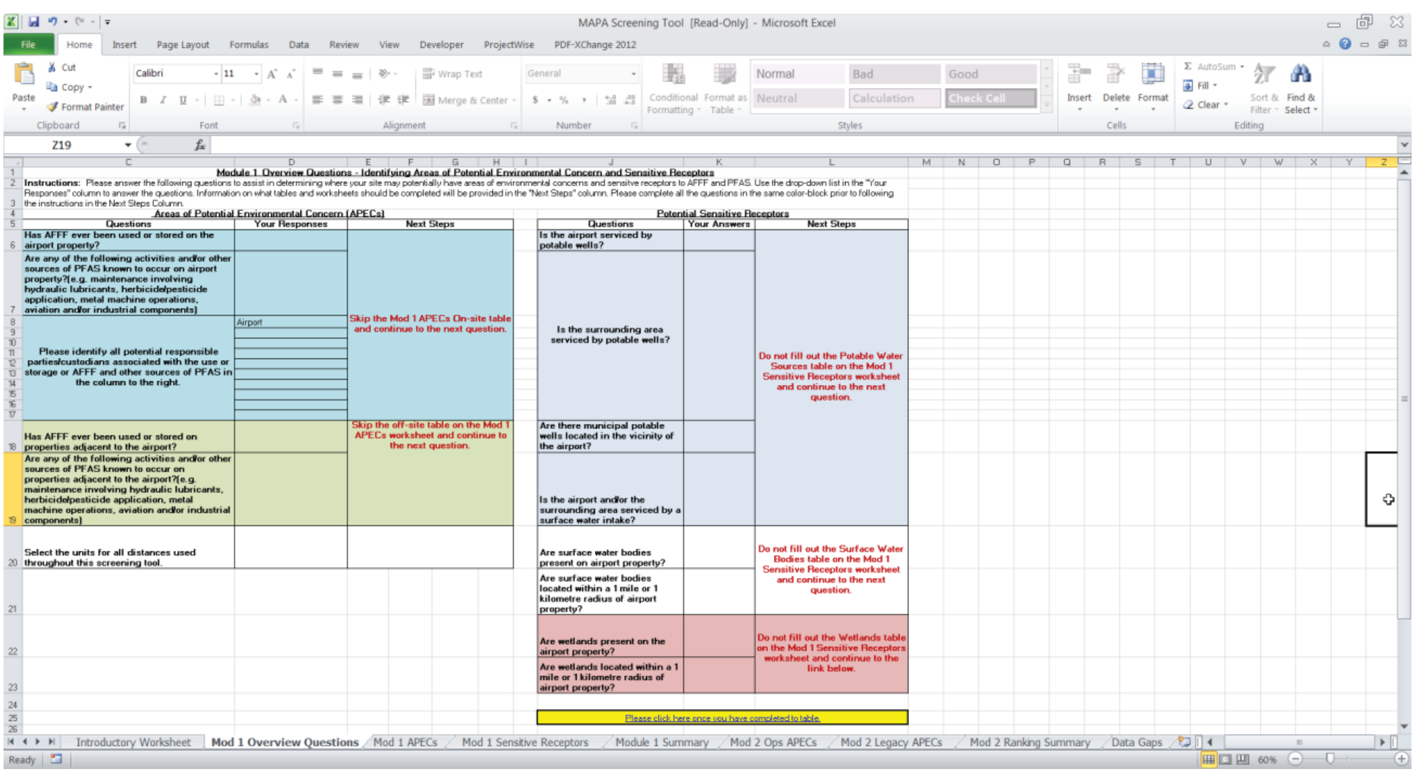


Figure 6-2. Module 1 Overview Questions screenshot.

Instructions to guide users through Module 1 are the following:

1. Starting with the APECs table located on the left side of the Module 1 Overview Questions screen, use the cells in the "Your Responses" column to answer the questions posed in the "Questions" column.
2. Answer each question within one color block (e.g., blue) and then follow the directions in the "Next Steps" column (see Figure 6-3).
3. When listing responsible parties/custodians (e.g., airport property tenants), begin in the cell below "Airport." These responsible parties/custodians will become a drop-down list on another worksheet. This list need not be limited to airport tenants; if there are other custodians or parties responsible for AFFF impacts, they should be listed as well.

After going through the next steps and filling out the form for each color group, users will need to return to the APECs "on-site" table and complete instructions for the next color group.

Repeat for the rest of the table and specify the units of distance (i.e., either English or metric) for use in the MAPA Screening Tool. Upon filling out the information for the APECs table in the Module 1 Overview Questions worksheet, users should follow the directions provided, as shown in Figure 6-3.

Upon completion of the APECs table in the Module 1 Overview Questions worksheet, users should answer the questions in the Potential Sensitive Receptors table (on the right hand side of the worksheet). Specifically, the cells in the "Your Responses" column should be used to answer

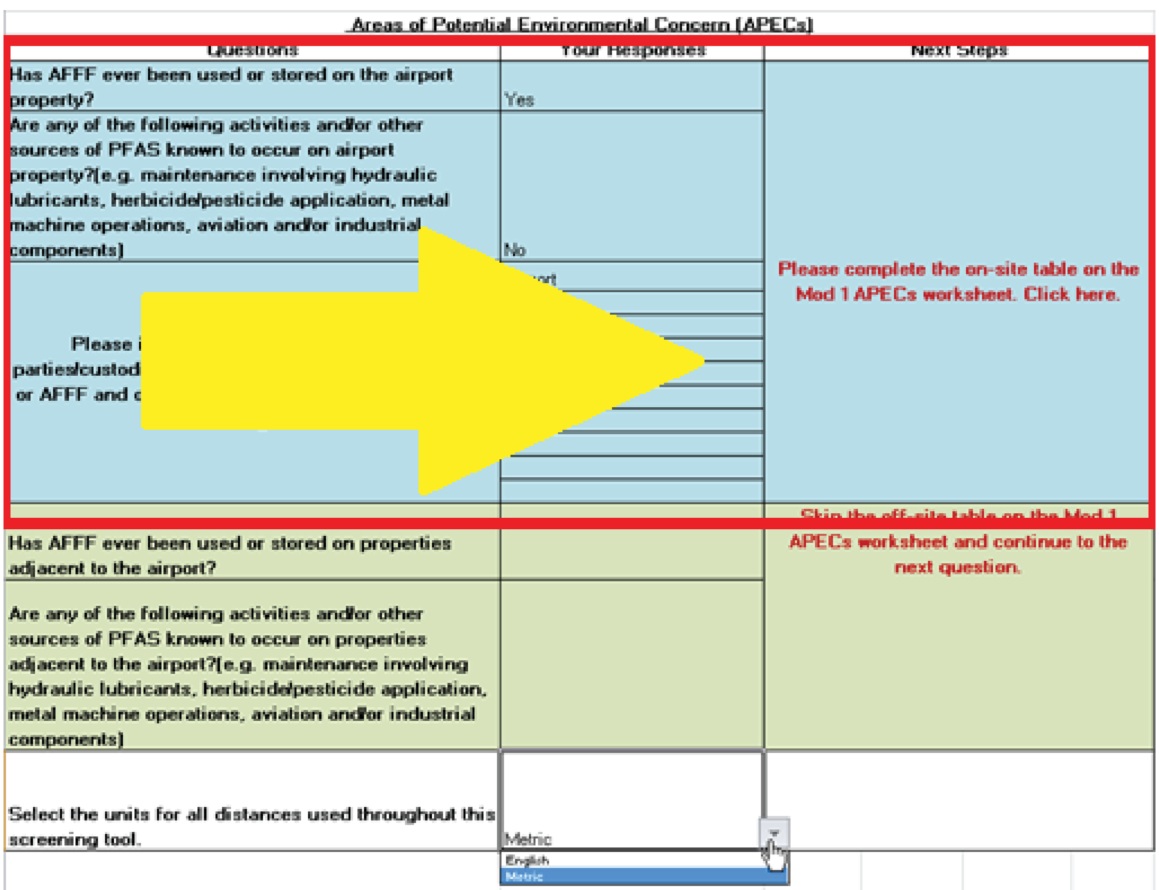


Figure 6-3. Module 1 Overview Questions categorization.

		Do not fill out the Potable Water Sources table on the Mod 1 Sensitive Receptors worksheet and continue to the next question.
Are there municipal potable wells located in the vicinity of the airport?	No	
Is the airport and/or the surrounding area serviced by a surface water intake?	No	
Are surface water bodies present on airport property?	Yes	Please fill out the Surface Water Bodies table on the Mod 1 Sensitive Receptors worksheet. Click here.
Are surface water bodies located within a 1 mile or 1 kilometre radius of airport property?	Yes	
Are wetlands present on the airport property?	No	Please fill out the Wetlands table on the Mod 1 Sensitive Receptors worksheet. Click here.
Are wetlands located within a 1 mile or 1 kilometre radius of airport property?	Yes	
Please click here once you have completed to table.		

Figure 6-4. Screenshot of completed Potential Sensitive Receptors table on the Module 1 Overview Questions worksheet.

the questions posed in the "Questions" column to the left. The user should only complete the action listed in the "Next Steps" column *after* answering all the questions within a single color block (e.g., blue) (see Figure 6-4).

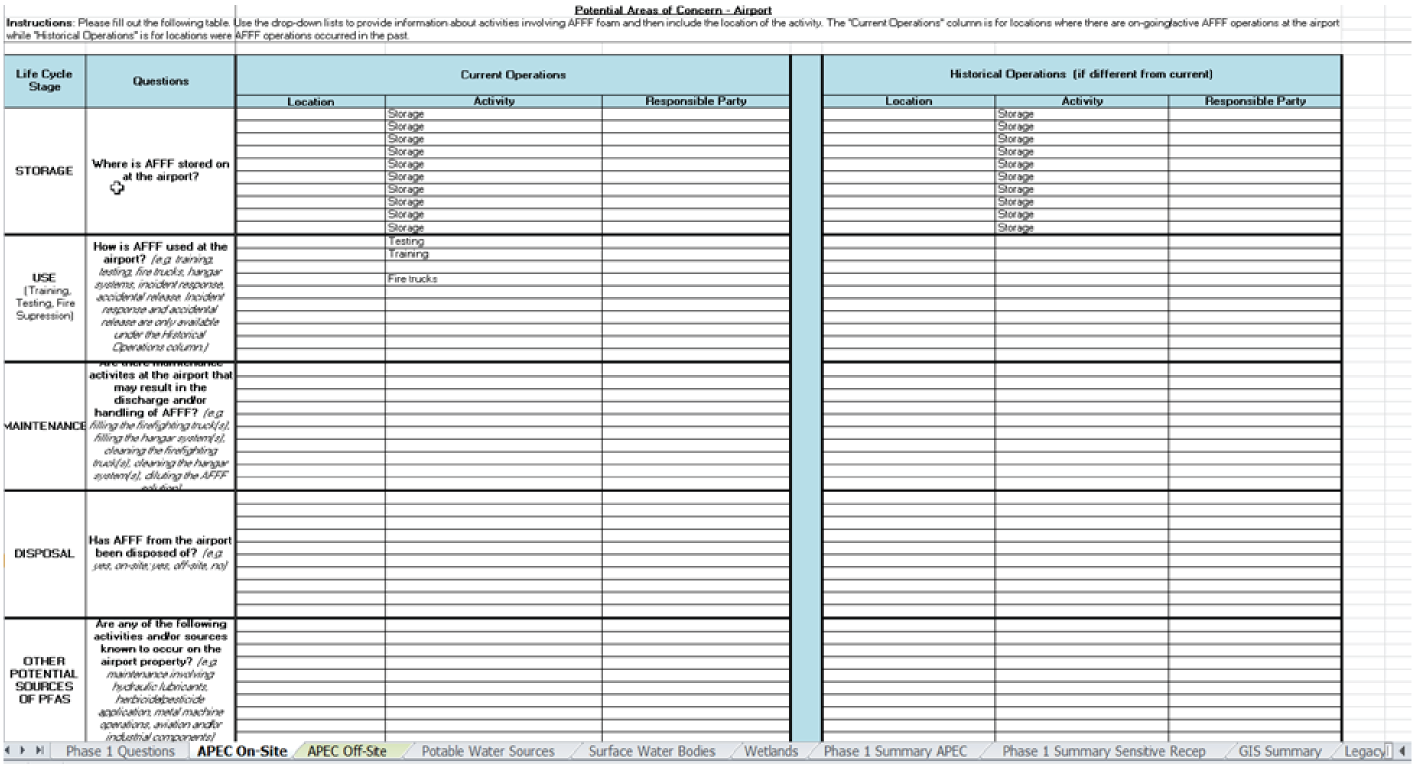
If a potential sensitive receptor is identified based on a user's input to the Potential Sensitive Receptors table on the Module 1 Overview Questions worksheet, the user will be directed to tables specific to the category of receptor. Each sensitive receptor category (i.e., potable water sources, surface water bodies, and wetlands) is described below.

6.2.1.2 Module 1 APECs Worksheet

APECs are categorized as "on-site" or "off-site." Specific details for each APEC are identified in "on-site" or "off-site" worksheets, as described in the following sections.

APECS—Airport

The purpose of this table is to gain a basic understanding of the life cycle of AFFF at an airport and specific locations of potential concern, if any exist. The table lists the AFFF life cycle stages and requires the user to provide the location, activity, and responsible party associated with AFFF on the airport property (see Figure 6-5).



Potential Areas of Concern - Airport

Instructions: Please fill out the following table. Use the drop-down lists to provide information about activities involving AFFF foam and then include the location of the activity. The "Current Operations" column is for locations where there are on-going/active AFFF operations at the airport while "Historical Operations" is for locations were AFFF operations occurred in the past.

Life Cycle Stage	Questions	Current Operations			Historical Operations (if different from current)		
		Location	Activity	Responsible Party	Location	Activity	Responsible Party
STORAGE	Where is AFFF stored on at the airport?		Storage Storage Storage Storage Storage Storage Storage Storage Storage Storage			Storage Storage Storage Storage Storage Storage Storage Storage Storage Storage	
USE (Training, Testing, Fire Supression)	How is AFFF used at the airport? *(e.g. training, testing, fire trucks, hangar systems, incident response, accidental release. Incident response and accidental release are only available under the Historical Operations column.)*		Testing Training Fire trucks				
MAINTENANCE	Are there maintenance activites at the airport that may result in the discharge and/or handling of AFFF? *(e.g. filling the firefighting truck(s), filling the hangar system(s), cleaning the firefighting truck(s), cleaning the hangar system(s), diluting the AFFF solution)*						
DISPOSAL	Has AFFF from the airport been disposed of? *(e.g. yes, on-site; yes, off-site; no)*						
OTHER POTENTIAL SOURCES OF PFAS	Are any of the following activities and/or sources known to occur on the airport property? *(e.g. maintenance involving hydraulic lubricants, herbicide/pesticide application, metal machine operations, aviation and/or industrial components)*						

Phase 1 Questions | APEC On-Site | APEC Off-Site | Potable Water Sources | Surface Water Bodies | Wetlands | Phase 1 Summary APEC | Phase 1 Summary Sensitive Recep | GIS Summary | Legacy

Figure 6-5. APECs—Airport table in Module 1 APECs worksheet.

In the table:

- Cells in the location column allow users to type the name of the on-site APEC as it will be identified going forward in MAPA.
- Cells in the activity column, except those associated with the storage life cycle stage, are to be populated from drop-down lists.
- Cells in the responsible party/custodian column are to be populated with drop-down lists that are generated from the responsible parties/custodians identified in the Module 1 Overview Questions worksheet (see Figure 6-6). If, at this stage, a user realizes they have forgotten a responsible party/custodian (e.g., a new tenant) that should be listed, they can return to the Module 1 Overview Questions worksheet and add them to the list by using the worksheet tabs at the bottom of the screen.

The MAPA Screening Tool has been designed to differentiate between current operations and historical operations for two reasons. First, the user's knowledge of and the information available for current and historical operations may vary; sometimes the user will have no information about a historical application or operation. Second, how an airport may or can act (e.g., implementing best management practices) will be different for current operations than historical operations. Consequently, MAPA asks the user to distinguish between current operations and historical operations on this input table. Use the "Historical Operations" section if AFFF activities have occurred in a location that is not currently used/exposed to AFFF. For example, if AFFF training occurred in a specific hangar in the past, but now occurs at a designated firefighting training area, the hangar would be listed under the "Historical Operations" section and the firefighting training area would be listed under "Current Operations" section.

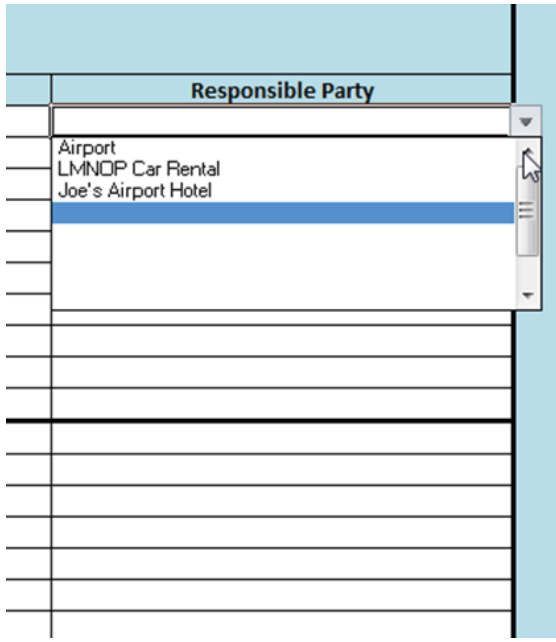


Figure 6-6. Responsible party/custodian lists generated from the Module 1 Overview Questions worksheet presented in a drop-down menu in the Module 1 APECs worksheet.

For activities on the drop-down list for the AFFF life cycle stage labeled “Use,” the options of “incident response” and “accidental release” are available under the “Historical Operations” section only. This is because these are events that have already happened and are not considered to be current.

APECs—Off-Site

The purpose of this table is to gain a basic understanding of the life cycle of AFFF in the vicinity of the airport and evaluate whether any locations of potential concern exist. The table lists the AFFF life cycle stages and requires the user to provide the location, activity, and land use type associated with AFFF on the property in the vicinity of the airport. The table has been constructed similarly to the table previously discussed and is located in the same worksheet. Please note:

- Cells in the location column allow users to type the name of the off-site APEC as it will be identified going forward in the MAPA Screening Tool.
- Cells in the activity column, except those associated with the storage life cycle stage, are to be populated from drop-down lists.
- Current operations and historical operations are considered unique. Use the “Historical Operations” column if AFFF activities occurred in a location in the past where they do not currently occur.

6.2.1.3 Module 1 Sensitive Receptors Worksheet

Upon completing the Module 1 APECs worksheet, users should return to the Module 1 Overview Questions worksheet to address potentially sensitive receptors. Module 1 of the MAPA Screening Tool considers potentially sensitive receptors at the airport scale. If AFFF and/or other APECs related to PFASs are identified at or near an airport, recognizing the presence of potentially sensitive ecological receptors is critical to evaluating the potential level of concern and ranking/prioritizing individual APECs. Questions focus on identifying key receptors (or receptor habitats) of interest, i.e., potable wells, surface water bodies, and wetlands.

Releases of small amounts of AFFF containing PFASs to the environment could significantly impact environmental media, wildlife, and potentially human populations as some PFASs are very persistent in the environment and bioaccumulate in living organisms. Many PFASs are water soluble and will ultimately be transported to groundwater or surface water bodies, providing potential exposure to sensitive receptors. The MAPA Screening Tool identifies receptors (or receptor habitats) that are on, in relatively close proximity to, or down-gradient of the airport property and/or APECs previously identified.

Potable water sources, or drinking water sources, if impacted by PFASs, may present an unacceptable risk to human health via ingestion. The following drop-down list options in the first column of the Potable Water Sources worksheet can be used to describe the type of potable water source:

- Potable well: groundwater
- Municipal water well supply: groundwater
- Surface water body: A surface water body (e.g., lake or river) that is used as a source of drinking water

The user should identify each potable water source by assigning a location name and indicating, if known, the proximate distance to the nearest APEC previously identified.

Surface water bodies (in addition to being a potential potable water source) also represent a potential habitat for sensitive receptors. The user should identify the type of surface water body (e.g., lake, river, stream, pond, ocean, ditch) using the drop-down menu, assign a location name, and indicate, if known, the proximate distance to the nearest APEC previously identified.

Wetlands, like surface water bodies, represent a potential habitat for sensitive receptors. Types of wetlands vary, but the user is encouraged to characterize the type of wetland using the basic descriptions provided in the screening tool using the drop-down menu. The user should identify each wetland by assigning a location name and indicating, if known, the proximate distance to the nearest APEC previously identified.

If, upon the completion of the two tables the user is still on this worksheet (Module 1 Overview Questions), click the yellow button below the Potential Sensitive Receptors table to continue on to the next applicable worksheet. If the user is on another worksheet, then do not return to this worksheet, use the yellow button at the bottom of the worksheet to continue to the next worksheet in the screening tool.

The output from Module 1 lists the identified APECs and sensitive receptors at the airport. The output is generated and presented in one worksheet, Module 1 Summary, which is divided into two tables: (1) APECs and (2) Sensitive Receptors.

The following sections describe how to generate this output.

6.2.1.4 Module 1 Summary Worksheet—APEC Table

This summary worksheet describes the APECs identified on-site and off-site in relation to life cycle stage and type of activity. Additionally, with user input, the coordinates of each APEC can be added to allow for APECs to be geo-referenced on a map (as presented in the GIS Summary worksheet).

To generate the list of APECs, click the button labeled Press to Start at the top of the worksheet before entering any data on this worksheet. The table will self-populate with the location name provided for the APEC, its associated life cycle stage, and the type of activity. If using the compatibility version of the tool, press Crtl, Shift, and F to activate the macro that populates the table appropriately.

In order to further characterize the APEC associated with current operations or a legacy environmental impact, users should answer the question posed in the column to the right of the "Type of Activity" column for each APEC (i.e., Is the APEC associated with past release into the environment?) using the drop-down list provided. Please note that for some activities, the corresponding cell is pre-populated based on previous input data (in an effort to make using the screening tool more efficient). If the user has knowledge that calls into question the pre-populated answer for a particular APEC, the response in the cell can be changed using the drop-down list. For example, if AFFF was stored in Hangar 4, the cell will be populated with the answer "No" because, in most cases, storage locations are not involved with releases of AFFF into the environment. However, if AFFF was spilled at the storage location or a storage container was leaking, the user should switch the answer to "Yes" so that on a subsequent worksheet the user will be prompted to provide more information about the release (see Figure 6-7).

To generate a data table suitable for using in GIS and mapping the location of APECs (as discussed below), enter latitudes and longitudes of identified APECs in decimal degrees in the columns on the right. The "Location Name for GIS" column is populated with the name chosen for the APEC or sensitive receptor when it was first identified. In order to use these location names in ArcGIS, however, special names that don't include spaces are required. The MAPA user or a GIS specialist should replace the location names with those that are appropriate for ArcGIS (e.g., Hangar 4 could become Hangar_4) in the first column ("APEC") of the table.

Visual representation helps identify potential omissions with regard to both APECs and sensitive receptors and fosters the development of a CSM, which can be used to understand and address legacy impacts of PFASs at the airport. In addition, from a capital project planning

Module 1 Summary Sheet - APEC

Instructions: This worksheet is auto-populated with information provided in previous worksheets. Press the button below before entering any data on this worksheet. Please fill in the latitudes and longitudes in decimal degrees. Also use the drop-down list to answer the question: "Is the AOPC associated with past release into the environment?"

Press to Start

		Activity			GIS		
APEC	Life Cycle Stage	Type of Activity	Is the APEC associated with past release into the environment?	Responsible Party	Latitude	Longitude	Location Name for GIS
0	Storage	Storage	No	0			
0	Storage	Storage	No	0			
0	Storage	Storage	No	0			
0	Storage	Storage	No	0			
0	Storage	Storage	No	0			
0	Storage	Storage	No	0			
0	Storage	Storage	No	0			
0	Storage	Storage	No	0			
0	Storage	Storage	No	0			
0	Storage	Storage	No	0			
0	Use	0	No	0			
0	Use	0		0			
0	Use	0		0			
0	Use	0		0			
0	Use	0		0			
0	Use	0	Yes	0			
0	Use	0	Yes	0			
0	Use	0	Yes	0			

Figure 6-7. Screenshot of the APEC table on the Module 1 Summary worksheet.

Phase 1 Summary Sheet - APEC

Instructions: This page is auto-populated with information provided in previous pages. Press the button below before entering any data on this page. Please fill in the latitudes and longitudes in decimal degrees. Also use the drop-down list to answer the question: "Is the AOPC associated with past release into the environment?"

Press to Start

APEC	Life Cycle Stage	Activity			
		Type of Activity	Is the APEC associated with past release into the environment?	Latitude	Longitude
Fire Department Building 1	Storage	Storage	No	-75.23415614	39.86637664670
Hangar 1	Use	Hangar system	No	-75.22738177	39.88113373580
Firefighting Training Area 1	Use	Training	Yes	-75.26393627	39.85998941
Runway 2	Use	Incident response	Yes	-75.27711628	39.86099169010
Manufacturing Site 1	Other	Metal plating operations	Yes	-75.28805236	39.86320842130
Manufacturing Site 2	Other	Metal plating operations	No	-75.21794143	39.89403797790

Click here once table is complete

Figure 6-8. Screenshot of a completed and compiled APEC table.

perspective, understanding where impacts of PFASs in soil and groundwater may be present is important because special handling, treatment, and/or disposal may be required (potentially at significant cost) for soil and groundwater impacted by PFASs (e.g., dewatering).

See Figure 6-8 for an example of a completed APEC table.

6.2.1.5 Module 1 Summary Worksheet—Sensitive Receptors Table

The Module 1 Summary Worksheet Sensitive Receptors table summarizes all the sensitive receptors identified previously based on the type of receptor (see Figure 6-9).

Module 1 Summary Sheet - Sensitive Receptors

Instructions: This worksheet is auto-populated with information provided in previous worksheets. Press the button below before entering any data on this worksheet then fill in the latitudes and longitudes in decimal degrees.

Press to Start

Sensitive Receptors				
Type of Receptor	Location	Latitude	Longitude	Location Name for GIS
0	0			
0	0			
0	0			
0	0			
0	0			
0	0			
0	0			
0	0			
0	0			
0	0			
0	0			
0	0			
0	0			
0	0			
0	0			

Click here once table is complete

Figure 6-9. Screenshot of the Sensitive Receptors table on the Module 1 Summary Sheet prior to data retrieval.

Click the button labeled Press to Start at the top of the worksheet before entering any data in this worksheet. This worksheet will self-populate with the type of receptor and the location name provided for the sensitive receptor. (See Figure 6-10.)

6.3 Module 2—APEC Scale Evaluation

Module 1 of the MAPA Screening Tool compiles a list of identified APECs and sensitive receptors. Module 2 facilitates a detailed desktop characterization of each APEC identified in Module 1. Module 2 also provides a ranking associated with each APEC to facilitate making relative comparisons and prioritizing future action, i.e., either focusing resources on select APECs or evaluating the overall effect of applying best management practices at a given APEC. Finally, Module 2 identifies potential data gaps associated with developing a CSM and having a holistic understanding of potential issues associated with historical and current uses of AFFF and other potential sources of PFASs. Module 2 specifically focuses on the following:

- Characterizing operational APECs based on their respective AFFF life cycle stage.
- Characterizing legacy environmental impacts based on release characteristics and site attributes.
- Ranking each APEC for relative comparison.
- Identifying data gaps required for further consideration.

The outcomes of Module 2 may include the following:

- Characterization of operational and environmental legacy APECs.
- Ranking of each APEC.
- Identification of data gaps needed for additional understanding of the concerns regarding AFFF and PFASs at an airport.
- Identification of appropriate management practices that, if implemented, may reduce an APEC's prioritization ranking.

6.3.1 Entering Module 2 Information

Module 2 consists of four worksheets, divided into four categories: operational APECs, legacy APECs, ranking summary, and data gap identification. Operational APECs are characterized via

Module 1 Summary Sheet - Sensitive Receptors

Instructions: This worksheet is auto-populated with information provided in previous worksheets. Press the button below before entering any data on this worksheet then fill in the latitudes and longitudes in decimal degrees.

Press to Start

Sensitive Receptors

Type of Receptor	Location	Latitude	Longitude	Location Name for GIS
Pond	Pond near Fire Dept. Building	-75.23483633	39.86517993	FireDept_Pond
River	River (east end of property)	-75.22445853	39.86409922	East_River
Ditch	Ditch by Hangar 1	-75.26836483	39.86067986	Hangar1_Ditch
Stream	Pilot's Creek (between Runways 3 and 4)	-75.289756	39.88010741	PilotsCreek
Ditch	Ditch behind Runway 2	-75.26286492	39.86555459	Runway2_Ditch
Pond	Pond at the nearby hotel	-75.27125501	39.8743837	Hotel_Pond
Swamp	Wildlife Refuge	-75.259333	39.88421112	Wildlife_Refuge

Click here once table is complete

Figure 6-10. Screenshot of a completed and compiled Module 1 Summary Sheet listing sensitive receptors.

individual worksheets for each of the following AFFF life cycle stages: storage, use, maintenance, and disposal (discussed further in Section 6.3.1.1).

The balance of this section walks the user through each step (i.e., worksheet) of Module 2.

6.3.1.1 Detailed APEC Characterization

Upon completion of Module 1, the user will be prompted to consider further questions associated with each APEC that allow for detailed characterization and relative ranking of each APEC. For operational APECs, questions relate to each of the AFFF life cycle stages: specifically, how AFFF is stored, used (including testing, training, and emergency response), and disposed of and how equipment and infrastructure used for distribution and application are maintained and cleaned. For legacy APECs, questions focus on release characteristics, presence of co-mingled contaminants, surface covering, and exposure pathways.

Operational APECs

Module 2 has a worksheet for APECs (Mod 2 Ops APECs) identified in each operational life cycle stage from Module 1. To initiate the characterization of each APEC identified for each operational stage, click the Press to Start button in the upper left hand side of the screen and the worksheet will automatically populate the table with the names of APECs identified in Module 1 (shown in Figure 6-11). If using the compatibility version of the tool, press Crtl, Shift, and A to activate the macro that populates the table appropriately. For each APEC, the user enters responses to each question on the left using the drop-down lists. Once entered, a score associated with each response will populate the cell to the right of the response. This score is used, in summation with other scores for each APEC, to rank the APEC. Ranking and prioritization are discussed in detail in Section 6.5.

Users can perform their own sensitivity analysis by changing their responses and seeing how different inputs affect the APEC ranking. This sensitivity analysis may then be considered in evaluating implementation of future operational and management practices.

The final row will contain a score for that life cycle stage and APEC. Once all the questions are completed for all the locations on the worksheet the user is on, the yellow cell at the bottom of the worksheet can be clicked to continue on to the next worksheet.

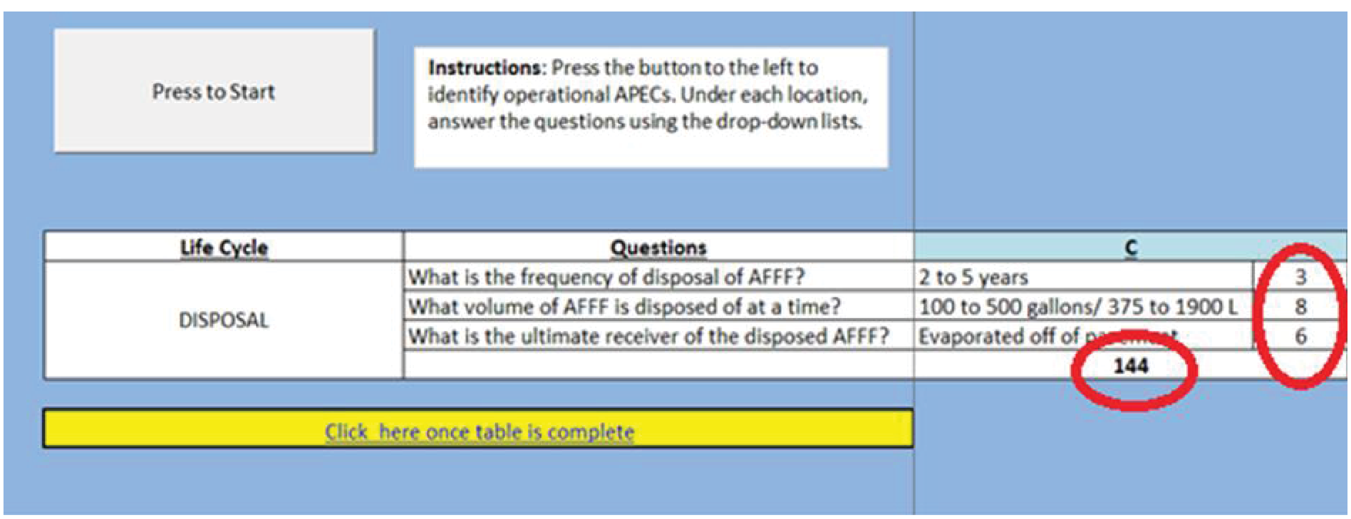


Figure 6-11. Life cycle stage scoring on the Mod 2 Ops APECs worksheet.

The questions posed on the Operational APECs worksheets are mostly related to best management practices:

- **Storage.** Questions posed are focused on how AFFF is being stored at the airport and whether there are any inherent risks with the storage methods in place. If containers are currently leaking or have leaked in the past, the user should identify the location as having a historical release (that could have resulted in a release to the environment, i.e., legacy). The following describes potential responses associated with the drop-down list. Users should enter the response most representative of the condition associated with each APEC:
  - Covering
    - Enclosed: AFFF storage container(s) are inside a fully enclosed space (four walls and a ceiling).
    - Covered: AFFF storage container(s) are covered from above but are exposed to the elements from the side (e.g., covered by a tarp or located in a building with no walls).
    - Outside or exposed directly to the elements: There is no covering of the storage container(s) (e.g., stored on the edge of a runway).
  - Containment
    - Double: Storage containers have (at least) secondary containment in addition to the original manufacturer-provided container.
    - Single: AFFF is stored only in the container in which it arrived from the manufacturer.
  - Flooring
    - Paved: Uncracked paved flooring (e.g., asphalt, concrete).
    - Slightly cracked pavement: 0 to 25 percent of the pavement is cracked or broken.
    - Moderately cracked pavement: 25 to 50 percent of the pavement is cracked or broken.
    - Heavily cracked/broken pavement: More than 50 percent of the pavement is cracked or broken.
    - Earthen: The flooring is not paved and is soil and/or gravel in nature.
- **Use (Application).** For the purpose of MAPA, the Use life cycle stage includes training, testing, and emergency response. Questions for this stage relate to how much AFFF is used, what is done with the waste AFFF, and what PPE is used when handling AFFF. The following describes potential responses (i.e., drop-down list) associated with select questions. Users should enter the response most representative of the condition associated with each APEC:
  - Amount of AFFF used: There are many options in this drop-down list as the amount of AFFF used will vary significantly with the different uses. For example, the amount of AFFF used in a foam test is expected to be significantly less than the amount used to suppress a fire.
  - Ultimate receiver: Potential responses are listed below. If the ultimate receiver is one of the first four listed, the user should identify the APEC in Module 1 under historical operations:
    - Washed down a drain/sewer.
    - Allowed to soak into ground.
    - Evaporated from pavement.
    - Washed into a surface water body/wetland.
    - Disposed off-site by licensed facility.
  - PPE: AFFF poses inhalation, dermal, and ingestion hazards to those handling the solution; therefore, PPE should be used to minimize potential health effects. This question asks how many types of PPE are regularly used when handling AFFF. Using all the PPE listed is considered ideal because it provides mitigation to the various exposure pathways.
  - Exposure contact: AFFF poses human health risks; therefore, this category is focused on identifying whether people are being exposed to AFFF without PPE and, if they are, how frequently, as long-term exposure increases the potential health risks.

- **Maintenance.** Maintenance of vehicles and deluge systems may result in handling and spills of AFFF. Questions for this stage relate to the frequency of AFFF equipment maintenance, the types of equipment cleaning agents, how AFFF is removed from the equipment, how the equipment is cleaned, and what is done with AFFF removed from the equipment. The following describes potential responses (i.e., drop-down list) associated with select questions. Users should enter the response most representative of the condition associated with each APEC:
  - AFFF equipment checks: Checking AFFF equipment is a good preventative measure against accidental releases as cracks and corrosion can be identified and resolved before a release occurs. Depending on the jurisdictional regulations for the airport and the frequency of incident response, AFFF and its equipment may not be in regular use; therefore, it may be worthwhile to add checking equipment for malfunctions to airport procedures.
  - Removal of AFFF from equipment: While for the most part AFFF is left in deluge systems and firefighting trucks after a single use, it may be removed when conducting maintenance on equipment or switching brands of AFFF solution to prevent coagulation. Methods for removal include
    - Mechanical pump: Lowest level of risk as this provides the most control and consistency in the speed of AFFF removal.
    - Manual pump: The risk with this method is a bit higher than with a mechanical pump as there is more room for human error and inconsistent speeds in AFFF removal, which could result in splashing and spills of the AFFF solution.
    - Gravity/drain valve: This method provides the least amount of control over the speed and direction of the AFFF solution and is therefore associated with the highest risk of spilling or splashing the solution on workers.
  - Cleaning equipment: While for the most part AFFF is left in deluge systems and firefighting trucks after a single use, it may be removed when switching brands; cleaning out the equipment at this point is common to reduce the risk of residue from the previous brand. Cleaning may involve
    - Rinsing/flushing with water: Rinsing with water implies that clean water (not gray water) is used to flush out build-up/residue in the equipment.
    - Cleaning with water and soap/detergent: Clean water (not gray water) and a soap or detergent is used to remove build-up/residue in the equipment.
    - Rinsing/flushing with a solvent: Due to the chemical nature of PFASs, cleaning equipment with an alcohol solvent, such as ethanol, is considered the most effective method of removing AFFF traces from distribution systems.
  - Handling procedures: Handling procedures are strong risk reduction measures when clearly communicated to all those involved in the AFFF life cycle. Methods included in the MAPA Screening Tool are two or more people involved in the handling of AFFF, clear procedural standards for AFFF use and handling, procedural training for those handling AFFF, and ensuring fittings and connections are tight on all AFFF-related equipment.
  - Ultimate receiver: Potential responses are listed below. If the ultimate receiver of AFFF rinsate and/or AFFF removed from distribution systems is one of the first four listed below, the user should identify the APEC in Module 1 under historical operations:
    - Washed down a drain/sewer.
    - Allowed to soak into ground.
    - Evaporated from pavement.
    - Washed into a surface water body/wetland.
    - Disposed off-site by licensed facility.
- **Disposal.** The location of AFFF (as either concentrate or as a mixed formulation) is disposal greatly impacts the potential risk to human health and the environment. A large quantity of AFFF concentrate returned to the manufacturer will not have the same impact as a small quantity of AFFF released directly into a surface water body. Question posed are used to gain

a sense of the quantity of AFFF being disposed of and the location of the ultimate receiver of the disposed AFFF.

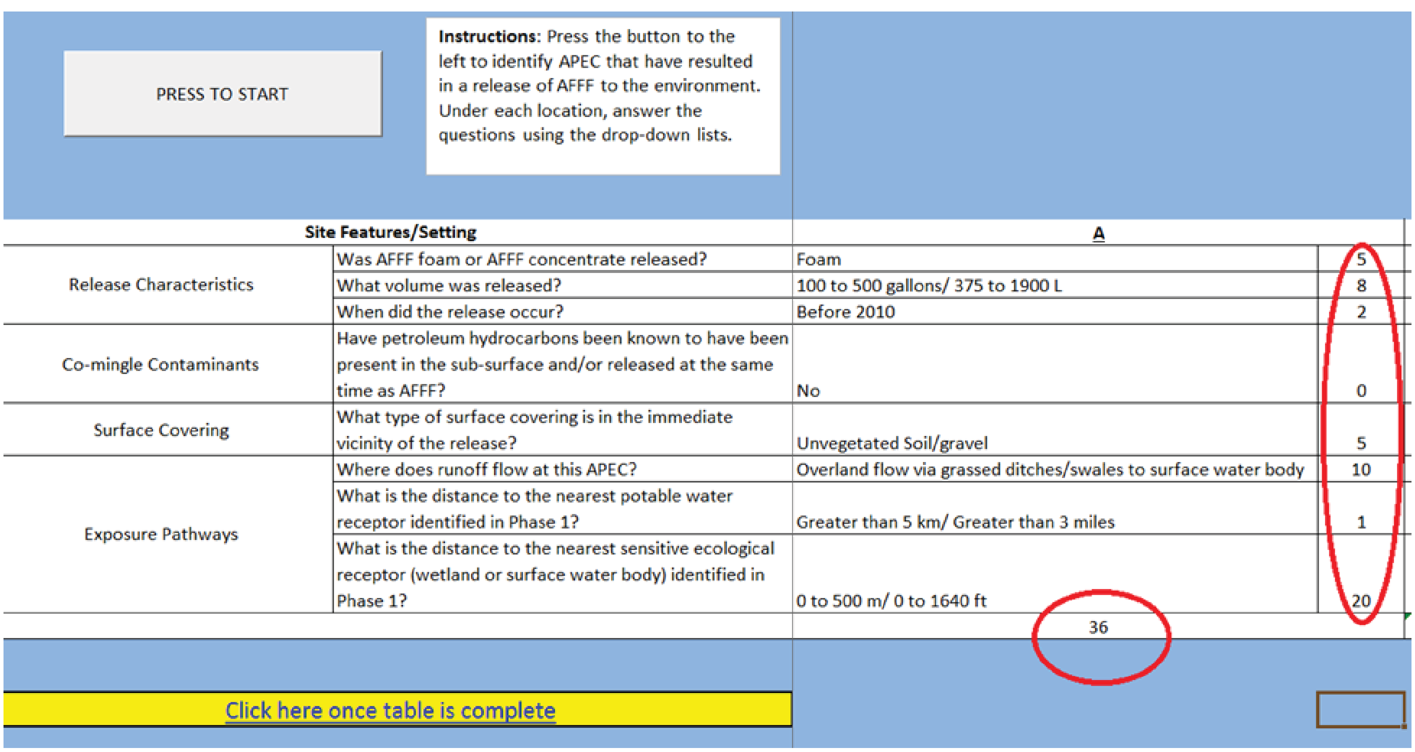
Module 2 Legacy APECs Worksheet

Within Module 2, there is a worksheet for APECs identified as legacy, i.e., historical activities that resulted in a release to the environment. On the Module 2 Legacy APECs worksheet, questions are posed to understand the nature of the release, whether other contaminants may have been present that would affect the fate and transport of PFASs in the environment, surface covering, and exposure pathways.

To initiate the characterization of each legacy APEC, click the Press to Start button in the upper left hand side of the screen, and the worksheet will automatically populate the table with the names of APECs identified in Module 1. If using the compatibility version of the tool, press Crtl, Shift, and B to activate the macro that populates the table appropriately. For each APEC, enter responses to each question on the left using the drop-down lists. Once a response is entered, a score associated with that response will populate the cell to the right of the response (see Figure 6-12). This score is used, in summation with other scores for each APEC, to rank the APEC. Ranking and prioritization are discussed in detail in Section 6.5. The last row will show a score for that APEC. Once a user has completed all the questions for all the locations on the worksheet they are on, they should click the yellow cell at the bottom of the worksheet to continue onto the next worksheet.

The following describes potential responses (i.e., drop-down list) associated with select questions on the Module 2 Legacy APECs worksheet. Users should enter the response most representative of the condition associated with each APEC:

- **Release characteristics.** Questions in this area are meant to determine the basic facts of the AFFF release. AFFF concentrate is diluted to make the AFFF solution that is actually used for



PRESS TO START

Instructions: Press the button to the left to identify APEC that have resulted in a release of AFFF to the environment. Under each location, answer the questions using the drop-down lists.

Site Features/Setting		A	
Release Characteristics	Was AFFF foam or AFFF concentrate released?	Foam	5
	What volume was released?	100 to 500 gallons/ 375 to 1900 L	8
	When did the release occur?	Before 2010	2
Co-mingle Contaminants	Have petroleum hydrocarbons been known to have been present in the sub-surface and/or released at the same time as AFFF?	No	0
Surface Covering	What type of surface covering is in the immediate vicinity of the release?	Unvegetated Soil/gravel	5
Exposure Pathways	Where does runoff flow at this APEC?	Overland flow via grassed ditches/swales to surface water body	10
	What is the distance to the nearest potable water receptor identified in Phase 1?	Greater than 5 km/ Greater than 3 miles	1
	What is the distance to the nearest sensitive ecological receptor (wetland or surface water body) identified in Phase 1?	0 to 500 m/ 0 to 1640 ft	20
		36	

Click here once table is complete

Figure 6-12. Scoring on the Module 2 Legacy APECS worksheet.

firefighting activities; therefore, this question includes the mass of AFFF released in the assessment of risk. Timing of the release is important for the migration of AFFF in the environment and the type of PFASs contained in the AFFF, as different compositions were used prior to and after 2010.
- **Co-mingle contaminants.** PFASs behave differently in the natural environment when released at the same time as petroleum hydrocarbons (PHCs) or into soils impacted by PHCs; therefore, the presence of PHCs increases the risk of a potential concern.
- **Surface covering.** Surface covering at the release location will influence the way that PFASs could potentially interact with sensitive receptors; overland flow could result in AFFF entering surface water bodies, while infiltration may result in AFFF in groundwater supplies.
- **Exposure pathways.** In combination with the questions posed about the surface covering at the release location, the questions associated with the topic of exposure pathways are designed to gain a preliminary understanding of the likelihood that AFFF is interacting with sensitive receptors.

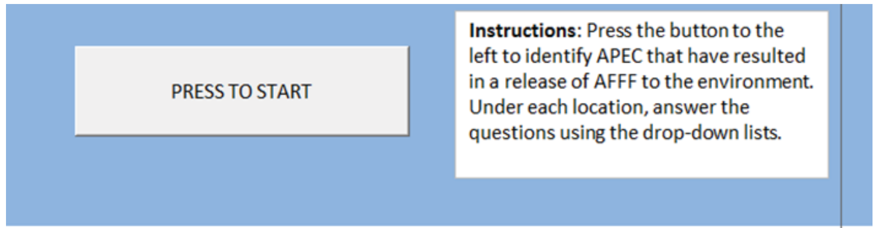
6.4 Data Gaps

The MAPA Screening Tool has been designed to preliminarily screen APECs associated with AFFF and other sources of PFASs and to provide utility as a data gap identification and analysis tool. Some of the questions in the MAPA Screening Tool, however, may be difficult for an airport to answer or address because the necessary information may not be readily available. For operational APECs, information may need to be provided by multiple departments in the airport and/or tenants. For legacy APECs, information may be available via previously conducted environmental site investigations or publicly available databases to address questions for which there is not a readily available response.

The MAPA Screening Tool allows users to flag questions to which they do not know the answer (e.g., entering a "Don't Know" response). Data gaps related to potential legacy environmental impacts (i.e., impacts of PFASs in environmental media such as soil, groundwater, sediment, or surface water) will be identified. A detailed CSM that identifies potential sources, exposure pathways, and receptors and includes a comprehensive understanding of the site's subsurface stratigraphy, hydrogeology, hydrogeochemistry, hydrology, and impacts of the fate and transport of PFASs will ultimately be needed to fully understand potential risks to human health and the environment.

The MAPA Screening Tool does not create the CSM, but the data gap tool allows the user to inventory available information (and missing information) that would be required to develop a CSM in the future, if needed. The MAPA Screening Tool includes a Data Gaps worksheet that allows the user to identify whether they have information pertinent to developing a rigorous CSM, including the following (see Figure 6-13):

- Land use and zoning for on- and off-site properties (agricultural, residential, commercial, and industrial).
- Soil conditions (e.g., soil texture, soil type, soil depth, soil chemistry).
- Geological conditions (e.g., depth to bedrock, type of underlying rock, till).
- Hydrogeological conditions (e.g., groundwater depth, flow rate, flow direction, chemistry).
- Surface water and sediment conditions (e.g., flow rate and direction, depth, hydrodynamics, substrate type, water and sediment chemistry, drainage patterns and systems, surface runoff patterns).
- Topographic features (e.g., elevation and gradient).
- Local climatology and meteorological conditions.



Site Features/Setting	
Surface Covering	USCS classification of soil
Meteorological Information	Snow cover
	Flood potential
	Amount of precipitation
Topography	Topography of APEC in relation to sensitive receptors
Geology	Depth of soil to bedrock
	Type of bedrock
Hydrogeology	Depth to groundwater
	Groundwater flow direction
	Groundwater flow rate
Permafrost	Permafrost depth
Groundwater	Precipitation infiltration rate
	Hydraulic conductivity rate
	Thickness and hydraulic conductivity of confining layer over aquifer/groundwater expsure pathway

Figure 6-13. Site features/settings as part of a CSM in the Module 2 Data Gaps worksheet.

- Potential preferential migration pathways or conduits for PFASs (e.g., former or current trenches, ditches, underground piping, and wiring).

  Information not available would be considered a potential data gap or uncertainty.

6.5 APEC Prioritization

MAPA has been designed to rank each APEC based on the characteristics identified in Module 2. Scoring, whether for individual responses or for APECs as a whole, generally represents an increasing potential for unacceptable risk to human health and environment as the values increase, i.e., the lower the score, the less the concern, and the higher the score, the greater the concern. Scoring is for comparative purposes only, and the absolute number has no meaning other than contextual.

Attachment A of Appendix C lists the questions asked in Module 2, scores associated with each response, the maximum score, and the calculations used to calculate the overall score for applicable life cycle stages.

6.6 Closing

The MAPA Screening Tool has been designed for airport representatives familiar with AFFF management and impacts of PFASs at the airport. The screening tool can assist airports in identifying and characterizing APECs on or near an airport, accounting for both historical and current use of AFFF and other sources of PFASs. The MAPA Screening Tool has been designed so that users can rely on readily available information to complete the screening effort. Should APECs be identified that require further investigation, airports should engage environmental consultants and contractors with experience and expertise in AFFF and PFASs.

The results that can be produced by use of the MAPA Screening Tool are the following:

- Identification of APECs on and adjacent to airport property.
- Identification of potential sensitive receptors on and adjacent to airport property.
- Collection of information needed to create GIS maps for visualization of APECs, sensitive receptors, and exposure pathways.
- Production of a preliminary ranking of potential concern for operational and legacy APECs.
- Identification of gaps in data needed for future in-depth analysis of AFFF impacts for each APEC.

The information resulting from the completion of the MAPA Screening Tool allows for documentation of potential liabilities and risk and planning for the future. The MAPA Screening Tool can be used

- As a summary of information that the airport has regarding the life cycle of AFFF.
- To rank areas of handling/use of PFASs by potential risk, allowing airport managers to prioritize efforts to mitigate/manage PFASs and plan for future capital expenditures.
- As a first step in the remediation of APECs for future development or changes to the airport property, in consultation with an AFFF remediation specialist.
- To identify operational practices that would decrease the potential environmental impacts associated with AFFF use.

Note that the MAPA Screening Tool is a preliminary desktop assessment of potential impacts and should not replace the consultation of a professional with experience in AFFF management and assessment and remediation of PFASs, depending on need.

CHAPTER 7

Recommendations for Future Research

Based on the findings from ACRP Project 02-60, the following data gaps regarding the use and potential impacts of AFFF containing PFASs at airports were identified and warrant further research. The data gaps have been listed in order (relative to representing an environmental concern) of being preventative, mitigative, and restorative.

Alternatives to AFFF Containing PFASs. There is a perceived need for the development of firefighting foam alternatives to AFFF that do not contain PFASs and can be used in the United States and Canada. The superior fire knockdown capabilities of AFFF are important from efficacy and safety perspectives. However, jurisdictions outside the United States and Canada have switched to non-fluorinated foams and/or foams that do not contain PFASs, and, while they do not meet the regulatory requirements of the FAA and Transport Canada, they are acceptable pursuant to the International Civil Aviation Organization's firefighting foam criteria. Moreover, even though the current regulations do not specify AFFF, the requirements for the foam (through MIL-SPEC or through Transport Canada) limit the types of products that can be used as true alternatives. Initial research into AFFF alternatives was conducted under ACRP 02-60 (and included as Appendix B); however, the scope of the project required identifying suitable AFFF alternatives available to airports within the United States and Canada. Further research is warranted on whether AFFF alternatives available outside North America can or should be acceptable (e.g., through specification requirement changes, product approvals, or advances in foam development).

Disposal Methods. The survey of airports conducted for this research identified a knowledge gap in how airports dispose of AFFF concentrate. Specifically, with changing regulations and increased awareness of the potential environmental impacts of AFFF containing PFASs (and, in particular, PFOS-containing AFFF), many airports interested in proactively making the switch to more environmentally friendly AFFF alternatives are wondering how to dispose of existing stock of PFOS- or PFOA-containing AFFF concentrate. Identified disposal options (e.g., return to manufacturer and incineration) may not be available or may be too costly, leaving airports to stockpile AFFF waste until more cost-effective options become available. Further research is recommended to identify viable, cost-effective disposal options.

Replacing AFFF in Existing Systems. Further research should evaluate whether residual PFASs bind to existing systems (e.g., hoses, storage containers, etc.). In the event that it is found that PFASs do bind to these systems, methods for eliminating residual PFASs should also be studied. Costs associated with these methods, which could include flushing the systems or full replacement, could be an element of this research.

Environmental Standards for AFFF. There are currently no standards for evaluating the environmental acceptability of a firefighting foam product. Further research into providing a standard that takes a more holistic approach to the potential long-term and short-term effects of these foams could be performed by looking at bioaccumulation, persistence, toxicity, and BOD/COD. A recognizable standard would assist airport representatives to more easily factor environmental considerations in the procurement, storage, application, and disposal of firefighting foam.

Evaluation of Existing Separation/Treatment Facilities for Processing Wastewater Impacted by PFASs. Responses to the survey indicated that some airports used existing glycol-water and/or fuel-water separation systems for pretreatment of wastewater impacted by PFASs prior to sending discharged foam solutions to a wastewater treatment facility. The efficacy of these systems in removing AFFF has not been studied, and it is not known whether amendments to these systems could foster adequate AFFF removal. Further research is also recommended to evaluate volume criteria for disposal in local water treatment facilities. Most local municipal or airport-specific water treatment plants may not be effective in processing large volumes of runoff impacted by PFASs following training, testing, or emergency response. The research will help airports assess the effectiveness and viability of disposing of waste impacted by PFASs (i.e., discharged AFFF/water mixtures) using existing facilities.

Understanding How Firefighting Can Be Optimized. Further research is recommended to identify how foam concentrate characteristics, equipment, and application techniques can be optimized to provide overall suppression performance equivalent to AFFF without the use of fluorochemicals. The literature suggests that application techniques can help compensate for limitations associated with specific foam concentrate characteristics. For example, in using non-film-forming foams, the ability of the foam to extinguish the fire (i.e., in the absence of the film formation typically provided by fluorocarbon surfactants) can be improved by adjusting other (e.g., mechanical) properties of the foam such as reducing the rate of water drainage in order to lower yield stress on the foam.

Broadly Applicable Analytical Methods. Current commercially available analytical methods do not quantify all PFASs, including precursors that may degrade and/or transform into more persistent daughter compounds. As a result, available standardized laboratory methodologies may be inadequate to fully characterize the nature and extent of the impacts of PFASs and the associated environmental risk and liability to an airport. Further research is recommended to assess the applicability of precursor analysis and total organic fluorine analysis and how the analytical results (as a better representation of concentrations of PFASs in environmental media) may influence the assessment of human health and ecological risk and the corresponding development of regulatory criteria for PFASs.

Environmental and Human Health Risks Associated with Short-Chain PFASs in AFFF. In response to evidence of potential environmental concern associated with some PFASs and subsequent changes in regulation, manufacturers have shifted to AFFF formulations that are created through telomerization using short-chain PFASs. Although the short-chain compounds of PFASs are thought to be less persistent and less bioaccumulative, limited research has evaluated the behavior of these compounds in the environment and/or the potential risks they pose to human health or the environment.

Collate User Data from the Screening Tool. As part of the ACRP Project 02-60 research, a screening tool was developed to assist airport representatives with understanding the potential risks involved in procuring, storing, handling, and disposing of AFFF at their sites. The screening tool ranks user responses and provides valuation that is non-contextual, as there is no scale for comparison. Further research could collate user inputs and their results, creating an airport-specific scale that could then provide ranking that is relevant to airport owners and operators, improving the applicability of the screening tool to evaluate potential risks related to PFASs.

Feasible, Cost-Effective Remediation Techniques and/or Approaches. The research showed that most remediation technologies did not work unilaterally for all PFASs, or had not been adequately demonstrated in field trials. It is recommended that prior to implementation of any remedial technology, feasibility studies be conducted during the remedial options process to allow airport managers to make decisions between the trade-offs of efficacy and cost.

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Abbreviations, Acronyms, Initialisms, and Symbols

AFFF	Aqueous film-forming foam
ANAB	ANSI-ASQ National Accreditation Board
APEC	Area of potential environmental concern
APFO	Ammonium pentadecafluorooctanoate
ARFF	Aircraft rescue and firefighting
ASTM	ASTM International
BOD	Biochemical oxygen demand
C_6	Carbon chain consisting of six carbons
C_8	carbon chain consisting of eight carbons
Ca_2+	Calcium ion
CALA	Canadian Association for Laboratory Accreditation Inc.
CARs	Canadian Aviation Regulations
CASRN	Chemical Abstract Services Registry Number
CEPA	Canadian Environmental Protection Act
CFR	Code of Federal Regulations
COD	Chemical oxygen demand
CSM	Conceptual site model
°C	Degrees Celsius
DEPA	Danish Ministry of the Environment
DoD	United States Department of Defense
EC50	Half maximal effective concentration (EC50) is the concentration of a substance that gives half-maximal response. Used as a measure of the substance's potency.
ELAP	Environmental Laboratory Accreditation Program
enHealth	Environmental Health Standing Committee (Australia)
EPTDS	Entry points to the distribution system
EQSD	Environmental Quality Standards Directive
EU	European Union
FCSAP	Federal Contaminated Sites Action Plan (Canada)
FFTA	Firefighting training area
FRB	Field reagent blank
FTOH	Flurorotelomer alcohol
FTS	Fluorotelomer sulfonic acid
GAC	Granulated activated carbon
GIS	Geographic information system
HDPE	High-density polyethylene
HPA	Health Protection Agency (UK)
IMAC	Interim maximum allowable concentration

ISE	Ion-selective electrode
ISO	International Organization for Standardization
kg	Kilogram
L	Liter
L-A-B	Laboratory Accreditation Bureau
LC-MS/MS	Liquid chromatography/tandem mass spectrometry
LC-QTOF-MS/MS	Liquid chromatography/quadrupole time of flight/tandem mass spectrometry
LC50	Lethal concentration at 50 percent. LC50 is the lethal concentration required to kill 50 percent of the population (longer-term exposure).
LD50	Lethal dose at 50 percent (LD50) is the amount of an ingested substance that kills 50 percent of a test sample (short-term exposure).
MAPA	Managing AFFF and PFASs at Airports (Screening Tool)
mg	Milligram
MIL-SPEC	United States Military Specification MIL-F-24385 (Fire Extinguishing Agent, Aqueous Film Forming Foam (AFFF), Liquid Concentrate, for Fresh and Seawater)
mL	Milliliter
MPC	Maximum permissible concentration
NCSAB	North Carolina Science Advisory Board
NFPA	National Fire Protection Association
ng	Nanogram
OEHHA	Office of Environmental Health Hazard Assessment (California)
PAC	Powdered activated carbon
PFAA	Perfluoroalkyl acid
PFASs	Perfluoroalkyl and polyfluoroalkyl substances
PFBA	Perfluorobutanoic acid
PFBS	Perfluorobutane sulfonic acid
PFCA	Perfluoroalykl carboxylic acid (e.g., PFOA)
PFCs	Perfluorinated compounds
PFHpA	Perfluoroheptanoic acid
PFHxA	Perfluorohexanoic acid
PFHxS	Perfluorohexane sulfonic acid
PFNA	Perfluorononanoic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PFOSA	Perfluorooctane sulfonamide
PFPeA	Perfluoropentanoic acid
PFSA	Perfluoroalkyl sulfonic acid
pH	Measure of the acidity or basicity of an aqueous solution
PHC	Petroleum hydrocarbon
PIGE	Particle-induced gamma-ray emission
PJLA	Perry Johnson Laboratory Accreditation
POCIS	Polar organic chemical integrative sampler
POP	Persistent organic pollutant
PPE	Personal protective equipment
PRB	Permeable reactive barrier
PTFE	Polytetrafluoroethylene
PVDF	Polyvinyl fluoride
QA/QC	Quality assurance/quality control
QPD	Qualified Products Database (U.S. Department of Defense)

RfD	Reference dose
RIVM	National Institute for Public Health and the Environment (Netherlands)
RO	Reverse osmosis
SCC	Standards Council of Canada
SDS	Safety data sheet
SDWA	Safe Drinking Water Act
SNUR	Significant New Use Rule
TDS	Technical data sheet
TGD	Technical Guidance Document
TOP	Total oxidizable precursor
TSCA	Toxic Substances Control Act
UCMR 3	Third Unregulated Contaminant Monitoring Rule
μg	microgram
UK	United Kingdom
UL	Underwriters Laboratory Inc.
UN	United Nations
UNEP	United Nations Environment Programme

Glossary

Bunded	A type of secondary containment around storage "where potentially polluting substances are handled, processed or stored, for the purposes of containing any unintended escape of material from that area until such time as remedial action can be taken" (Wikipedia).
Category A Airport	FAA ARFF Category airport that serves aircraft less than 90 feet in length.
Category B Airport	FAA ARFF Category airport that serves aircraft at least 90 feet but less than 126 feet in length.
Category C Airport	FAA ARFF Category airport that serves aircraft at least 126 feet but less than 159 feet in length.
Category D Airport	FAA ARFF Category airport that serves aircraft at least 159 feet but less than 200 feet in length.
Category E Airport	FAA ARFF Category airport that serves aircraft at least 200 feet in length.
Class B Fire	Fires whose fuel is flammable or combustible liquid or gas (e.g., gasoline, diesel fuel, petroleum oil, paint, propane, butane).
Designated Airport	Per Transport Canada, an airport at which the total of the number of passengers that are enplaned and the number of passengers that are deplaned is more than 180,000 per year.
Exposure Pathway	Pathway through which receptor(s) would be exposed to contaminants of concern.
Fluorotelomer	Fluorocarbon-based oligomers, or telomers, synthesized by telomerisation.
Hydrophilic	A compound that is polar, that is attracted to water.
Hydrophobic	A compound that is non-polar, that is not attracted to water.
Long-chain	Perfluoroalkyl carboxylic acids (PFCAs) with eight carbons and greater (i.e., with seven or more perfluorinated carbons); perfluoroalkyl sulfonic acids (PFSAs) with six carbons and greater (i.e., with six or more perfluorinated carbons).
Oleophobic	A compound that is repelled from oil.
Participating Airport	In Canada, an airport, other than a designated airport, for which a critical category for firefighting is specified in the Canada Flight Supplement (Transport Canada).
Perfluorinated	The replacement of all hydrogens by fluorine in the aliphatic chain structure.
Polyfluorinated	The replacement of most hydrogens by fluorine in the aliphatic chain structure.

Receptor	A human or ecological receptor that would be exposed to the contaminant of concern.
Short-chain	Perfluoroalkyl carboxylic acids (PFCAs) with less than eight carbons and perfluoroalkyl sulphonates (PFSAs) with less than six carbon molecules.
Source	A chemical found at such concentration to be of potential concern to human health or the environment.
Surfactant	A substance that tends to reduce the surface tension of a liquid in which it is dissolved.

APPENDIX A

Survey Methodology and Findings

CONTENTS

[1] Attachment C is not published herein but is available upon request from Cooperative Research Programs Senior Program Officer Joe Navarrete, at jnavarrete@nas.edu.

I. INTRODUCTION

The research findings presented in this report derive from a survey of North American airports that was commissioned by Dillon Consulting on behalf of the Airport Cooperative Research Program and conducted by JD Franz Research of Sacramento. Encompassing 167 completed interviews, the survey commenced on December 7, 2015 and was concluded on February 18, 2016. One additional airport was contacted as late as March 7 due to a miscommunication, and that final interview was completed.

The primary purpose of the survey was to determine how airports manage Aqueous Film-Forming Foam, or AFFF. Primary areas of inquiry were as follows:

- Criteria for the procurement of AFFF
- Nature of the places AFFF is stored
- Manner in which AFFF is removed from firefighting equipment or systems
- Extent and nature of foam tests at airports
- Use and disposition of AFFF during foam tests
- Circumstances under which AFFF is replaced
- Manner of disposing of AFFF
- Manner of handling AFFF
- Prevalence of firefighter training at airports
- Use and disposition of AFFF during firefighter training
- Protective gear used in handling AFFF
- Best management practices for preventing spills of AFFF
- Use of AFFF in actual airport firefighting
- Extent to which airports have histories of known contamination from firefighting
- Nature and outcomes of the contamination
- Prevalence, nature, and results of environmental studies relative to the release of AFFF into the environment
- Awareness and use of alternative formulations of AFFF
- Additional comments

Following this Introduction, the report is divided into two additional sections. **Section II** contains a detailed discussion of the **Research Methods** used in conducting the survey, while **Section III** presents and discusses the **Findings**.

For reference, there are also five attachments. **Attachment A** contains a copy of the **Survey Instrument** that is was used in conducting the research, while **Attachment B** includes **Detailed Data Tabulations for All Responding Airports. Attachment C** presents **Verbatim**

Transcriptions of Open-Ended Responses to all of the survey's questions of this nature.[2] **Attachment D** contains **Statistically Significant Cross-Tabulations by County**, and **Attachment E** includes **Statistically Significant Cross-Tabulations by Airport Size**.

[2] Attachment C is not published herein but is available upon request from Cooperative Research Programs Senior Program Officer Joe Navarrete, at jnavarrete@nas.edu.

II. RESEARCH METHODS

Instrument Design

The instrument that was used to conduct this survey was designed by the President of JD Franz Research in consultation with representatives of Dillon Consulting and Mead & Hunt. After several rounds of review and revision, the instrument was tested at three airports by Dillon and Mead & Hunt personnel. As these test interviews did not reveal any major problems, the final draft of the instrument was accepted for implementation.

During subsequent interviewing, it became apparent that one question was not necessarily clear to respondents. This question was then modified for clarification, but not to the extent that the meaning was altered.

The final questionnaire contained 42 questions, 16 of them open-ended. The average interview length was 21 minutes.

Sample Selection

The sample for the survey was provided by Dillon and was based on the population information included in the Amplified Work Plan for the project prepared in August, 2015. (*National Academy of Sciences: Airport Cooperative Research Program. Amplified Work Plan – ACRP 02-60: Use and Potential Impacts of AFFF Containing PFASs at Airports, Page 12.*) Consistent with the proposed approach that emphasized larger airports, the sample included all of the airports in ARFF Categories C (90 airports), D (28 airports), and E (30 airports).

The overall sample was then rounded out by adding proportional samples of airports in Categories A and B to create a total sample of 229. After the sample was adjusted by the call center administering the interviews to account for duplications, the net sample was 225.

Interviewer Training

All of the staff conducting the survey were experienced business-to-business interviewers with Pacific Market Research (PMR) in the Seattle area. PMR has an extensive airport interviewing background, both as a subcontractor to JD Franz Research and as the data collection contractor for the Seattle-Tacoma International Airport.

Interviewer training at PMR includes instruction in interviewing techniques, orientation to the mechanics of sample selection and recording, use of the firm's Computer Assisted Telephone Interviewing (CATI) software, and comprehensive practice with survey instruments as well as with a systematic approach to answering respondents' inquiries. The briefing for this particular survey, which included an in-depth introduction to the subject matter as well as a question-by-question review of the instrument, was conducted by the President of JD Franz Research.

Survey Implementation

Interviewing for the survey was conducted from PMR's centralized, CATI-equipped, and fully monitored facility. All of the interviewing took place under the ongoing oversight of full-time supervisors. Calls were placed during regular business hours, local airport time, unless a potential respondent requested otherwise. Customary calling hours were 6:45 a.m. to 1:45 p.m. Pacific time.

Upon completion of each interview, a supervisor checked it for accuracy, clarity, and completeness. Further review was subsequently undertaken by the President of JD Franz Research (qualitative results) and the firm's Vice President & Data Analysis Manager (quantitative data). In cases where there were problems or concerns, respondents were called back for clarification or amplification.

Up to 17 attempts were made to reach a potential respondent at each airport in the sample. When respondents referred interviewers to another individual for the answers to one or more of the survey questions, attempts were also made to contact and interview these individuals.

From the 225 unduplicated cases with viable telephone numbers, 167 interviews were completed. Given a total population of 580 airports, the margin of error for the survey at the 95 confidence level is ± 6.4 percent.

The response rate for the survey based on the net sample size of 225 is 74 percent, which is generally viewed as being very good to excellent. Only eleven of the airport representatives who could be contacted actually refused to cooperate and complete the interview; three people terminated the interview before they finished it. This level of breakoffs is also a very good result.

Distribution of the Completed Interviews

Table 1 shows the distribution of the survey responses by country. As this chart indicates, most of the interviews were completed in the United States, and the response rate for that country was also higher. In both countries, however, the level of response exceeded the 50 percent rate that is the mathematical limiting case and that also represents the majority of the sample. Assuming the sample is representative, it is reasonable to conclude with a majority response that the results are representative as well.

Table 1

DISTRIBUTION OF RESPONSES BY COUNTRY

	Unduplicated Valid Sample	Completed Interviews	Percent of Sample
United States	199	149	75%
Canada	26	18	69%
Total	**225**	**167**	**74%**

Table 2 portrays the distribution of the responses by airport size. Here again, all of the response rates are majorities, with the largest, perhaps not surprisingly, representing the smallest airports. Even among the largest airports, however, more than half of those sampled participated. The largest absolute number of airports can be found in Category C; the smallest number is in Category E.

Table 2

DISTRIBUTION OF RESPONSES BY AIRPORT SIZE CATEGORY

	Unduplicated Valid Sample	Completed Interviews	Percent of Sample
Category A	48	40	83%
Category B	29	22	76%
Category C	90	69	77%
Category D	28	19	68%
Category E	30	17	57%
Total	**225**	**167**	**74%**

Finally, **Table 3** depicts the distribution of the responses by country and airport size. As would be expected, by far the majority of the results consists of United States airports. According to the data presented in the Amplified Work Plan for the project, 9 percent of the target audience of airports is Canadian; the result is actually slightly greater at 11 percent.

Airports in Category C predominate in the United States; those in Category B predominate in Canada, although the Canadian numbers are small enough that differences are not particularly meaningful. In the United States, the smallest group of airports is found in Category E; in Canada, there is almost no differentiation among categories.

Table 3

DISTRIBUTION OF RESPONSES BY COUNTRY AND AIRPORT SIZE CATEGORY

	United States		Canada		Combined	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Category A	37	22%	3	2%	40	24%
Category B	17	10%	5	3%	22	13%
Category C	65	39%	4	2%	69	41%
Category D	16	10%	3	2%	19	11%
Category E	14	8%	3	2%	17	10%
Total	**149**	**89%**	**18**	**11%**	**167**	**100%**

Data Coding, Tabulation, and Analysis

Coding

Coding of the survey's closed-ended questions was accomplished by the interviewers as they conduct the interviews. Coding of the survey's open-ended questions was then undertaken by the President of JD Franz Research, who reviewed all of the responses to each question, developed the appropriate codebooks, and coded the responses. Thirty percent of this coding was then checked and validated by the Vice President and Data Analysis Manager.

Given that the number of "other" responses is relatively small, it was not deemed necessary to undertake a common next step, namely of attempting to add new codes and decrease the proportions of "other." For reference in the event the reader is interested, however, all of the responses to each of the open-ended questions can be found in Attachment C[3].

Interpretation of the Coded Data

As the reader is reviewing the coded data, it is important to bear in mind that the open-ended questions in this survey were extremely broad in nature and had the potential to encompass a wide variety of subtopics. In addition, there were no specific probes interviewers were instructed to use if all possible subtopics were not addressed.

Although this approach posed some challenges, it was an intentional aspect of the research design for two reasons: first, because no one on the research team knew with any precision what all of the possible answers might be (a prerequisite for constructing more

[3] Attachment C is not published herein but is available upon request from Cooperative Research Programs Senior Program Officer Joe Navarrete, at jnavarrete@nas.edu.

closed-ended items), and second, because alternative designs would have greatly added to an already lengthy interview. As a result, some people addressed one aspect of a question while others addressed a different one.

A few of the data tables could therefore be a bit misleading in a purely quantitative sense. This is particularly true of Table 8 (processes and solutions for removing AFFF from firefighting equipment or systems), where some respondents explained the manner of offloading the foam, others talked about where the resulting foam was stored, and still others mentioned the ultimate disposition of the foam. This suggests that the percentages in the table are not the kinds of absolute values one might find in a purely quantitative design, but rather the more relative values of a qualitative formulation.

Tables 11 and 16 were structured somewhat differently in an attempt to overcome this challenge by developing subcategories of responses, but even these subcategories are likely only quantitatively valid in comparison with one another. In all of these instances, then, we would encourage the reader to review the verbatim responses in Attachment C[4], which tend to give a more thorough picture of what is actually transpiring in the field. We also believe that if truly quantitative data are needed to understand airport practices in areas such as these, additional study may be required.

Analysis of the Data by Country and Airport Size

In order to understand how practices and experiences might differ in the two participating countries (the United States and Canada) and across airport size categories, all of the quantitative data were cross-tabulated by these two sets of independent variables and tested for statistical significance using the chi-square technique.[5] All of the statistically significant results ($p<.05$) were then further examined to identify results with managerially or practically important differences and to exclude those with extremely small sub-sample sizes.

The results of this analysis are presented in the following section of this report following the discussions of the main findings for the applicable questions. All of the statistically significant cross-tabulations can be found in Attachment D (country) and Attachment E (airport size).

[4] Attachment C is not published herein but is available upon request from Cooperative Research Programs Senior Program Officer Joe Navarrete, at jnavarrete@nas.edu.
[5] Although it is possible to cross-tabulate qualitative survey findings, the statistical techniques have in our opinion yet to be perfected. In addition, the results are difficult to interpret and commonly of limited utility.

III. FINDINGS

Findings from the survey are presented here in the same order in which the questions were posed to airport representatives. Readers who are interested in the precise phrasing of the inquiries are invited to consult the copy of the survey instrument that can be found in Attachment A.

AFFF Procurement Criteria

Table 4 displays airports' answers when they were asked about their most important procurement criteria for the acquisition of AFFF. By far the most prominent criterion mentioned is complying with government regulations. This is followed by cost or price, the use of an external purchasing agency or organization, the availability of sufficient quantities, and the use of a required list of vendors.

Table 4

MOST IMPORTANT CRITERIA FOR AFFF PROCUREMENT

	Frequency	Percent
Compliance With Government Regulations (FAA, Transport Canada, Mil Spec, Three Percent, Regulation 139)	109	65.7
Cost Or Price/Have A Budget To Meet/ Request Prices From Three Vendors/Have To Take Winning Bid/Product Is Expensive	61	36.7
Handled By A Purchasing Agent/Other Agency/ Other Organization	13	7.8
Availability Of Sufficient Quantities	12	7.2
Required To Use A List Of Vendors Provided By The Military/DOD/State/City	12	7.2
Consistency Of Brand To Avoid Mixing Brands And Resulting Compatibility Issues	7	4.2
Availability In A Timely Manner	5	3.0
Environmental Considerations	3	1.8
Other	21	12.7
Don't Know	2	1.2

Characteristics of AFFF Storage

Figure 1 presents the mean existence of various characteristics of the places where AFFF is stored on a four-point scale where one equals none and four equals all. As this graphic indicates, storage areas are most likely to be enclosed, be covered, and have a cement or concrete floor. Least likely to characterize the places where AFFF is stored are double containment, underground storage tanks, and earth or gravel floors.

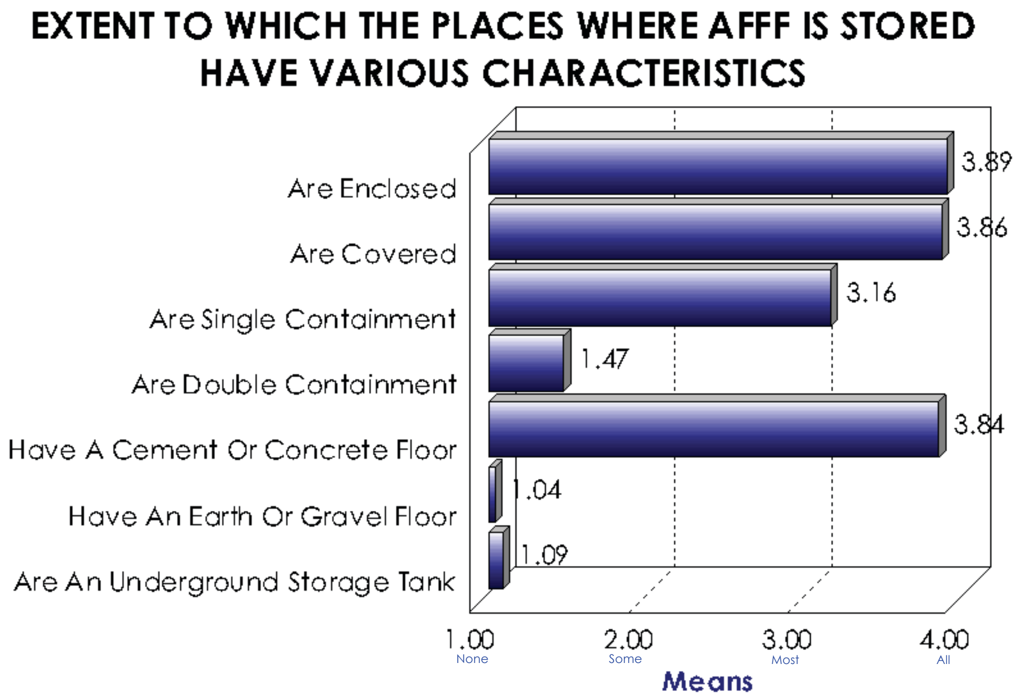

Figure 1

The extent to which the places where AFFF is stored are enclosed varies by country, as shown in **Table 5**. Enclosed storage is substantially more common in the United States than it is in Canada.

Table 5

EXTENT TO WHICH AFFF STORAGE IS ENCLOSED BY COUNTRY

	US	Canada
	Percent	
None	.7	11.1
Some	.7	5.6
Most	3.4	5.6
All	95.3	77.8

(p=.003)

The extent to which double containment is used for AFFF storage varies by airport size, as **Table 6** indicates. While the relationship is not linear, the larger airports are more likely than the smaller ones to use double containment. The total absence of double containment is most likely to be the case among Category B airports and least likely to be the case among those in Category D.

Table 6

EXTENT TO WHICH AFFF STORAGE IS DOUBLE CONTAINMENT BY AIRPORT SIZE

	Category A	Category B	Category C	Category D	Category E
	Percent				
None	82.5	90.9	84.1	57.9	70.6
Some	5.0	-	4.3	21.1	5.9
Most	-	-	-	-	5.9
All	12.5	9.1	11.6	21.1	17.6

(p=.048)

The extent to which the places where AFFF is stored have earth or gravel floors varies by country, as **Table 7** demonstrates. Canadian airports are more likely than American airports to have such floors in their storage areas.

Table 7

EXTENT TO WHICH AFFF STORAGE AREAS HAVE EARTH OR GRAVEL FLOORS BY COUNTRY

	US	Canada
	Percent	
None	99.3	88.9
Some	-	5.6
All	.7	5.6

(p=.003)

Processes and Solutions for Removal of AFFF from Equipment or Systems

Table 8 portrays the processes or solutions airports said they use when AFFF needs to be removed from firefighting equipment or systems. Most prevalent among the responses is noting that the foam is drained or pumped into containers. This is followed by pumping the foam out with an unspecified type of pump, draining it out by using gravity, and pumping it with a mechanical or electric pump.

Table 8

PROCESSES AND SOLUTIONS FOR REMOVING AFFF FROM EQUIPMENT OR SYSTEMS

	Frequency	Percent
Drained Or Pumped Into Containers (Training Pit, Trailer, Holding Tank, Drums, Barrels, Totes)	89	53.3
Pumped From The Truck – Mechanism Not Specified	70	41.9
Drained From The Truck/Gravity Fed From Truck	30	18.0
Pumped By Mechanical Or Electric Pump From The Truck	24	14.4
Have Never Done This	13	7.8
Use The Nozzles On The Truck	7	4.2
Flushed And Treated As Runoff/Diluted With Water	7	4.2
Pumped By Hand From The Truck	6	3.6
It Is Flushed Out And Contained	4	2.4
Other	14	8.4
Don't Know	5	3.0

Conduct of Foam Tests

As shown in **Figure 2**, almost all airports conduct foam tests, meaning tests of both the AFFF foam mixture and the equipment. Only two percent do not.

EXTENT TO WHICH AIRPORTS CONDUCT FOAM TESTS

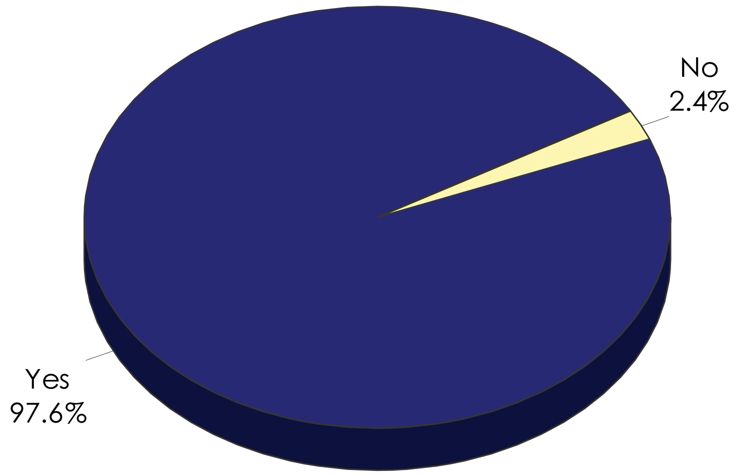

Figure 2

Figure 3 indicates that a majority of the airports that conduct foam tests do so between every six months and once a year; the second largest group conducts such tests every four to six months. When these figures are summed, they total almost nine in ten airports (88 percent).

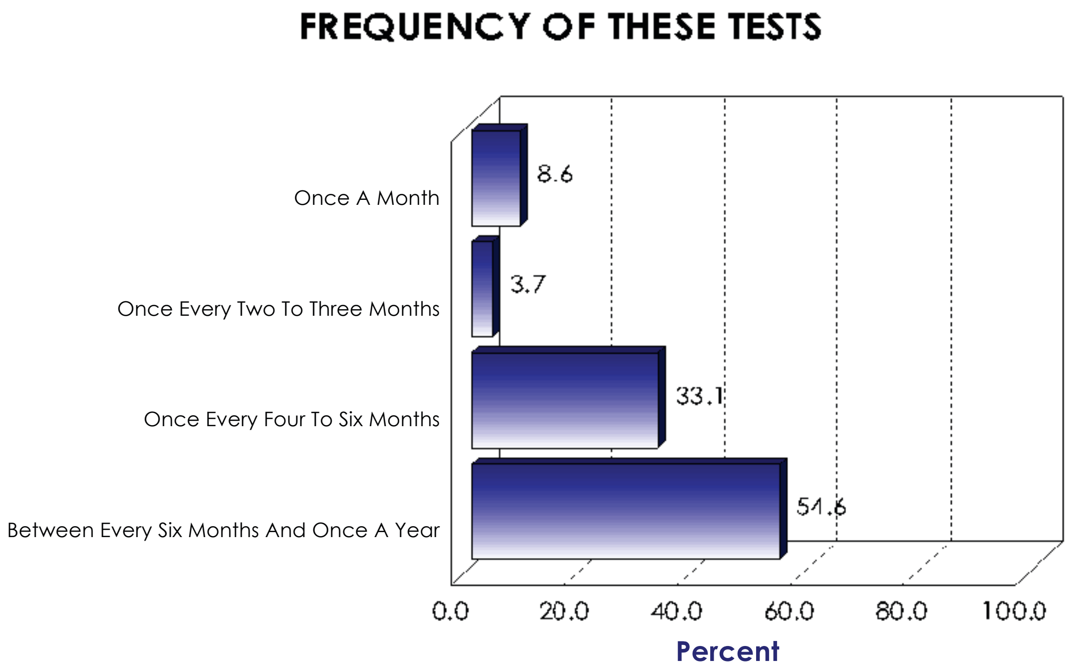

Figure 3

The frequency of foam testing varies by country, as illustrated in **Table 9**. Almost all Canadian airports conduct these tests between every six months and once a year. In the United States, the frequency of testing is considerably more variable.

Table 9

FREQUENCY OF FOAM TESTING BY COUNTRY

	US	Canada
	Percent	
Once A Month	9.7	-
Once Every Two To Three Months	4.1	-
Once Every Four To Six Months	36.6	5.6
Between Every Six Months And Once A Year	49.7	94.4

(p=.005)

Foam testing frequency also varies by airport size, as portrayed in **Table 10**. With the exception of airports in Category E, testing between every six months and once a year decreases with increasing size, while testing once every four to six months increases with increasing size.

Table 10

FREQUENCY OF FOAM TESTING BY AIRPORT SIZE

	Category A	Category B	Category C	Category D	Category E
	Percent				
Once A Month	10.0	-	10.4	10.5	6.3
Once Every Two To Three Months	-	-	4.5	15.8	-
Once Every Four To Six Months	22.5	38.1	38.8	42.1	18.8
Between Every Six Months And Once A Year	67.5	61.9	46.3	31.6	75.0

(p=.039)

As illustrated in **Figure 4**, only seven percent of airports conduct tests of hangar foam systems. More than nine in ten do not.

EXTENT TO WHICH AIRPORTS THAT CONDUCT FOAM TESTS TEST HANGAR FOAM SYSTEMS

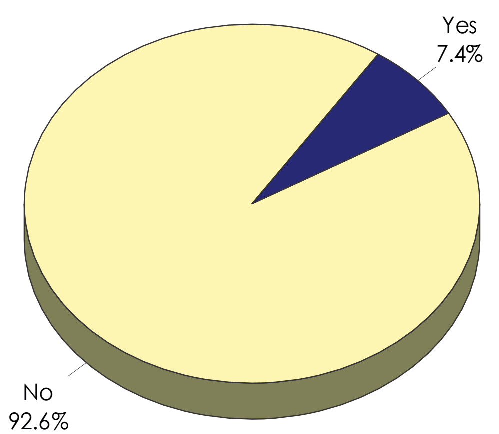

Figure 4

Among airports that conduct hangar foam system tests, as demonstrated in **Figure 5**, about nine in ten test both the sprinkler system and the foam generation system. The remaining about ten percent test only the sprinkler system. No airports test only the foam generation system.

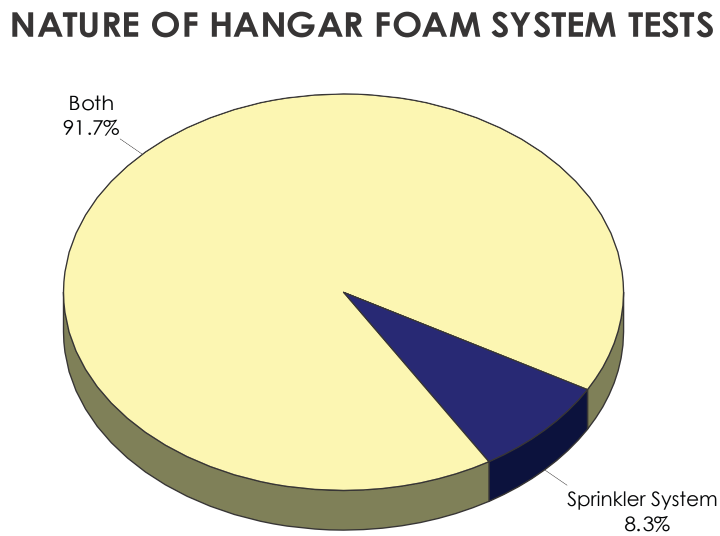

Figure 5

Figure 6 shows that over two-thirds of airports discharge the AFFF used in foam tests onto the ground. Only about a third discharges it into an engineered containment system.

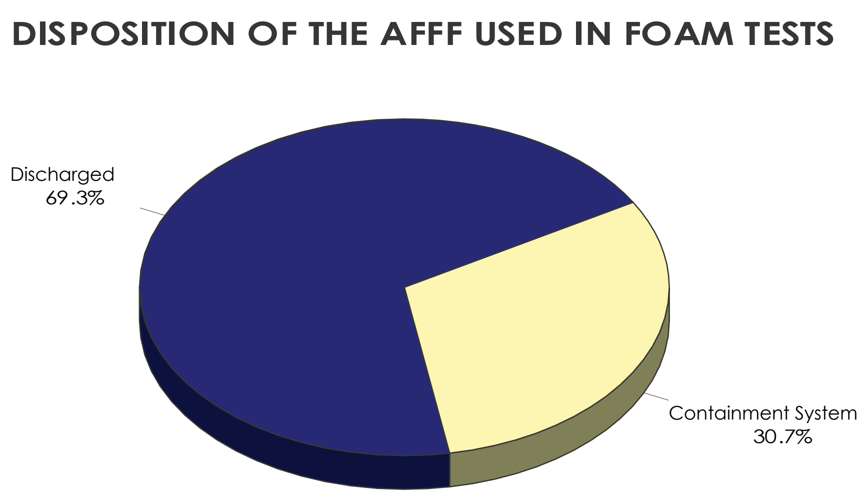

Figure 6

Table 11 presents airports' descriptions of the engineered containment systems that are used in collecting the AFFF used in foam tests. For clarity, these responses have been subdivided into two categories: those that relate to capture and containment and those that address disposition.

The latter category is quite small and does not appear to suggest any particularly prominent practices. With respect to the former, the leading answers are capture in a small or non-permanent vessel and capture in a more durable facility. In third place is the use of some type of separator.

Table 11

ENGINEERED CONTAINMENT SYSTEMS USED FOR COLLECTING AFFF FROM FOAM TESTS

	Frequency	Percent
Capture and Containment:		
Captured In Container/Bucket/Inflatable Pool/ Tub/Specimen Cup	18	36.0
Captured In Collection Facility/Containment Basin/Collection Tanks/Concrete Tub/Wash Pit/ Fire Pit/Training Pit	14	28.0
Use Separator (Water/Foam, Oil/Water)/ Scrubbing System	10	20.0
Sprayed Onto A Target/Contained Area	4	8.0
Disposition:		
Released To Sewer System	3	6.0
Someone Else Handles This/Another Organization Handles This	3	6.0
Goes To Treatment Plant/Sanitary System	2	4.0
Other	10	20.0
Don't Know	2	4.0

Disposal of AFFF

Figure 7 displays the proportions of airports that indicated they replace AFFF under various circumstances. As this chart illustrates, all of the listed circumstances lead to replacement at the majority of airports. Most likely to prompt replacement are use of AFFF during emergency situations, use of AFFF in testing or maintaining equipment, and loss due to spills.

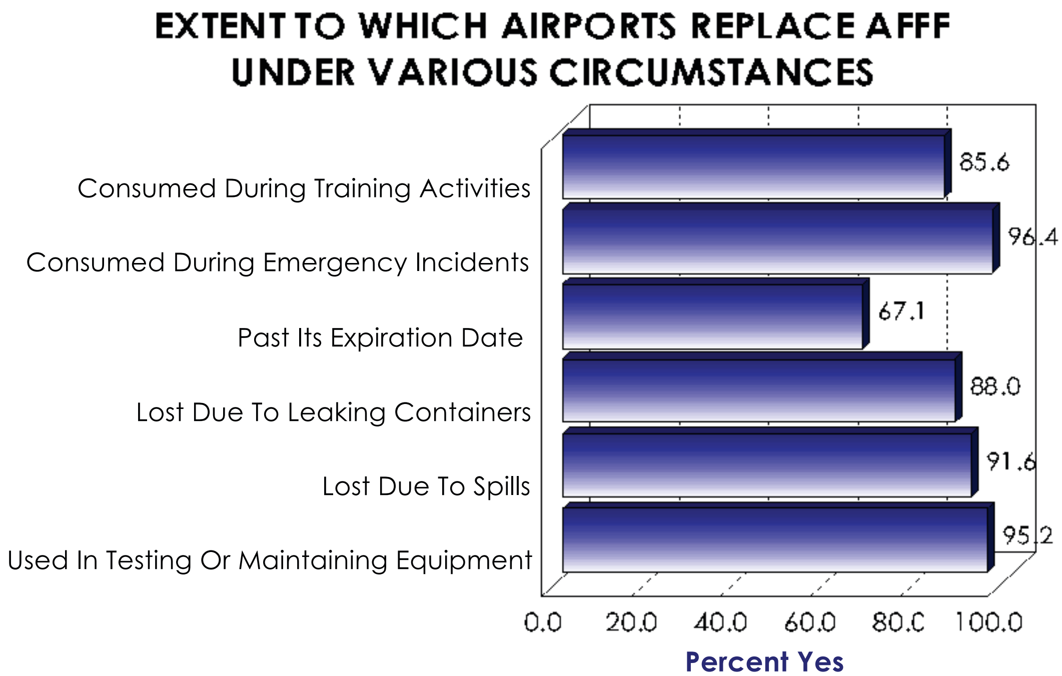

Figure 7

Figure 8 indicates that close to one in five airports replace AFFF in circumstances other than those listed in the previous question. These circumstances are depicted in **Table 12**. Chief among them are providing AFFF in mutual aid to another agency and situations in which the AFFF fails testing or doesn't work.

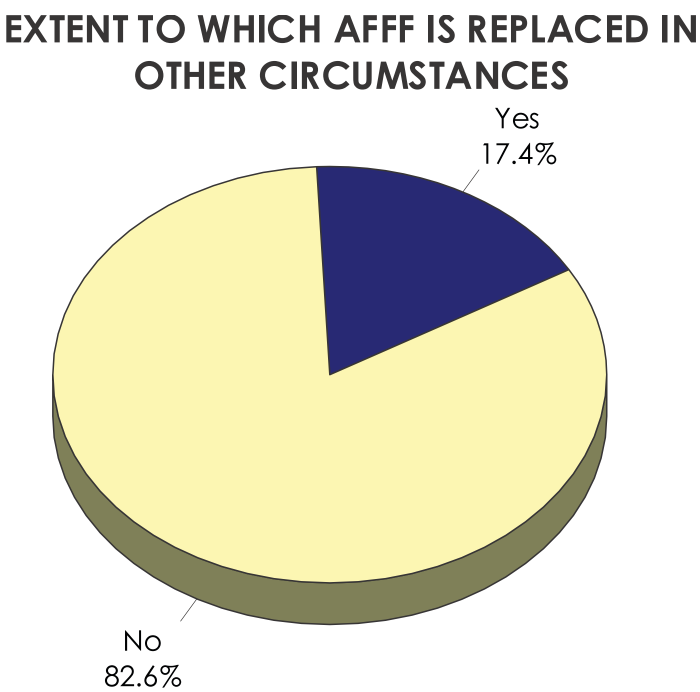

Figure 8

Table 12 OTHER CIRCUMSTANCES IN WHICH AFFF IS REPLACED		
	Frequency	Percent
Given To Another Agency When They Needed It	5	17.2
Foam Fails Testing Or Doesn't Work	5	17.2
Breakdown Of Equipment With Foam Loss Or Contamination	3	10.3
Inventory Goes Below Required Minimum	3	10.3
Foam Gets Contaminated	3	10.3
Bad Batch/Manufacturer Buyback/Manufacturer Recall	2	6.9
Used In An Emergency	2	6.9
Other	6	20.7

Figure 9 shows the mean extent to which airports dispose of spent or unused AFFF in various ways. The data in this figure are calculated on a scale of one to five where one equals never and five equals always. As this graphic illustrates, none of the listed disposal methods

even achieve the level of "rarely," and half are closer to the level of "never." Most prominent are using a wastewater management contractor and letting it infiltrate into the soil.

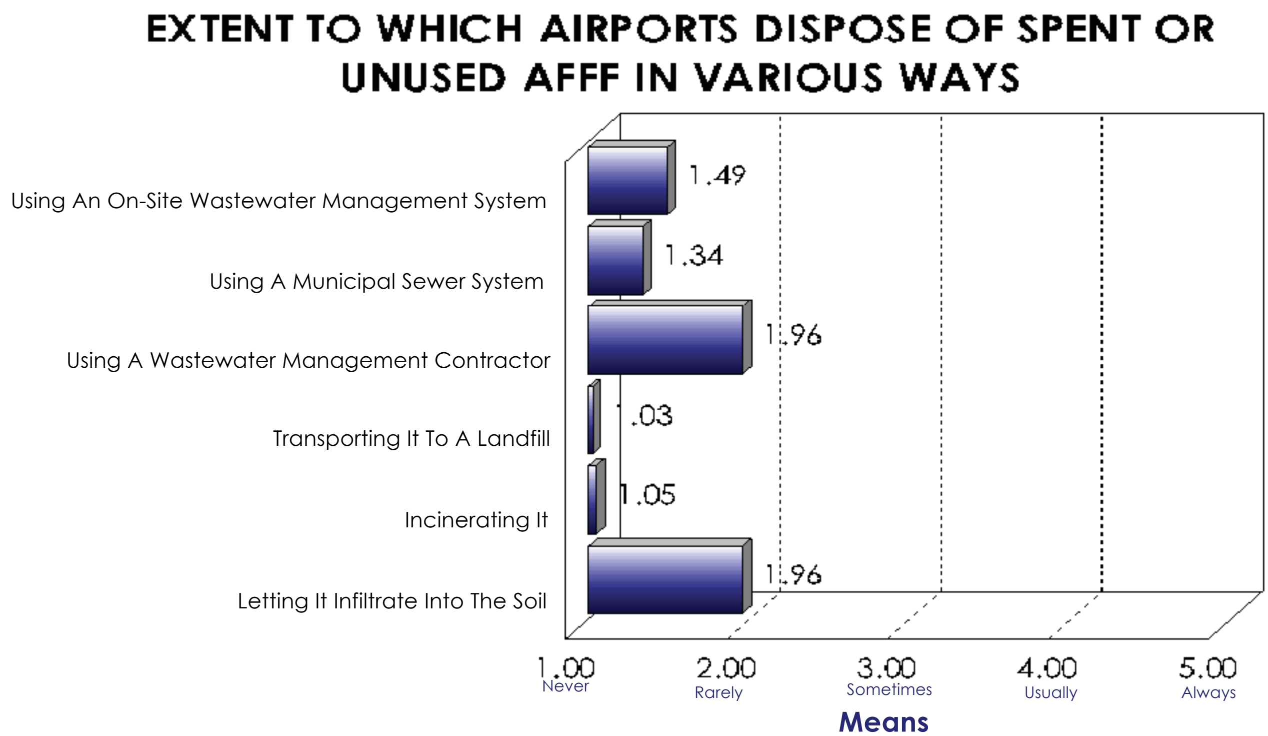

Figure 9

The use of wastewater management contractors varies by country, as portrayed in **Table 13**. Airports in the United States are substantially less likely than their counterparts in Canada to use such services.

Table 13

USE OF WASTEWATER MANAGEMENT CONTRACTORS BY COUNTRY

	US	Canada
	Percent	
Never	71.8	33.3
Rarely	5.4	11.1
Sometimes	6.0	11.1
Usually	1.3	11.1
Always	15.4	33.3

(p=.006)

Handling Materials That Come Into Contact With AFFF

Figure 10 illustrates the mean degree to which airports handle containers and other materials that come into contact with AFFF in various ways. Here again, the scale contains five points ranging from one for never to five for always. In this instance, one of the approaches – storing the materials on-site – almost achieves the level of "sometimes," and another – using a hazardous waste disposal facility – is above the level of "rarely." The remaining three strategies are below, although close to, the level of "rarely."

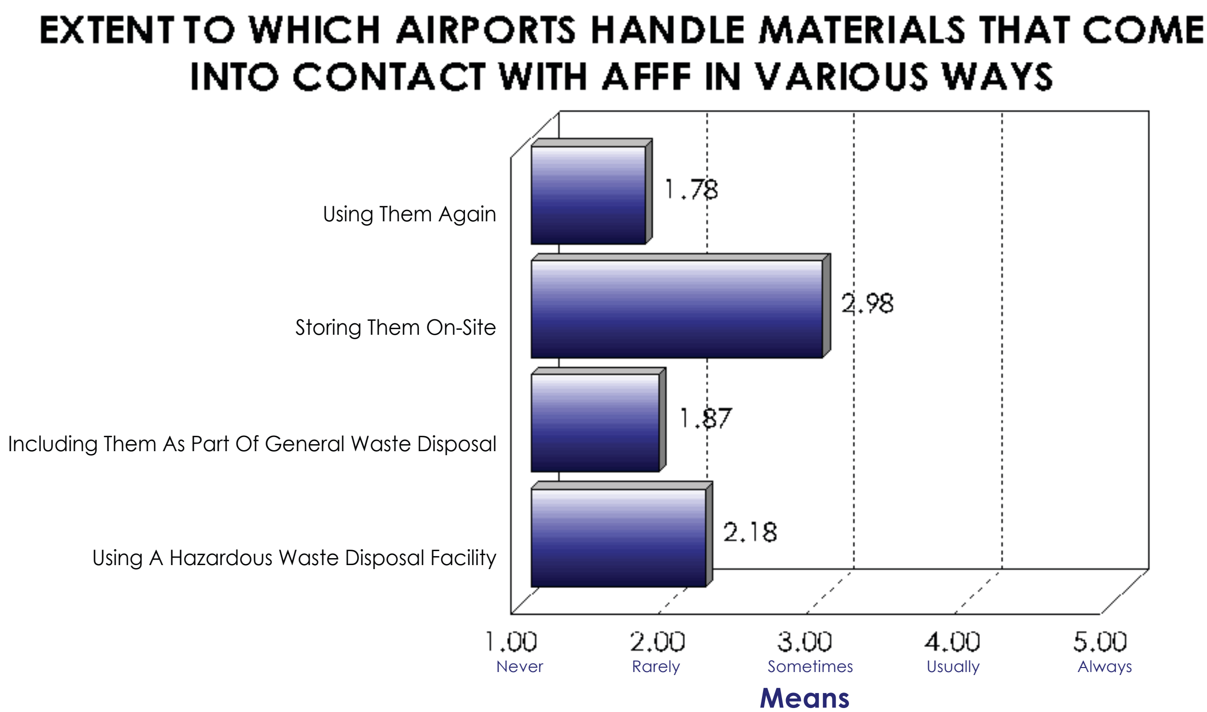

Figure 10

On-site storage of materials that come into contact with AFFF varies by country, as **Table 14** indicates. United States airports are noticeably more likely never to do so but also somewhat more likely always to do so. Answers of never and rarely total close to half (45 percent) in the United States versus a third (33 percent) in Canada. Responses of usually or always sum to about two-fifths (42 percent) in the United States and the majority (56 percent) in Canada. Thus it would appear that, overall, this practice is more prevalent in Canada than it is in the United States.

Table 14

EXTENT TO WHICH AIRPORTS HANDLE MATERIALS THAT COME INTO CONTACT WITH AFFF ON-SITE BY COUNTRY

	US	Canada
	Percent	
Never	40.9	27.8
Rarely	4.0	5.6
Sometimes	12.8	11.1
Usually	4.0	22.2
Always	38.3	33.3

(p=.044)

Firefighter Training

As depicted in **Figure 11**, close to nine in ten airports have held firefighter training on their premises at some point in time. Of these, as illustrated in **Figure 12**, the majority have used AFFF in selected training exercises. Almost a quarter, on the other hand, have not used AFFF in any training exercises.

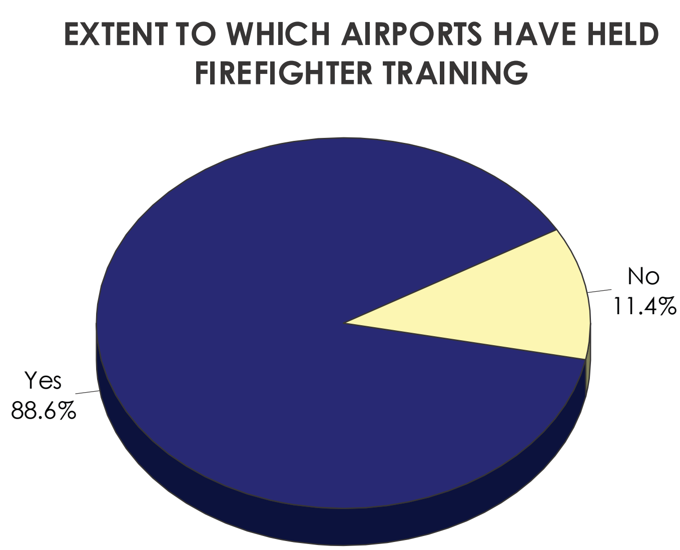

Figure 11

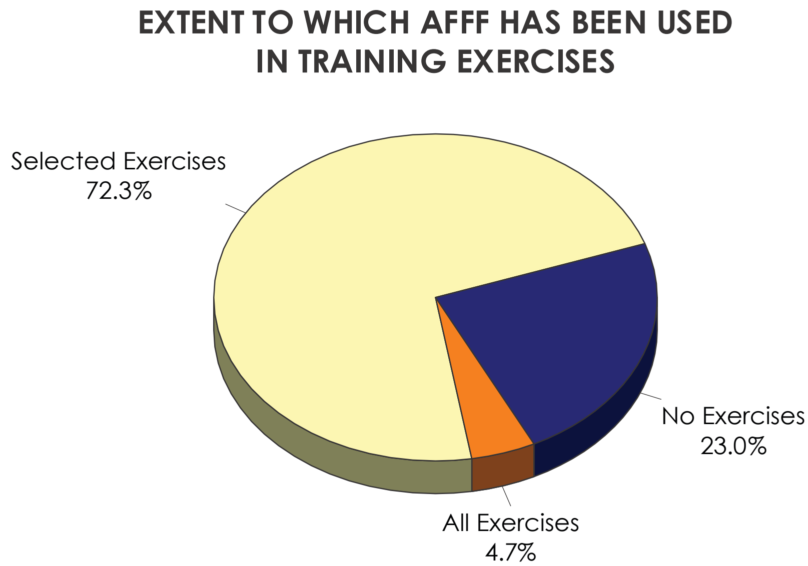

Figure 12

Figure 13 shows that by far the majority of the airports using AFFF in firefighter training discharge it onto the ground. Slightly over one in five discharge it into engineered containment systems.

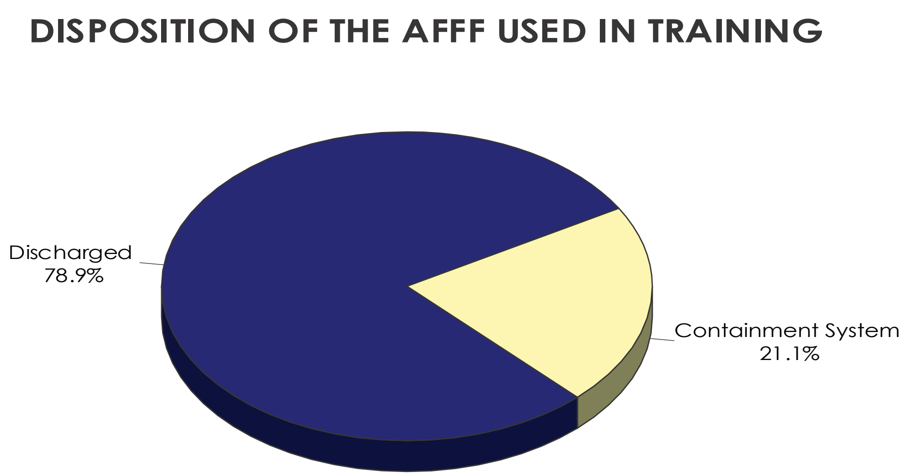

Figure 13

Table 15 portrays the manner in which the AFFF discharged during training has been handled. The most prevalent response is that it is discharged onto the ground and left to evaporate, dissolve, or dissipate. This is followed by discharging the material onto the ground where it is left to soak in or infiltrate and by discharging it onto the ground and diluting it.

Table 15

MANNER IN WHICH THE AFFF DISCHARGED DURING FIREFIGHTER TRAINING IS HANDLED

	Frequency	Percent
Discharged Onto The Ground And Left To Evaporate, Dissolve, Or Dissipate	32	35.6
Discharged Onto The Ground/Soil And Left To Soak In Or Infiltrate	23	25.6
Discharged Onto The Ground And Diluted	16	17.8
Sent To Or Handled By Hazardous Waste Treatment	6	6.7
Discharged Onto The Ground And Contained Or Cleaned Up	6	6.7
Discharged Onto The Ground – No Specifics of Outcome	5	5.6
Discharged Into A Fire Training Pit	2	2.2
Discharged Into Wastewater Treatment System	2	2.2
It Is Environmentally Safe	2	2.2
Other	6	6.7
Don't Know	2	2.2

Table 16 displays airports' descriptions of the engineered containment systems that are used in collecting the AFFF used in firefighter training. Here again, these responses have been subdivided into two categories: those that relate to capture and containment and those that address disposition.

As previously, the second category contains relatively few responses. Leading practices appear to be sending the foam to a retention pond or tank and dispersing the foam in a way that is not detailed, although the numbers involved here are so small that they should be treated with considerable caution. In the first category, the most prominent answers are capturing the material in a collection facility or training pit and using some type of separator.

Table 16

ENGINEERED CONTAINMENT SYSTEMS USED FOR COLLECTING AFFF FROM FIREFIGHTER TRAINING

	Frequency	Percent
Capture and Containment:		
Captured In Collection Facility/Training Pit	16	66.7
Use Separator (Water/Foam, Oil/Water)/Water Reclamation System	9	37.5
Dispersed Onto A Paved Surface	2	8.3
Disposition:		
Goes to Retention Pond/Tank	4	16.7
Dispersed or Released – Unclear Where	3	12.5
Vacuumed Up With Vacuum Truck	2	8.3
Taken Away By Contractor	2	8.3
Goes To Treatment Plant/Sanitary System	2	8.3
Other	3	12.5

Staff and Trainee Handling of AFFF

Figure 14 illustrates the extent to which staff and trainees who handle AFFF wear various types of protective gear when doing so. As this illustration indicates, almost all airports outfit those handling AFFF with work gloves and eye protection; strong majorities provide safety boots, turnout gear, and fire-retardant clothing. Substantially less likely to be used are nitrile or other one-time-use gloves.

Figure 14

Best Management Practices for Preventing Spills during AFFF Handling

Table 17 presents airports' assessments of the best management practices for preventing spills during the handling of AFFF. The two leading practices, mentioned by equal numbers of airports, are taking one's time or using caution and using some form of containment or containers. These are followed by providing thorough training on procedures, making sure connections are correct or tight, and actually following procedures.

Table 17

BEST MANAGEMENT PRACTICES FOR PREVENTING SPILLS

	Frequency	Percent
Use Caution/Be Careful/Take Your Time/Pay Attention/Attend To Detail	36	21.6
Use Containment/Containers	36	21.6
Provide Thorough Training On Procedures	27	16.2
Make Sure Connections Are Correct/Are Tight	26	15.6
Follow Procedures	26	15.6
Use Pumps	20	12.0
Have Clear Procedures/Checklists	20	12.0
Use The Right Equipment/Make Sure Equipment Is Set Up Properly	19	11.4
Do Not Do It Alone/Involve Multiple People	17	10.2
We Have Never Had An Issue or Problem/We Don't Spill	14	8.4
Use Safety Gear	13	7.8
Work In A Contained Area/ Closed Area/Safe Area	13	7.8
Put Safety First/Make Safety A Priority/Use Safety Precautions	8	4.8
Maintain Trucks Well/Maintain Equipment Well	7	4.2
Make People Aware That The Goal Is Not To Have A Spill	7	4.2
Use A Closed System	6	3.6
Have Absorbent Material Available	6	3.6
Make Sure Spill Containment Is Available If Needed	2	1.2
Make People Aware Of The Foam's Cost	2	1.2
Other	37	22.2
Don't Know	2	1.2

Experiences with AFFF in Firefighting

Figure 15 demonstrates that close to three-quarters of airports have used AFFF for actual firefighting purposes. Of these, as shown in **Table 18**, the largest proportion has used AFFF in firefighting between six and ten times. The second largest groups have used it two times and more than ten times. Use of AFFF in firefighting five or fewer times represents the majority (61 percent).

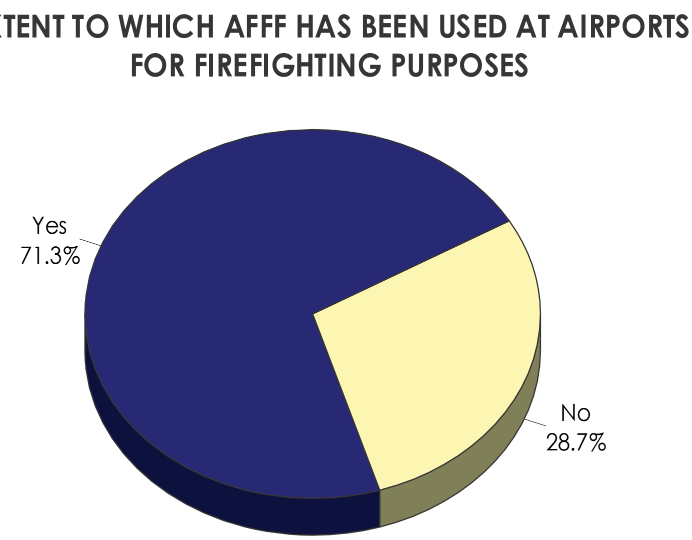

Figure 15

Table 18 NUMBER OF TIMES THIS HAS OCCURRED IN THE PAST TEN YEARS		
	Frequency	**Percent**
1	15	12.6
2	18	15.1
3	17	14.3
4	7	5.9
5	15	12.6
6 To 10	29	24.3
More Than 10	18	15.0

The extent to which AFFF has been used for actual firefighting purposes varies by airport size, as illustrated in **Table 19**. Here, the trend is virtually linear, with the largest airports having the highest frequency of use and the smallest airports having the second lowest. The lowest use is seen in Category B airports, although the difference between Categories A and B is not substantial.

Table 19

USE OF AFFF IN ACTUAL FIREFIGHTING BY AIRPORT SIZE

	Category A	Category B	Category C	Category D	Category E
	Percent				
Yes	57.5	50.0	78.3	78.9	94.1
No	42.5	50.0	21.7	21.1	5.9

(p=.005)

Figure 16 indicates that only three percent of the airports that have used AFFF in firefighting have a history of known contamination as a result of these activities. Almost all do not.

EXTENT TO WHICH AIRPORTS HAVE A HISTORY OF KNOWN CONTAMINATION AS A RESULT OF FIREFIGHTING ACTIVITIES

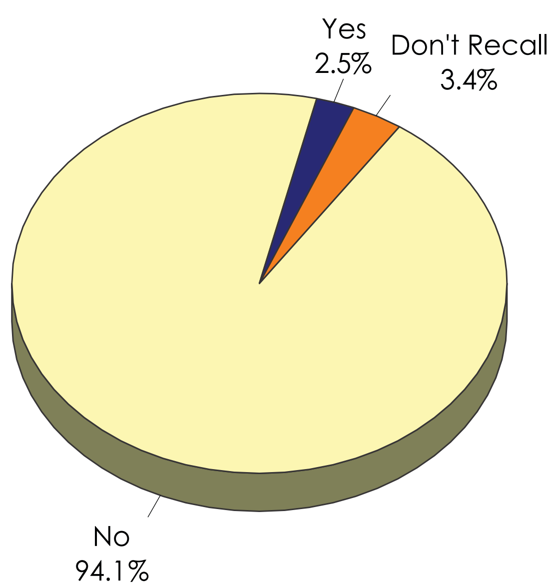

Figure 16

Verbatim descriptions of what happened during instances of contamination are presented below. As these responses represent only three airports, they do not suggest any themes.

- One time we had a fuel spill and they did ground testing and they removed the soil that was contaminated by the spill.
- When it was discharged onto the field at the airport, the environmental group was contacted and they scraped of the topsoil and took it to a landfill.
- There was a fire and we knew some AFFF got on the soil.

Figure 17 demonstrates that none of the airports with a known history of contamination as a result of firefighting activities changed their AFFF management practices as a result of these incidents. Thus none were offered the opportunity to discuss any changes they might have made.

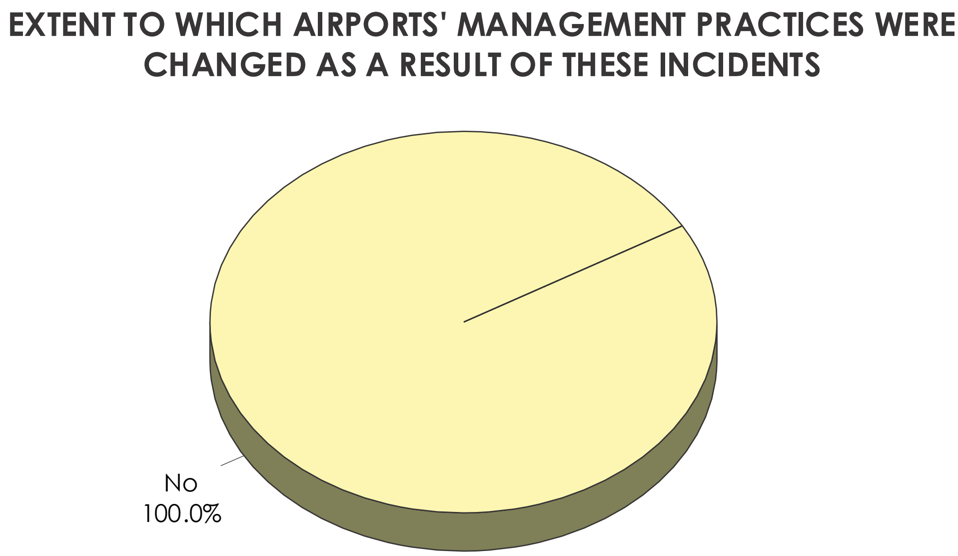

Figure 17

Environmental Site Investigations

As shown in **Figure 18**, only about one in ten airports have conducted environmental site investigations relative to AFFF that specifically relate to the release of AFFF into the environment. Of these, as depicted in **Figure 19**, the majority have conducted only a single such investigation.

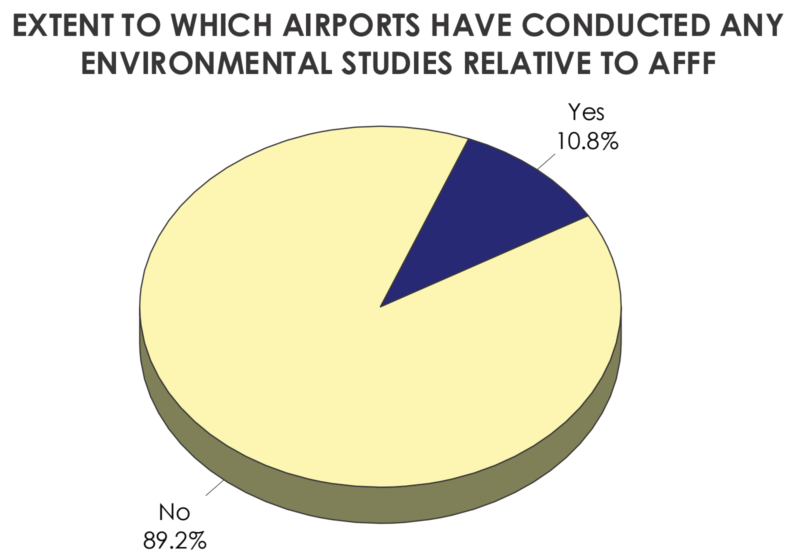

Figure 18

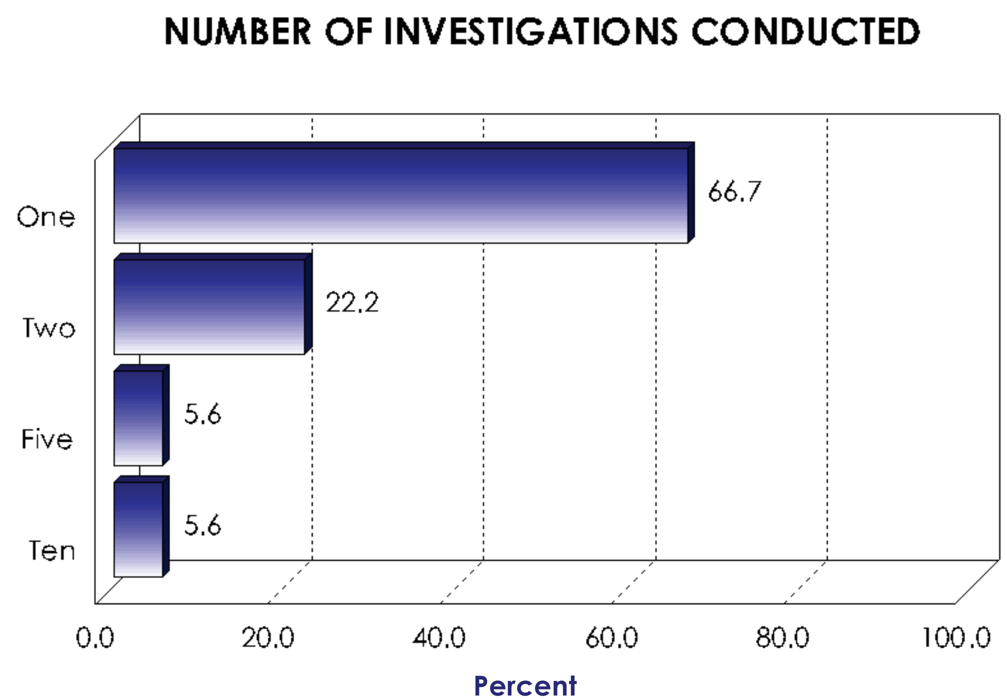

Figure 19

The extent to which airports have conducted environmental site investigations relative to the release of AFFF into the environment is a function of airport size, as illustrated in **Table 20**.

Here, the relationship is virtually linear, with Category E airports being most likely to say they have and Category B airports being most likely to say they have not. Category A airports are somewhat more likely to say yes than Category B airports, but the difference represents only a single airport.

Table 20

EXTENT TO WHICH AIRPORTS HAVE CONDUCTED ENVIRONMENTAL SITE INVESTIGATIONS RELATIVE TO THE RELEASE OF AFFF BY AIRPORT SIZE

	Category A	Category B	Category C	Category D	Category E
	Percent				
Yes	2.5	-	13.0	21.1	23.5
No	97.5	100.0	87.0	78.9	76.5

(p=.028)

Figure 20 indicates that among those who have conducted such an investigation, the majority do not know what UCMR 3 is.[6] Almost all of the remainder does not know how many of the investigations were conducted in accordance with this regulation. A single airport reported a UCMR 3-compliant investigation.

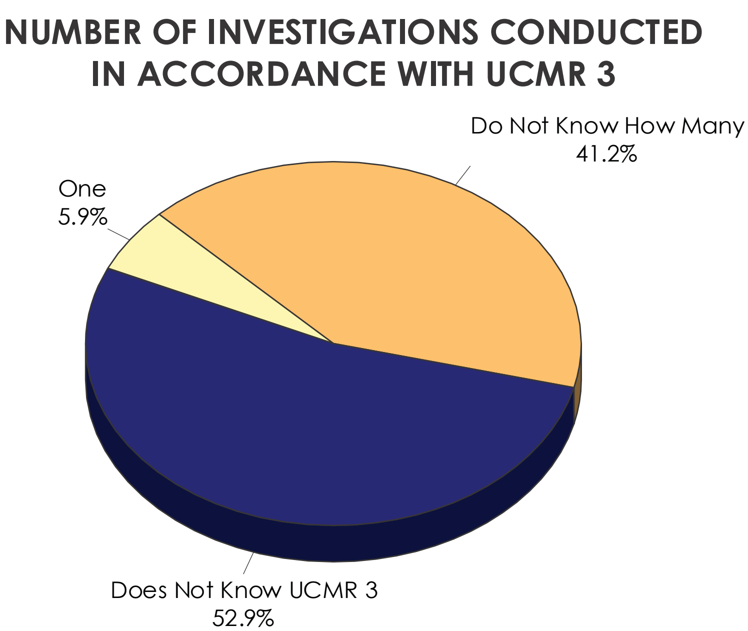

Figure 20

[6] This question was asked only of American airport representatives, as Canadian airports are not subject to UCMR 3.

Figure 21 displays the extent to which the airports' environmental site investigations relative to AFFF have included various activities. As this graphic illustrates, the activities most likely to be included are an environmental risk assessment, a human health risk assessment, specialized field methods for sampling for PFAS, specialized analytical methods for testing for PFAS, and measurement of the prevalence of PFAS in soil.

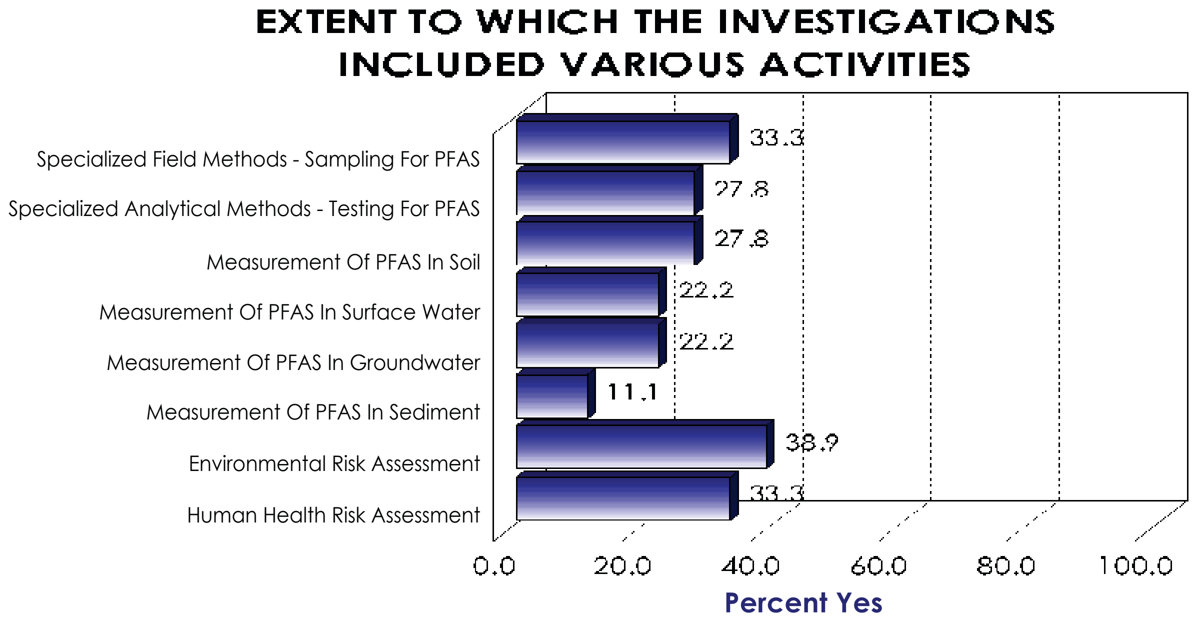

Figure 21

Figure 22 demonstrates that the majority of airports do not know whether their investigations led to analyses of remedial options or not; only one in ten (two airports) said they did. The descriptions these airports offered of the options that were considered and recommended are presented below.

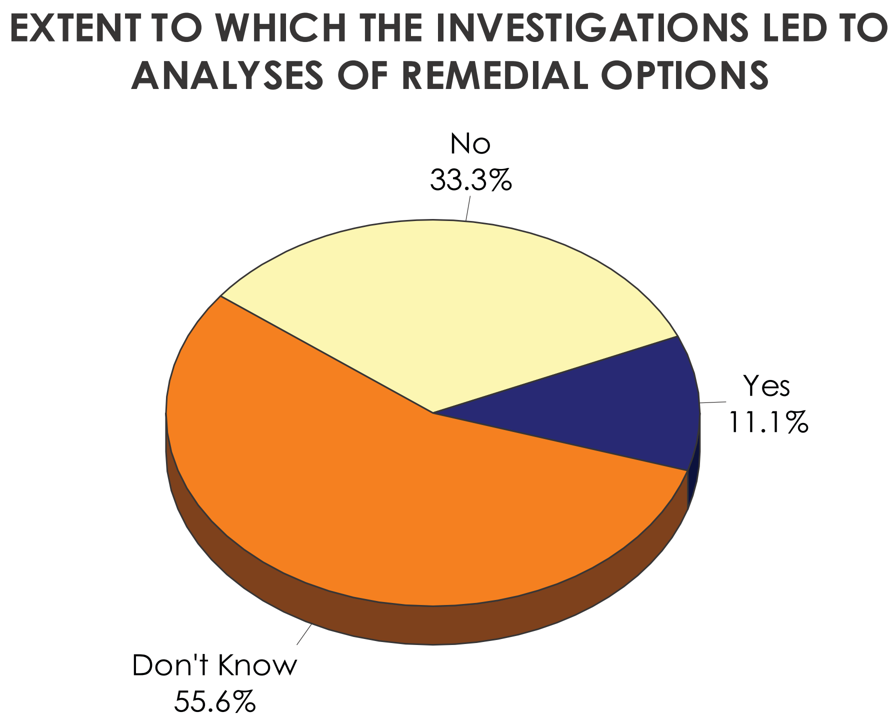

Figure 22

As shown in **Figure 23**, one of the two airports actually implemented the remedial options that were considered and recommended. This airport's description of what was implemented can be found below.

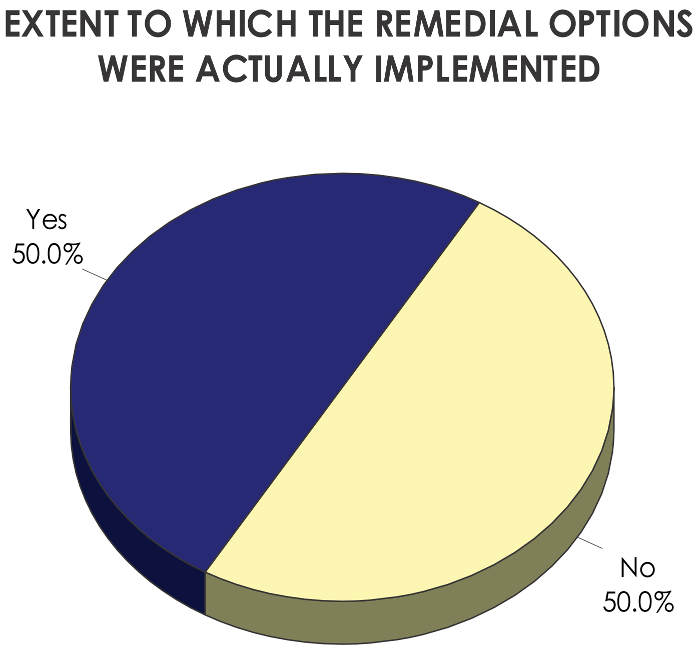

Figure 23

- The analysis, everything was implemented was the way we handled that. To isolate whenever we test or flow AFFF for training or testing. It is flowed into a contained area where it can be contained.

Alternative Formulations of AFFF

Figure 24 indicates that about a quarter of airports are aware of alternative formulations of AFFF; the majority is not. **Table 21** presents these airports' descriptions of the alternatives of which they are aware. As this graphic indicates, most of these descriptions are vague or admittedly uncertain. The leading category of comments is knowing that there are alternatives but not being able to be specific or state what their names are.

AWARENESS OF ALTERNATIVE FORMULATIONS OF AFFF

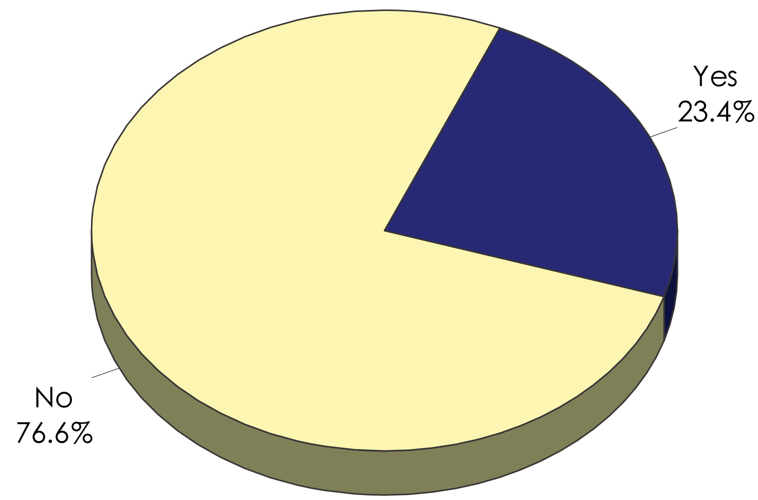

Figure 24

Table 21 ALTERNATIVES OF WHICH AIRPORTS ARE AWARE	Frequency	Percent
There Are Different Types/Manufacturers – Not Specific, Can't Remember Names	13	34.2
Mentions Unique Specific Types or Names	9	23.7
Alcohol-Based Product/Alcohol-Resistant Product	5	13.2
Fluorine-Free Foams/Fluoride-Free Agent/PFAS and PFOA Free	5	13.2
Environmentally Friendly Foams/Bio-Friendly Foams	5	13.2
Training Foams	5	13.2
Mentions Europe or European	4	10.5
Other	4	10.5

Among those who are aware of alternative formulations of AFFF, as illustrated in **Figure 25**, about a quarter actually uses alternatives. Verbatim reasons for using these alternatives among the nine airports that do so are presented below. Reasons for not doing so are displayed in **Table 22**. Chief among these is that the alternatives are not in compliance with government regulations.

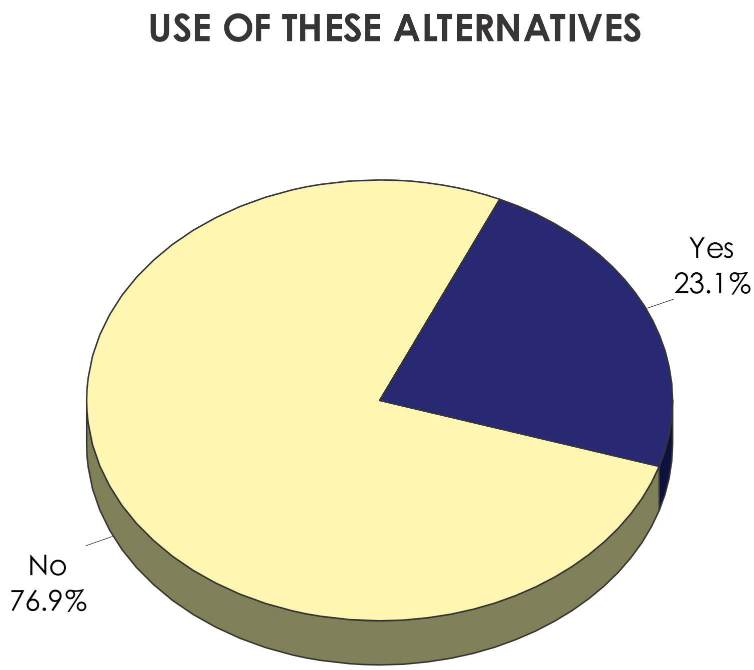

Figure 25

Reasons for Using Alternatives to AFFF:

- Alcohol AFFF on Ethanol, you can't use the non-alcohol-based on fuel.
- You have multi-million dollar planes and it causes less damage to the plane.
- Just to reduce the amount of AFFF we use. It's environmentally friendly and can be only used in testing and training.
- Just different types of hazards that are in our response district.
- We use AFFF, it is alcohol resistant and works on ethanol.
- There are different applications for fires, like an engine fire or a fuel spill. We don't want to use the wrong agent for a specific application.
- We use the various foams due to cost of mitigation.
- We also do municipal firefighting, but not at the airport.
- For two railroad tracks that carry crude oil. We use if for any kind of alcohol fires.

Table 22

REASONS FOR NOT USING ALTERNATIVES TO AFFF

	Frequency	Percent
They Do Not Conform To Specifications/They Are Not In Compliance With Regulations/They Are Not Mil Spec	19	63.3
We Are Using What We Have Always Used	4	13.3
AFFF Is Compatible With Our Equipment/What We Already Have	4	13.3
We Are Looking At Alternatives For Future Procurements/We Have Just Received Approval To Use An Alternative	3	10.0
Alternatives Are More Expensive	3	10.0
Other	2	6.7
Don't Know	2	6.7

Concluding Comments

At the close of the interview, respondents were asked, "Before we conclude this conversation, is there anything you would like to add about the procurement, storage, handling, use, or mitigation of AFFF?" As shown in **Table 23**, by far the majority of airports answered this by saying either "None," "Nothing," or something similar. Two far smaller groups indicated that they had never had any problems with AFFF and that AFFF is needed for safety or effectiveness. The remaining comments follow.

Table 23

CONCLUDING COMMENTS

	Frequency	Percent
We Have Never Had Any Problems	5	3.0
We Need AFFF For Safety Or Effectiveness/The Product Is Effective	3	1.8
None/Nothing	143	85.6
Other	17	10.2

- At our airport we have a contracted environmental engineer who monitors the water, but I'm not sure they look for AFFF.
- I have been in this industry for 30 years and we are heavily regulated. I do believe that there are suitable agents that are not AFFF. The AFFF has to have the foam encapsulate, the product to eliminate the release of foam and there are others that are not foam. Australia banned AFFF and went to foam-based. There is one called

Cold Fire, it bonds with a molecular level, but it's not a foam. It nerves the fuel molecule and you cannot light it. I believe it is safer. I also believe air pressure water would be effective.

- We don't go through a lot of it here. We have less than 500 gallons on site and have minimal use for it with an airport our size.
- We would like to use AFFF at the airport in case of fires with alcohol and ethanol. On procurement, I would like to see FAA fund more in regards to the foam.
- As aviation improves for small and medium airports, it would seem like we should have the industry look at other standards for safety.
- We don't train with it often enough because of the expense, and our new recruit hasn't been able to use the foam. It's just for fires only.
- Just that I think personally it is extremely hazardous to someone's health when you come in contact with it. Just by reading and researching online myself, I think it needs to be explored.
- Understanding the regulatory regulations of the US and Canada. I'm familiar with the ACRP and Dillon Consulting. I want to make sure it addresses regulatory differences in AFFF. I notice they are geared toward the US side and don't address the Canada side, I find that quite weak. They are not recognizing that there are different regulatory requirements. It might not be much, but they don't acknowledge that. If it's an American document, it should state this is an American requirement and not sure if it is applicable in Canada. It should say this is an American or Canadian document upfront, clarified for the reader.
- They are working on a procurement for all the airports to work together to buy from a central location. I think it could probably be beneficial.
- Trying to follow all the rules. Federal, state, and all the government rules. And try to keep it off the floor because it eats paint. We don’t want any leaks.
- We are required by FAA to make sure that it is all Mil Spec.
- We don't routinely use AFFF at our airport for training, we use water. For our actual fire training we use the Chicago Airport.
- Whatever the price comes in the lowest is what we are going to buy, and we don't mix brands. We don't want to mix two manufacturers together, you can't be sure the formula is the same.
- I do know the technology in the new fire trucks allows to test the foam without having to discharge it.
- I would just make sure as a Firefighter Agency or Operator make sure they have the approval from their Environmental Division to handle the AFFF in the event there is a release, just approval of local Environmental Agency.
- We need to begin to move from Fluorine foam and concentrate on something less toxic.
- Make it cheaper. I would recommend that a lot of airports won't train with it because it is so expensive. That's why we do it only once a year.

ATTACHMENT A

Survey Instrument

AIRPORT COOPERATIVE RESEARCH PROGRAM

SURVEY ABOUT THE USE OF AQUEOUS FILM-FORMING FOAM (AFFF) AT NORTH AMERICAN AIRPORTS

Respondent Selection

IF RESPONDENT NAME IS PROVIDED, ASK FOR RESPONDENT BY NAME.

IF NO NAME IS PROVIDED, ASK TO SPEAK TO THE FOLLOWING. YOU ARE LOOKING FOR SOMEONE WHO IS FAMILIAR WITH THE AIRPORT'S USE OF AFFF AND CAN REPRESENT THE AIRPORT ON THAT TOPIC.

- Fire Chief, Fire Captain, Deputy Fire Chief, or Deputy Fire Captain
- Public Safety Chief or Director
- Environmental Manager or Director
- Director of Operations
- Airport Manager or Director
- Assistant Airport Manager or Director
- Manager or Director of Tenant Operations

Introduction

Mr./Ms. ____________________, this is YOUR FULL NAME calling on behalf of Dillon Consulting, which is undertaking a research study for the Airport Cooperative Research Program of the Transportation Research Board. We are conducting a survey among representatives of North American airports to explore the use of aqueous film-forming foam, commonly referred to as A-Triple F and used in firefighting.

The results of this research will be used to develop best management practice guidelines for use by facility operators and managers. All of the results will be reported in the aggregate; individual responses will be kept strictly confidential and will not be attributed to particular airports.

Is this a convenient time to talk for about XX minutes?

YES – THANK AND CONTINUE
NO – ACCEPT AND RESCHEDULE

Interview

1. Thinking first about the acquisition of AFFF ("A-Triple-F" HERE AND HEREAFTER), what are your airport's most important procurement criteria? PROBE FOR CLARITY AND SPECIFICS. PROBE FOR OTHER CRITERIA: What else?

____

____

____

____

____

____

2. Considering all of the places where AFFF is stored at your airport, would you say that all, most, some, or none of them _______________? How about _________________?

	ALL	MOST	SOME	NONE
are enclosed	❒4	❒3	❒2	❒1
are covered	❒4	❒3	❒2	❒1
are single containment	❒4	❒3	❒2	❒1
are double containment	❒4	❒3	❒2	❒1
have a cement or concrete floor	❒4	❒3	❒2	❒1
have an earth or gravel floor	❒4	❒3	❒2	❒1
are an underground storage tank	❒4	❒3	❒2	❒1

3. When AFFF needs to be removed from firefighting equipment or systems, what processes and solutions do you use? PROBE FOR CLARITY AND SPECIFICS. PROBE FOR OTHER THINGS: What else?

____

____

____

____

____

4. Does your airport ever conduct foam tests, by which we mean tests of both the AFFF foam mixture and the equipment?

   1 YES (CONTINUE)
   2 NO (SKIP TO Q10)

☛ **IF YES, ASK:**

5. And about how often do you conduct these tests?

   ____

   1 ONCE A MONTH
   2 ONCE EVERY TWO TO THREE MONTHS
   3 ONCE EVERY FOUR TO SIX MONTHS
   4 BETWEEN EVERY SIX MONTHS AND ONCE A YEAR
   5 LESS OFTEN THAN ONCE A YEAR

6. Do you ever conduct tests of hangar foam systems?

   1 YES (CONTINUE)
   2 NO (SKIP TO Q8)

☛ **IF YES, ASK:**

7. During hangar system tests, do you test the sprinkler system, the foam generation system, or both?

   1 SPRINKLER SYSTEM
   2 FOAM GENERATION SYSTEM
   3 BOTH

8. Is the AFFF used in the foam tests discharged onto the ground or collected in an engineered containment system?

   1 DISCHARGED (SKIP TO Q10)
   2 ENGINEERED CONTAINMENT SYSTEM (CONTINUE)

☛ **IF ENGINEERED CONTAINMENT SYSTEM, ASK:**

9. Could you please describe the engineered containment system that is used for collecting AFFF from foam tests? PROBE FOR CLARITY AND SPECIFICS.

   ____
   ____
   ____
   ____
   ____
   ____

10. Now turning to the disposal of AFFF ... Do you replace the AFFF at your airport when ______________? How about ____________?

	YES	NO
it is consumed during training activities	❐1	❐2
it is consumed during emergency incidents	❐1	❐2
it is past its expiration date	❐1	❐2
it is lost due to leaking containers	❐1	❐2
it is lost due to spills	❐1	❐2
it is used in testing or maintaining firefighting equipment	❐1	❐2

11. Are there other circumstances under which you replace AFFF?

1 YES (CONTINUE)
2 NO (SKIP TO Q13)

IF NO TO ALL OF Q10 AND TO Q11, SKIP TO Q14.

☛IF YES, ASK:

12. And what would those be? PROBE FOR CLARITY AND SPECIFICS. PROBE FOR OTHER CIRCUMSTANCES: What else?

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13. Does your airport always, usually, sometimes, rarely, or never dispose of spent or unused AFFF by ____________? How about ____________?

	ALWAYS	USUALLY	SOMETIMES	RARELY	NEVER
using an on-site wastewater management system	❒5	❒4	❒3	❒2	❒1
using a municipal sewer system	❒5	❒4	❒3	❒2	❒1
using a wastewater management contractor	❒5	❒4	❒3	❒2	❒1
transporting it to a landfill	❒5	❒4	❒3	❒2	❒1
Incinerating it	❒5	❒4	❒3	❒2	❒1
letting it infiltrate into the soil	❒5	❒4	❒3	❒2	❒1

14. (IF THERE IS DISPOSAL OF AFFF: And) does your airport always, usually, sometimes, rarely, or never handle containers and other materials that come into contact with AFFF by ____________? How about ____________?

	ALWAYS	USUALLY	SOMETIMES	RARELY	NEVER
using them again	❒5	❒4	❒3	❒2	❒1
storing them on-site	❒5	❒4	❒3	❒2	❒1
including them as part of general waste disposal	❒5	❒4	❒3	❒2	❒1
using a hazardous waste disposal facility	❒5	❒4	❒3	❒2	❒1

15. Now thinking about firefighter training … Has firefighter training ever been held at your airport?

1 YES (CONTINUE)
2 NO (SKIP TO Q20)

☛ **IF YES, ASK:**

16. And has AFFF been used in all of the training exercises, in selected training exercises, or in no training exercises?

    3 ALL EXERCISES (CONTINUE)
    2 SELECTED EXERCISES (CONTINUE)
    1 NO EXERCISES (SKIP TO Q20)
    9 VOLUNTEERED: ALTERNATIVE FOAMS ARE USED (CONTINUE)

17. Has the AFFF used in the training been discharged onto the ground or collected in an engineered containment system?

    1 DISCHARGED (CONTINUE)
    2 ENGINEERED CONTAINMENT SYSTEM (SKIP TO Q19)

☛ **IF DISCHARGED, ASK:**

18. How has the AFFF been handled after it is discharged? PROBE FOR CLARITY AND SPECIFICS.

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☛ **IF ENGINEERED CONTAINMENT SYSTEM, ASK:**

19. Could you please describe the engineered containment system that is used in collecting the foam used in training exercises? PROBE FOR CLARITY AND SPECIFICS.

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____

20. When staff (IF THERE IS TRAINING: or trainees) are handling AFFF for whatever reason, do they wear ____________? How about __________________?

	YES	NO
eye protection	❒ 1	❒ 2
work gloves	❒ 1	❒ 2
nitrile gloves	❒ 1	❒ 2
other one-time-use gloves	❒ 1	❒ 2
safety boots	❒ 1	❒ 2
fire-retardant clothing	❒ 1	❒ 2
turnout gear	❒ 1	❒ 2

21. From your perspective, what are the best management practices for preventing spills during the handling of AFFF? PROBE FOR CLARITY AND SPECIFICS. PROBE FOR OTHER THINGS: What else?

____

____

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____

____

22. Now I would like to talk about your experience with the use of AFFF. Has AFFF been used at your airport, either on the airport proper or on tenant properties, for actual firefighting purposes?

1 YES (CONTINUE)
2 NO (SKIP TO Q29)

☛ **IF YES, ASK:**

23. And how many times has this happened in the past 10 years?

____ ____

24. Does the airport have any history of known contamination as a result of these firefighting activities?

1 YES (CONTINUE)
2 NO (SKIP TO Q29)
3 NOT SURE (SKIP TO Q29)

☛ **IF YES, ASK:**

25. Could you please describe what happened? PROBE FOR CLARITY AND SPECIFICS.

____

____

____

____

26. And what was done as a result? PROBE FOR CLARITY AND SPECIFICS. PROBE FOR OTHER ACTIONS: What else?

____

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____

☛ **ASK Q26 IF NOT ANSWERED IN Q25.**

27. Were any of the airport's AFFF management practices changed as a result of (this incident) (these incidents)?

1 YES (CONTINUE)
2 NO (SKIP TO Q29)

☛ **IF YES, ASK:**

28. And what was changed? PROBE FOR CLARITY AND SPECIFICS. PROBE FOR OTHER THINGS: What else?

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29. Now I would like to ask you about any environmental studies you may have conducted relative to AFFF. Has your airport ever conducted an environmental site inspection specifically related to the release of AFFF into the environment?

1 YES (CONTINUE)
2 NO (SKIP TO Q37)

☛ **IF YES, ASK:**

30. And how many such investigations has your airport conducted?
___ ___

ASK Q31 IF IN THE UNITED STATES. IF IN CANADA, SKIP TO Q32.

31. How many of these investigations have been conducted in accordance with UCMR 3? ___ ___

98 DOES NOT KNOW WHAT UCMR 3 IS
99 DOES NOT KNOW HOW MANY

32. Did (this investigation) (any of these investigations) include _______?
How about ________________?

	YES	NO	DON'T KNOW
specialized field methods for sampling for P-F-A-S	❒ 1	❒ 2	❒ 3
specialized analytical methods for testing for P-F-A-S	❒ 1	❒ 2	❒ 3
measurement of the prevalence of P-F-A-S in soil	❒ 1	❒ 2	❒ 3
measurement of the prevalence of P-F-A-S in surface water	❒ 1	❒ 2	❒ 3
measurement of the prevalence of P-F-A-S in groundwater	❒ 1	❒ 2	❒ 3
measurement of the prevalence of P-F-A-S in sediment	❒ 1	❒ 2	❒ 3
environmental risk assessment	❒ 1	❒ 2	❒ 3
human health risk assessment	❒ 1	❒ 2	❒ 3

33. And did (this investigation) (any of these investigations) lead to an analysis of remedial options?

1 YES (CONTINUE)
2 NO (SKIP TO Q37)
3 DON'T KNOW (SKIP TO Q37)

☛ **IF YES, ASK:**

34. What options were considered and recommended? PROBE FOR CLARITY AND SPECIFICS. PROBE FOR OTHER THINGS: What else?

____

____

____

____

35. Were any of the options actually implemented?

1 YES (CONTINUE)
2 NO (SKIP TO Q37)

☛ **IF YES, ASK:**

36. And what options were implemented? PROBE FOR CLARITY AND SPECIFICS. PROBE FOR OTHER THINGS: What else?

37. Are you aware of any alternative formulations of AFFF?

1 YES (CONTINUE)
2 NO (SKIP TO Q42)

☛ **IF YES, ASK:**

38. And what alternatives are you aware of? PROBE FOR CLARITY AND SPECIFICS.

39. Do you use any of these alternatives?

1 YES (CONTINUE)
2 NO (SKIP TO Q41)

☛ **IF ALTERNATIVES ARE USED, ASK:**

40. And why do you use them? PROBE FOR CLARITY AND SPECIFICS. PROBE FOR OTHER REASONS: Why else?

____

____

____

☛ **IF ALTERNATIVES ARE NOT USED, ASK:**

41. Could you please tell me why you do not use them? PROBE FOR CLARITY AND SPECIFICS. PROBE FOR OTHER REASONS: Why else?

____

____

____

42. Before we conclude this conversation, is there anything you would like to add about the procurement, storage, handling, use or mitigation of AFFF?

____

____

____

____

____

THANK RESPONDENT!

RECORD AIRPORT CODE: ____ ____ ____

RECORD AIRPORT CLASS:

1 I
2 II
3 III
4 IV

NAME OF RESPONDENT: ______________________________

TITLE OF RESPONDENT: ______________________________

DATE COMPLETED: ___ ___/___ ___/___ ___

INTERVIEWER: ______________________________

ATTACHMENT B

Detailed Data Tabulations for Responding Airports

Country

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 US	149	89.2	89.2	89.2
	2 Canada	18	10.8	10.8	100.0
	Total	167	100.0	100.0	

Sample Group

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 SAMPLE GROUP1 - CAT E AIRPORTS	17	10.2	10.2	10.2
	2 SAMPLE GROUP2 - CAT D AIRPORTS	19	11.4	11.4	21.6
	3 SAMPLE GROUP3 - CAT C AIRPORTS	69	41.3	41.3	62.9
	4 SAMPLE GROUP4 - CAT B AIRPORTS	22	13.2	13.2	76.0
	5 SAMPLE GROUP5 - CAT A AIRPORTS	40	24.0	24.0	100.0
	Total	167	100.0	100.0	

$Q1 Thinking first about the acquisition of AFFF, what are your airport's most important procurement criteria?

		Responses		Percent of Cases (166)
		N	Percent	
$Q1	Compliance With Government Regulations - FAA, Transport Canada, Mil Spec, Three Percent, Regulation 139	109	44.5%	65.7%
	Consistency Of Brand To Avoid Mixing Brands And Resulting Compatibility Issues	7	2.9%	4.2%
	Availability Of Sufficient Quantities	12	4.9%	7.2%
	Availability In A Timely Manner	5	2.0%	3.0%
	Required To Use A List Of Vendors Provided By The Military - DOD - State - City	12	4.9%	7.2%
	Cost Or Price - Have A Budget To Meet - Request Prices From Three Vendors - Have To Take Winning Bid - Product Is Expensive	61	24.9%	36.7%
	Handled By A Purchasing Agent - Other Agency - Other Organization	13	5.3%	7.8%
	Environmental Considerations	3	1.2%	1.8%
	Other	21	8.6%	12.7%
	Don’t Know	2	.8%	1.2%
Total		245	100.0%	147.6%

Q2A. Considering all of the places where AFFF is stored at your airport, would you say that all, most, some, or none of them are enclosed?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 NONE	3	1.8	1.8	1.8
	2 SOME	2	1.2	1.2	3.0
	3 MOST	6	3.6	3.6	6.6
	4 ALL	156	93.4	93.4	100.0
	Total	167	100.0	100.0	

Q2B. How about are covered?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 NONE	5	3.0	3.0	3.0
	2 SOME	2	1.2	1.2	4.2
	3 MOST	5	3.0	3.0	7.2
	4 ALL	155	92.8	92.8	100.0
	Total	167	100.0	100.0	

Q2C. How about are single containment?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 NONE	38	22.8	22.8	22.8
	2 SOME	10	6.0	6.0	28.7
	3 MOST	6	3.6	3.6	32.3
	4 ALL	113	67.7	67.7	100.0
	Total	167	100.0	100.0	

Q2D. How about are double containment?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 NONE	134	80.2	80.2	80.2
	2 SOME	10	6.0	6.0	86.2
	3 MOST	1	.6	.6	86.8
	4 ALL	22	13.2	13.2	100.0
	Total	167	100.0	100.0	

Q2E. How about have a cement or concrete floor?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 NONE	7	4.2	4.2	4.2
	2 SOME	2	1.2	1.2	5.4
	3 MOST	2	1.2	1.2	6.6
	4 ALL	156	93.4	93.4	100.0
	Total	167	100.0	100.0	

Q2F. How about have an earth or gravel floor?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 NONE	164	98.2	98.2	98.2
	2 SOME	1	.6	.6	98.8
	4 ALL	2	1.2	1.2	100.0
	Total	167	100.0	100.0	

Q2G. How about are an underground storage tank?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 NONE	161	96.4	96.4	96.4
	2 SOME	1	.6	.6	97.0
	3 MOST	1	.6	.6	97.6
	4 ALL	4	2.4	2.4	100.0
	Total	167	100.0	100.0	

$Q3 When AFFF needs to be removed from firefighting equipment or systems, what processes and solutions do you use?

		Responses		Percent of Cases (167)
		N	Percent	
$Q3	Drained From The Truck - Gravity Fed From Truck	30	11.2%	18.0%
	Pumped By Hand From The Truck	6	2.2%	3.6%
	Pumped By Mechanical Or Electric Pump From The Truck	24	8.9%	14.4%
	Pumped From The Truck – Mechanism Not Specified	70	26.0%	41.9%
	Use The Nozzles On The Truck	7	2.6%	4.2%
	Drained Or Pumped Into Containers - Training Pit, Trailer, Holding Tank, Drums, Barrels, Totes	89	33.1%	53.3%
	Flushed And Treated As Runoff - Diluted With Water	7	2.6%	4.2%
	Have Never Done This	13	4.8%	7.8%
	It Is Flushed Out And Contained	4	1.5%	2.4%
	Other	14	4.5%	8.4%
	Don't Know	5	1.9%	3.0%
Total		269	100.0%	161.1%

Q4. Does your airport ever conduct foam tests, by which we mean tests of both the AFFF foam mixture and the equipment?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	163	97.6	97.6	97.6
	2 NO	4	2.4	2.4	100.0
	Total	167	100.0	100.0	

Q5. And about how often do you conduct these tests?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 ONCE A MONTH	14	8.4	8.6	8.6
	2 ONCE EVERY TWO TO THREE MONTHS	6	3.6	3.7	12.3
	3 ONCE EVERY FOUR TO SIX MONTHS	54	32.3	33.1	45.4
	4 BETWEEN EVERY SIX MONTHS AND ONCE A YEAR	89	53.3	54.6	100.0
	Total	163	97.6	100.0	
Missing	System	4	2.4		
Total		167	100.0		

Q6. Do you ever conduct tests of hangar foam systems?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	12	7.2	7.4	7.4
	2 NO	151	90.4	92.6	100.0
	Total	163	97.6	100.0	
Missing	System	4	2.4		
Total		167	100.0		

Q7. During hangar system tests, do you test the sprinkler system, the foam generation system, or both?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 SPRINKLER SYSTEM	1	.6	8.3	8.3
	3 BOTH	11	6.6	91.7	100.0
	Total	12	7.2	100.0	
Missing	System	155	92.8		
Total		167	100.0		

Q8. Is the AFFF used in the foam tests discharged onto the ground or collected in an engineered containment system?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 DISCHARGED	113	67.7	69.3	69.3
	2 ENGINEERED CONTAINMENT SYSTEM	50	29.9	30.7	100.0
	Total	163	97.6	100.0	
Missing	System	4	2.4		
Total		167	100.0		

$Q9 Could you please describe the engineered containment system that is used for collecting AFFF from foam tests?

		Responses		Percent of Cases (50)
		N	Percent	
$Q9	Captured In Container - Bucket - Inflatable Pool - Tub - Specimen Cup	18	27.3%	36.0%
	Captured In Collection Facility - Containment Basin - Collection Tanks - Concrete Tub - Wash Pit - Fire Pit - Training Pit	14	21.2%	28.0%
	Sprayed Onto A Target - Contained Area	4	6.1%	8.0%
	Use Separator - Water - Foam, Oil - Water - Scrubbing System	10	15.2%	20.0%
	Released To Sewer System	3	4.5%	6.0%
	Goes To Treatment Plant - Sanitary System	2	3.0%	4.0%
	Someone Else Handles This - Another Organization Handles This	3	4.5%	6.0%
	Other	10	10.6%	20.0%
	Don't Know	2	3.0%	4.0%
Total		66	100.0%	132.0%

Q10A. Do you replace the AFFF at your airport when it is consumed during training activities?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	143	85.6	85.6	85.6
	2 NO	24	14.4	14.4	100.0
	Total	167	100.0	100.0	

Q10B. How about when it is consumed during emergency incidents?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	161	96.4	96.4	96.4
	2 NO	6	3.6	3.6	100.0
	Total	167	100.0	100.0	

Q10C. How about when it is past its expiration date?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	112	67.1	67.1	67.1
	2 NO	55	32.9	32.9	100.0
	Total	167	100.0	100.0	

Q10D. How about when it is lost due to leaking containers?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	147	88.0	88.0	88.0
	2 NO	20	12.0	12.0	100.0
	Total	167	100.0	100.0	

Q10E. How about when it is lost due to spills?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	153	91.6	91.6	91.6
	2 NO	14	8.4	8.4	100.0
	Total	167	100.0	100.0	

Q10F. How about when it is used in testing or maintaining firefighting equipment?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	159	95.2	95.2	95.2
	2 NO	8	4.8	4.8	100.0
	Total	167	100.0	100.0	

Q11. Are there other circumstances under which you replace AFFF?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	29	17.4	17.4	17.4
	2 NO	138	82.6	82.6	100.0
	Total	167	100.0	100.0	

$Q12 And what would those be?

		Responses		Percent of Cases (29)
		N	Percent	
$Q12	Given To Another Agency When They Needed It	5	17.2%	17.2%
	Foam Fails Testing Or Doesn't Work	5	17.2%	17.2%
	Breakdown Of Equipment With Foam Loss Or Contamination	3	10.3%	10.3%
	Inventory Goes Below Required Minimum	3	10.3%	10.3%
	Foam Gets Contaminated	3	10.3%	10.3%
	Bad Batch - Manufacturer Buyback - Manufacturer Recall	2	6.9%	6.9%
	Used In An Emergency	2	6.9%	6.9%
	Other	6	20.6%	20.7%
Total		29	100.0%	100.0%

Q13A. Does your airport always, usually, sometimes, rarely, or never dispose of spent or unused AFFF by using an on-site wastewater management system?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 NEVER	140	83.8	83.8	83.8
	2 RARELY	2	1.2	1.2	85.0
	3 SOMETIMES	9	5.4	5.4	90.4
	4 USUALLY	2	1.2	1.2	91.6
	5 ALWAYS	14	8.4	8.4	100.0
	Total	167	100.0	100.0	

Q13B. How about by using a municipal sewer system?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 NEVER	145	86.8	86.8	86.8
	2 RARELY	7	4.2	4.2	91.0
	3 SOMETIMES	4	2.4	2.4	93.4
	4 USUALLY	2	1.2	1.2	94.6
	5 ALWAYS	9	5.4	5.4	100.0
	Total	167	100.0	100.0	

Q13C. How about by using a wastewater management contractor?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 NEVER	113	67.7	67.7	67.7
	2 RARELY	10	6.0	6.0	73.7
	3 SOMETIMES	11	6.6	6.6	80.2
	4 USUALLY	4	2.4	2.4	82.6
	5 ALWAYS	29	17.4	17.4	100.0
	Total	167	100.0	100.0	

Q13D. How about by transporting it to a landfill?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 NEVER	163	97.6	97.6	97.6
	2 RARELY	3	1.8	1.8	99.4
	3 SOMETIMES	1	.6	.6	100.0
	Total	167	100.0	100.0	

Q13E. How about by incinerating it?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 NEVER	162	97.0	97.0	97.0
	2 RARELY	3	1.8	1.8	98.8
	3 SOMETIMES	1	.6	.6	99.4
	5 ALWAYS	1	.6	.6	100.0
	Total	167	100.0	100.0	

Q13F. How about by letting it infiltrate into the soil?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 NEVER	102	61.1	61.1	61.1
	2 RARELY	15	9.0	9.0	70.1
	3 SOMETIMES	21	12.6	12.6	82.6
	4 USUALLY	12	7.2	7.2	89.8
	5 ALWAYS	17	10.2	10.2	100.0
	Total	167	100.0	100.0	

Q14A. And does your airport always, usually, sometimes, rarely, or never handle containers and other materials that come into contact with AFFF by using them again?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 NEVER	114	68.3	68.3	68.3
	2 RARELY	15	9.0	9.0	77.2
	3 SOMETIMES	13	7.8	7.8	85.0
	4 USUALLY	11	6.6	6.6	91.6
	5 ALWAYS	14	8.4	8.4	100.0
	Total	167	100.0	100.0	

Q14B. How about by storing them on-site?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 NEVER	66	39.5	39.5	39.5
	2 RARELY	7	4.2	4.2	43.7
	3 SOMETIMES	21	12.6	12.6	56.3
	4 USUALLY	10	6.0	6.0	62.3
	5 ALWAYS	63	37.7	37.7	100.0
	Total	167	100.0	100.0	

Q14C. How about by including them as part of general waste disposal?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 NEVER	111	66.5	66.5	66.5
	2 RARELY	16	9.6	9.6	76.0
	3 SOMETIMES	14	8.4	8.4	84.4
	4 USUALLY	2	1.2	1.2	85.6
	5 ALWAYS	24	14.4	14.4	100.0
	Total	167	100.0	100.0	

Q14D. How about by using a hazardous waste disposal facility?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 NEVER	98	58.7	58.7	58.7
	2 RARELY	13	7.8	7.8	66.5
	3 SOMETIMES	16	9.6	9.6	76.0
	4 USUALLY	8	4.8	4.8	80.8
	5 ALWAYS	32	19.2	19.2	100.0
	Total	167	100.0	100.0	

Q15. Has firefighter training ever been held at your airport?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	148	88.6	88.6	88.6
	2 NO	19	11.4	11.4	100.0
	Total	167	100.0	100.0	

Q16. And has AFFF been used in all of the training exercises, in selected training exercises, or in no training exercises?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 NO EXERCISES	34	20.4	23.0	23.0
	2 SELECTED EXERCISES	107	64.1	72.3	95.3
	3 ALL EXERCISES	7	4.2	4.7	100.0
	Total	148	88.6	100.0	
Missing	System	19	11.4		
Total		167	100.0		

Q17. Has the AFFF used in the training been discharged onto the ground or collected in an engineered containment system?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 DISCHARGED	90	53.9	78.9	78.9
	2 ENGINEERED CONTAINMENT SYSTEM	24	14.4	21.1	100.0
	Total	114	68.3	100.0	
Missing	System	53	31.7		
Total		167	100.0		

$Q18 How has the discharged AFFF been handled?

		Responses		Percent of Cases (90)
		N	Percent	
$Q18	Sent To Or Handled By Hazardous Waste Treatment	6	5.9%	6.7%
	Discharged Into A Fire Training Pit	2	2.0%	2.2%
	Discharged Into Wastewater Treatment System	2	2.0%	2.2%
	Discharged Onto The Ground And Diluted	16	15.7%	17.8%
	Discharged Onto The Ground And Left To Evaporate Or Dissolve Or Dissipate	32	31.4%	35.6%
	It Is Environmentally Safe	2	2.0%	2.2%
	Discharged Onto The Ground – No Specifics of Outcome	5	4.9%	5.6%
	Discharged Onto The Ground - Soil And Left To Soak In Or Infiltrate	23	22.5%	25.6%
	Discharged Onto The Ground And Contained Or Cleaned Up	6	5.9%	6.7%
	Other	6	5.9%	6.7%
	Don't Know	2	2.0%	2.2%
Total		102	100.0%	113.3%

$Q19 Could you please describe the engineered containment system that is used in collecting the foam used in training exercises?

		Responses		Percent of Cases (24)
		N	Percent	
$Q19	Captured In Collection Facility - Training Pit	16	37.2%	66.7%
	Use Separator - Water - Foam, Oil - Water - Water Reclamation System	9	20.9%	37.5%
	Dispersed Onto A Paved Surface	2	4.7%	8.3%
	Goes to Retention Pond - Tank	4	9.3%	16.7%
	Vacuumed Up With Vacuum Truck	2	4.7%	8.3%
	Taken Away By Contractor	2	4.7%	8.3%
	Dispersed or Released – Unclear Where	3	7.0%	12.5%
	Goes To Treatment Plant - Sanitary System	2	4.7%	8.3%
	Other	3	2.3%	12.5%
Total		43	100.0%	179.2%

Q20A. When staff or trainees are handling AFFF for whatever reason, do they wear eye protection?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	154	92.2	92.2	92.2
	2 NO	13	7.8	7.8	100.0
	Total	167	100.0	100.0	

Q20B. How about work gloves?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	159	95.2	95.2	95.2
	2 NO	8	4.8	4.8	100.0
	Total	167	100.0	100.0	

Q20C. How about nitrile gloves?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	63	37.7	37.7	37.7
	2 NO	104	62.3	62.3	100.0
	Total	167	100.0	100.0	

Q20D. How about other one-time-use gloves?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	68	40.7	40.7	40.7
	2 NO	99	59.3	59.3	100.0
	Total	167	100.0	100.0	

Q20E. How about safety boots?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	147	88.0	88.0	88.0
	2 NO	20	12.0	12.0	100.0
	Total	167	100.0	100.0	

Q20F. How about fire-retardant clothing?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	132	79.0	79.0	79.0
	2 NO	35	21.0	21.0	100.0
	Total	167	100.0	100.0	

Q20G. How about turnout gear?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	136	81.4	81.4	81.4
	2 NO	31	18.6	18.6	100.0
	Total	167	100.0	100.0	

$Q21 From your perspective, what are the best management practices for preventing spills during the handling of AFFF?

		Responses		Percent of Cases (167)
		N	Percent	
$Q21	Use Caution - Be Careful - Take Your Time - Pay Attention - Attend To Detail	36	10.5%	21.6%
	Put Safety First - Make Safety A Priority - Use Safety Precautions	8	2.3%	4.8%
	Use Safety Gear	13	3.8%	7.8%
	Do Not Do It Alone - Involve Multiple People	17	4.9%	10.2%
	Use Containment - Containers	36	10.5%	21.6%
	Use Pumps	20	5.8%	12.0%
	Use The Right Equipment - Make Sure Equipment Is Set Up Properly	19	5.5%	11.4%
	Use A Closed System	6	1.7%	3.6%
	Make Sure Spill Containment Is Available If Needed	2	.6%	1.2%
	Make Sure Connections Are Correct - Are Tight	26	7.6%	15.6%
	Have Clear Procedures - Checklists	20	5.8%	12.0%
	Provide Thorough Training On Procedures	27	7.8%	16.2%
	Follow Procedures	26	7.6%	15.6%
	Maintain Trucks Well - Maintain Equipment Well	7	2.0%	4.2%
	Make People Aware That The Goal Is Not To Have A Spill	7	2.0%	4.2%
	Make People Aware Of The Foam's Cost	2	.6%	1.2%
	We Have Never Had An Issue or Problem - We Don't Spill	14	4.1%	8.4%
	Have Absorbent Material Available	6	1.7%	3.6%
	Work In A Contained Area - Closed Area - Safe Area	13	3.8%	7.8%
	Other	37	10.5%	22.2%
	Don't Know	2	.6%	1.2%
Total		344	100.0%	206.0%

Q22. Now I would like to talk about your experience with the use of AFFF. Has AFFF been used at your airport, either on the airport proper or on tenant properties, for actual firefighting purposes?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	119	71.3	71.3	71.3
	2 NO	48	28.7	28.7	100.0
	Total	167	100.0	100.0	

Q23. And how many times has this happened in the past 10 years?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	15	9.0	12.6	12.6
	2	18	10.8	15.1	27.7
	3	17	10.2	14.3	42.0
	4	7	4.2	5.9	47.9
	5	15	9.0	12.6	60.5
	6	8	4.8	6.7	67.2
	7	3	1.8	2.5	69.7
	8	3	1.8	2.5	72.3
	9	1	.6	.8	73.1
	10	14	8.4	11.8	84.9
	12	4	2.4	3.4	88.2
	15	1	.6	.8	89.1
	20	2	1.2	1.7	90.8
	25	1	.6	.8	91.6
	30	3	1.8	2.5	94.1
	40	1	.6	.8	95.0
	50	4	2.4	3.4	98.3
	75	1	.6	.8	99.2
	100	1	.6	.8	100.0
	Total	119	71.3	100.0	
Missing	System	48	28.7		
Total		167	100.0		

Q24. Does the airport have any history of known contamination as a result of these firefighting activities?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	3	1.8	2.5	2.5
	2 NO	112	67.1	94.1	96.6
	3 NOT SURE	4	2.4	3.4	100.0
	Total	119	71.3	100.0	
Missing	System	48	28.7		
Total		167	100.0		

Q27. Were any of the airport's AFFF management practices changed as a result of (this incident) (these incidents)?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2 NO	3	1.8	100.0	100.0
Missing	System	164	98.2		
Total		167	100.0		

Q29. Now I would like to ask you about any environmental studies you may have conducted relative to AFFF. Has your airport ever conducted an environmental site inspection specifically related to the release of AFFF into the environment?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	18	10.8	10.8	10.8
	2 NO	149	89.2	89.2	100.0
	Total	167	100.0	100.0	

Q30. And how many such investigations has your airport conducted?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	12	7.2	66.7	66.7
	2	4	2.4	22.2	88.9
	5	1	.6	5.6	94.4
	10	1	.6	5.6	100.0
	Total	18	10.8	100.0	
Missing	System	149	89.2		
Total		167	100.0		

Q31. How many of these investigations have been conducted in accordance with UCMR 3?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	1	.6	5.9	5.9
	98 DOES NOT KNOW WHAT UCMR 3 IS	9	5.4	52.9	58.8
	99 DOES NOT KNOW HOW MANY	7	4.2	41.2	100.0
	Total	17	10.2	100.0	
Missing	System	150	89.8		
Total		167	100.0		

Q32A. Did this investigation include specialized field methods for sampling for PFAS?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	6	3.6	33.3	33.3
	3 DON'T KNOW	12	7.2	66.7	100.0
	Total	18	10.8	100.0	
Missing	System	149	89.2		
Total		167	100.0		

Q32B. How about specialized analytical methods for testing for PFAS?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	5	3.0	27.8	27.8
	3 DON'T KNOW	13	7.8	72.2	100.0
	Total	18	10.8	100.0	
Missing	System	149	89.2		
Total		167	100.0		

Q32C. How about measurement of the prevalence of PFAS in soil?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	5	3.0	27.8	27.8
	2 NO	2	1.2	11.1	38.9
	3 DON'T KNOW	11	6.6	61.1	100.0
	Total	18	10.8	100.0	
Missing	System	149	89.2		
Total		167	100.0		

Q32D. How about measurement of the prevalence of PFAS in surface water?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	4	2.4	22.2	22.2
	2 NO	2	1.2	11.1	33.3
	3 DON'T KNOW	12	7.2	66.7	100.0
	Total	18	10.8	100.0	
Missing	System	149	89.2		
Total		167	100.0		

Q32E. How about measurement of the prevalence of PFAS in groundwater?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	4	2.4	22.2	22.2
	2 NO	2	1.2	11.1	33.3
	3 DON'T KNOW	12	7.2	66.7	100.0
	Total	18	10.8	100.0	
Missing	System	149	89.2		
Total		167	100.0		

Q32F. How about measurement of the prevalence of PFAS in sediment?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	2	1.2	11.1	11.1
	2 NO	3	1.8	16.7	27.8
	3 DON'T KNOW	13	7.8	72.2	100.0
	Total	18	10.8	100.0	
Missing	System	149	89.2		
Total		167	100.0		

Q32G. How about environmental risk assessment?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	7	4.2	38.9	38.9
	2 NO	1	.6	5.6	44.4
	3 DON'T KNOW	10	6.0	55.6	100.0
	Total	18	10.8	100.0	
Missing	System	149	89.2		
Total		167	100.0		

Q32H. How about human health risk assessment?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	6	3.6	33.3	33.3
	2 NO	1	.6	5.6	38.9
	3 DON'T KNOW	11	6.6	61.1	100.0
	Total	18	10.8	100.0	
Missing	System	149	89.2		
Total		167	100.0		

Q33. And did this investigation lead to an analysis of remedial options?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	2	1.2	11.1	11.1
	2 NO	6	3.6	33.3	44.4
	3 DON'T KNOW	10	6.0	55.6	100.0
	Total	18	10.8	100.0	
Missing	System	149	89.2		
Total		167	100.0		

Q35. Were any of the options actually implemented?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	1	.6	50.0	50.0
	2 NO	1	.6	50.0	100.0
	Total	2	1.2	100.0	
Missing	System	165	98.8		
Total		167	100.0		

Q37. Are you aware of any alternative formulations of AFFF?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	39	23.4	23.4	23.4
	2 NO	128	76.6	76.6	100.0
	Total	167	100.0	100.0	

$Q38 And what alternatives are you aware of?

		Responses		Percent of Cases (38)
		N	Percent	
$Q38	Alcohol-Based Product - Alcohol-Resistant Product	5	10.0%	13.2%
	Fluorine-Free Foams - Fluoride-Free Agent - PFAS and PFOA Free	5	10.0%	13.2%
	Environmentally Friendly Foams - Bio-Friendly Foams	5	10.0%	13.2%
	Training Foams	5	10.0%	13.2%
	There Are Different Types - Manufacturers – Not Specific, Can't Remember Names	13	26.0%	34.2%
	Mentions Unique Specific Types or Names	9	18.0%	23.7%
	Mentions Europe or European	4	8.0%	10.5%
	Other	4	4.0%	10.5%
Total		50	100.0%	131.6%

Q39. Do you use any of these alternatives?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1 YES	9	5.4	23.1	23.1
	2 NO	30	18.0	76.9	100.0
	Total	39	23.4	100.0	
Missing	System	128	76.6		
Total		167	100.0		

$Q41 Could you please tell me why you do not use them?

		Responses		Percent of Cases (30)
		N	Percent	
$Q41	They Do Not Conform to Specifications - They Are Not In Compliance With Regulations - They Are Not Mil Spec	19	51.4%	63.3%
	We Are Using What We Have Always Used	4	10.8%	13.3%
	We Are Looking At Alternatives For Future Procurements - We Have Just Received Approval To Use An Alternative	3	8.1%	10.0%
	AFFF Is Compatible With Our Equipment - What We Already Have	4	10.8%	13.3%
	Alternatives Are More Expensive	3	8.1%	10.0%
	Other	2	5.4%	6.7%
	Don't Know	6	2.7%	6.7%
Total		37	100.0%	123.3%

$Q42 Is there anything you would like to add about the procurement, storage, handling, use or mitigation of AFFF?

		Responses		Percent of Cases (167)
		N	Percent	
$Q42(a)	We Have Never Had Any Problems	5	3.0%	3.0%
	We Need AFFF For Safety Or Effectiveness - The Product Is Effective	3	1.8%	1.8%
	None - Nothing	143	85.1%	85.6%
	Other	17	10.1%	10.2%
Total		168	100.0%	100.6%

a Group

Date of Interview

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	20151207	12	7.2	7.2	7.2
	20151208	11	6.6	6.6	13.8
	20151209	13	7.8	7.8	21.6
	20151211	5	3.0	3.0	24.6
	20151214	7	4.2	4.2	28.7
	20151215	7	4.2	4.2	32.9
	20151216	4	2.4	2.4	35.3
	20151217	3	1.8	1.8	37.1
	20151218	4	2.4	2.4	39.5
	20151221	4	2.4	2.4	41.9
	20151222	5	3.0	3.0	44.9
	20151223	2	1.2	1.2	46.1
	20151228	5	3.0	3.0	49.1
	20151229	3	1.8	1.8	50.9
	20160104	5	3.0	3.0	53.9
	20160105	4	2.4	2.4	56.3
	20160106	5	3.0	3.0	59.3
	20160107	5	3.0	3.0	62.3
	20160108	4	2.4	2.4	64.7
	20160111	3	1.8	1.8	66.5
	20160112	2	1.2	1.2	67.7
	20160113	7	4.2	4.2	71.9
	20160114	2	1.2	1.2	73.1
	20160115	4	2.4	2.4	75.4
	20160118	1	.6	.6	76.0
	20160122	2	1.2	1.2	77.2
	20160125	3	1.8	1.8	79.0
	20160126	7	4.2	4.2	83.2
	20160127	4	2.4	2.4	85.6
	20160129	2	1.2	1.2	86.8
	20160201	1	.6	.6	87.4
	20160202	1	.6	.6	88.0
	20160203	4	2.4	2.4	90.4
	20160205	4	2.4	2.4	92.8
	20160208	1	.6	.6	93.4
	20160210	2	1.2	1.2	94.6
	20160211	1	.6	.6	95.2
	20160212	1	.6	.6	95.8
	20160217	4	2.4	2.4	98.2
	20160218	2	1.2	1.2	99.4
	20160307	1	.6	.6	100.0
	Total	167	100.0	100.0	

Length of Interview

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	6	1	.6	.6	.6
	7	1	.6	.6	1.2
	8	2	1.2	1.2	2.4
	10	2	1.2	1.2	3.6
	11	1	.6	.6	4.2
	12	7	4.2	4.2	8.4
	13	5	3.0	3.0	11.4
	14	8	4.8	4.8	16.2
	15	10	6.0	6.0	22.2
	16	11	6.6	6.6	28.7
	17	15	9.0	9.0	37.7
	18	8	4.8	4.8	42.5
	19	5	3.0	3.0	45.5
	20	12	7.2	7.2	52.7
	21	6	3.6	3.6	56.3
	22	10	6.0	6.0	62.3
	23	5	3.0	3.0	65.3
	24	7	4.2	4.2	69.5
	25	6	3.6	3.6	73.1
	26	9	5.4	5.4	78.4
	27	11	6.6	6.6	85.0
	28	5	3.0	3.0	88.0
	29	3	1.8	1.8	89.8
	30	4	2.4	2.4	92.2
	31	3	1.8	1.8	94.0
	33	3	1.8	1.8	95.8
	36	1	.6	.6	96.4
	37	1	.6	.6	97.0
	41	1	.6	.6	97.6
	42	1	.6	.6	98.2
	48	1	.6	.6	98.8
	50	1	.6	.6	99.4
	59	1	.6	.6	100.0
	Total	167	100.0	100.0	

ATTACHMENT C

Verbatim Transcriptions of Open-Ended Responses

(**Note:** Attachment C is not published herein, but is available upon request from Cooperative Research Programs Senior Program Officer Joe Navarrete, at jnavarrete@nas.edu.)

ATTACHMENT D

Statistically Significant Cross-Tabulations by Country

Q2A. Considering all of the places where AFFF is stored at your airport, would you say that all, most, some, or none of them are enclosed? * Country

Crosstab

			Country		Total
			1 US	2 Canada	
Q2A. Considering all of the places where AFFF is stored at your airport, would you say that all, most, some, or none of them are enclosed?	1 NONE	Count	1	2	3
		% within Country	.7%	11.1%	1.8%
	2 SOME	Count	1	1	2
		% within Country	.7%	5.6%	1.2%
	3 MOST	Count	5	1	6
		% within Country	3.4%	5.6%	3.6%
	4 ALL	Count	142	14	156
		% within Country	95.3%	77.8%	93.4%
Total		Count	149	18	167
		% within Country	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	13.688(a)	3	.003
Likelihood Ratio	7.976	3	.047
Linear-by-Linear Association	12.863	1	.000
N of Valid Cases	167		

a 5 cells (62.5%) have expected count less than 5. The minimum expected count is .22.

Q2F. How about have an earth or gravel floor? * Country

Crosstab

			Country		Total
			1 US	2 Canada	
Q2F. How about have an earth or gravel floor?	1 NONE	Count	148	16	164
		% within Country	99.3%	88.9%	98.2%
	2 SOME	Count	0	1	1
		% within Country	.0%	5.6%	.6%
	4 ALL	Count	1	1	2
		% within Country	.7%	5.6%	1.2%
Total		Count	149	18	167
		% within Country	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.655(a)	2	.003
Likelihood Ratio	6.549	2	.038
Linear-by-Linear Association	5.820	1	.016
N of Valid Cases	167		

a 4 cells (66.7%) have expected count less than 5. The minimum expected count is .11.

Q5. And about how often do you conduct these tests? * Country

Crosstab

			Country		Total
			1 US	2 Canada	
Q5. And about how often do you conduct these tests?	1 ONCE A MONTH	Count	14	0	14
		% within Country	9.7%	.0%	8.6%
	2 ONCE EVERY TWO TO THREE MONTHS	Count	6	0	6
		% within Country	4.1%	.0%	3.7%
	3 ONCE EVERY FOUR TO SIX MONTHS	Count	53	1	54
		% within Country	36.6%	5.6%	33.1%
	4 BETWEEN EVERY SIX MONTHS AND ONCE A YEAR	Count	72	17	89
		% within Country	49.7%	94.4%	54.6%
Total		Count	145	18	163
		% within Country	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	13.009(a)	3	.005
Likelihood Ratio	16.489	3	.001
Linear-by-Linear Association	9.120	1	.003
N of Valid Cases	163		

a 2 cells (25.0%) have expected count less than 5. The minimum expected count is .66.

Q13C. How about by using a wastewater management contractor? * Country

Crosstab

			Country		Total
			1 US	2 Canada	
Q13C. How about by using a wastewater management contractor?	1 NEVER	Count	107	6	113
		% within Country	71.8%	33.3%	67.7%
	2 RARELY	Count	8	2	10
		% within Country	5.4%	11.1%	6.0%
	3 SOMETIMES	Count	9	2	11
		% within Country	6.0%	11.1%	6.6%
	4 USUALLY	Count	2	2	4
		% within Country	1.3%	11.1%	2.4%
	5 ALWAYS	Count	23	6	29
		% within Country	15.4%	33.3%	17.4%
Total		Count	149	18	167
		% within Country	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	14.386(a)	4	.006
Likelihood Ratio	11.724	4	.020
Linear-by-Linear Association	9.073	1	.003
N of Valid Cases	167		

a 5 cells (50.0%) have expected count less than 5. The minimum expected count is .43.

Q14B. How about by storing them on-site? * Country

Crosstab

			Country		Total
			1 US	2 Canada	
Q14B. How about by storing them on-site?	1 NEVER	Count	61	5	66
		% within Country	40.9%	27.8%	39.5%
	2 RARELY	Count	6	1	7
		% within Country	4.0%	5.6%	4.2%
	3 SOMETIMES	Count	19	2	21
		% within Country	12.8%	11.1%	12.6%
	4 USUALLY	Count	6	4	10
		% within Country	4.0%	22.2%	6.0%
	5 ALWAYS	Count	57	6	63
		% within Country	38.3%	33.3%	37.7%
Total		Count	149	18	167
		% within Country	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	9.810(a)	4	.044
Likelihood Ratio	6.731	4	.151
Linear-by-Linear Association	.550	1	.458
N of Valid Cases	167		

a 3 cells (30.0%) have expected count less than 5. The minimum expected count is .75.

ATTACHMENT E

Statistically Significant Cross-Tabulations by Airport Size

Q2D. How about are double containment? * Size

Crosstab

Q2D. How about are double containment?			Size					Total
			CAT E	CAT D	CAT C	CAT B	CAT A	
	1 NONE	Count	12	11	58	20	33	134
		% within Size	70.6%	57.9%	84.1%	90.9%	82.5%	80.2%
	2 SOME	Count	1	4	3	0	2	10
		% within Size	5.9%	21.1%	4.3%	.0%	5.0%	6.0%
	3 MOST	Count	1	0	0	0	0	1
		% within Size	5.9%	.0%	.0%	.0%	.0%	.6%
	4 ALL	Count	3	4	8	2	5	22
		% within Size	17.6%	21.1%	11.6%	9.1%	12.5%	13.2%
Total		Count	17	19	69	22	40	167
		% within Size	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	21.136(a)	12	.048
Likelihood Ratio	15.367	12	.222
Linear-by-Linear Association	1.945	1	.163
N of Valid Cases	167		

a 13 cells (65.0%) have expected count less than 5. The minimum expected count is .10.

Q5. And about how often do you conduct these tests? * Size

Crosstab

Q5. And about how often do you conduct these tests?		Size: CAT E	CAT D	CAT C	CAT B	CAT A	Total
1 ONCE A MONTH	Count	1	2	7	0	4	14
	% within Size	6.3%	10.5%	10.4%	.0%	10.0%	8.6%
2 ONCE EVERY TWO TO THREE MONTHS	Count	0	3	3	0	0	6
	% within Size	.0%	15.8%	4.5%	.0%	.0%	3.7%
3 ONCE EVERY FOUR TO SIX MONTHS	Count	3	8	26	8	9	54
	% within Size	18.8%	42.1%	38.8%	38.1%	22.5%	33.1%
4 BETWEEN EVERY SIX MONTHS AND ONCE A YEAR	Count	12	6	31	13	27	89
	% within Size	75.0%	31.6%	46.3%	61.9%	67.5%	54.6%
Total	Count	16	19	67	21	40	163
	% within Size	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	21.841(a)	12	.039
Likelihood Ratio	23.464	12	.024
Linear-by-Linear Association	1.126	1	.289
N of Valid Cases	163		

a 9 cells (45.0%) have expected count less than 5. The minimum expected count is .59.

Q22. Now I would like to talk about your experience with the use of AFFF. Has AFFF been used at your airport, either on the airport proper or on tenant properties, for actual firefighting purposes? * Size

Crosstab

Q22. Now I would like to talk about your experience with the use of AFFF. Has AFFF been used at your airport, either on the airport proper or on tenant properties, for actual firefighting purposes?		Size					Total
		CAT E	CAT D	CAT C	CAT B	CAT A	
1 YES	Count	16	15	54	11	23	119
	% within Size	94.1%	78.9%	78.3%	50.0%	57.5%	71.3%
2 NO	Count	1	4	15	11	17	48
	% within Size	5.9%	21.1%	21.7%	50.0%	42.5%	28.7%
Total	Count	17	19	69	22	40	167
	% within Size	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	15.089(a)	4	.005
Likelihood Ratio	15.878	4	.003
Linear-by-Linear Association	11.833	1	.001
N of Valid Cases	167		

a 1 cells (10.0%) have expected count less than 5. The minimum expected count is 4.89.

Q29. Now I would like to ask you about any environmental studies you may have conducted relative to AFFF. Has your airport ever conducted an environmental site inspection specifically related to the release of AFFF into the environment? * Size

Crosstab

Q29. Now I would like to ask you about any environmental studies you may have conducted relative to AFFF. Has your airport ever conducted an environmental site inspection specifically related to the release of AFFF into the environment?			Size					Total
			CAT E	CAT D	CAT C	CAT B	CAT A	
	1 YES	Count	4	4	9	0	1	18
		% within Size	23.5%	21.1%	13.0%	.0%	2.5%	10.8%
	2 NO	Count	13	15	60	22	39	149
		% within Size	76.5%	78.9%	87.0%	100.0%	97.5%	89.2%
Total		Count	17	19	69	22	40	167
		% within Size	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	10.836(a)	4	.028
Likelihood Ratio	13.286	4	.010
Linear-by-Linear Association	9.480	1	.002
N of Valid Cases	167		

a 4 cells (40.0%) have expected count less than 5. The minimum expected count is 1.83.

APPENDIX B

AFFF Alternatives

Understanding of the Problem

Firefighting foam used for extinguishing aircraft fires has been described as being a stable mass of small air-filled bubbles, which have a lower specific gravity than that of hydrocarbon fuels or water (FAA, 2004). In airport operations in North America, AFFF is used as a fire-extinguishing agent to suppress Class B fires: i.e., fires of flammable and combustible liquids such as crude oil, gasoline and fuel oils. AFFF exhibits unique properties that make it very effective as a fire-extinguishing agent, but can be potentially problematic relative to human health and the environment.

Many historical AFFF formulations contained PFOS as the predominant active ingredient. Due to concerns associated with PFOS's ubiquity and persistence in the environment, alternative formulations containing fluorochemicals with a perfluorinated eight-carbon (C_8) "tail" have been used. Similar concerns (i.e., the breakdown of these long chained fluorotelomers to PFOA, which, like PFOS, has been shown to be very persistent in the environment) caused manufacturers to look for other alternate formulations that included fluorinated chemicals with shorter chain lengths, such as C_6-based fluorotelomers.

Alternatives

Due to the environmental concerns associated with PFOS, the United Nations Environment Programme (UNEP) (2011) referenced a PFOS alternative as: "*When compared to PFOS, either reduces the potential for harm to human health or the environment or has not been shown to be a potential persistent organic pollutant itself.*" Two guiding documents on the identification and assessment of PFOS alternatives were prepared and released by UNEP under the Stockholm Convention (2011):

- *Draft guidance on alternatives to perfluorooctane sulfonic acid and its derivatives* (UNEP/POPS/POPRC.6/13/Add.3/Rev.1), which presents information on alternatives to PFOS and its derivatives. It also includes a breakdown of the uses of PFOS (e.g., coating, metal plating, firefighting foams) and indicates where alternatives have been suggested, are available, or have already been introduced to markets. The intent of this document was to enhance the capacity to transition to phase out of PFOS.
- *Technical paper on the identification and assessment of alternatives to the use of perfluorooctane sulfonic acid in open applications* (UNEP/POPS/POPRC.8/INF/17.3) prepared for use by the Persistent Organic Pollutants Review Committee to develop recommendations on alternatives to PFOS in open applications.

Alternatives suggested by UNEP are in no way exhaustive. Challenges continue to exist today in that there is often more information on PFOS-based AFFF than on non-PFOS based alternatives.

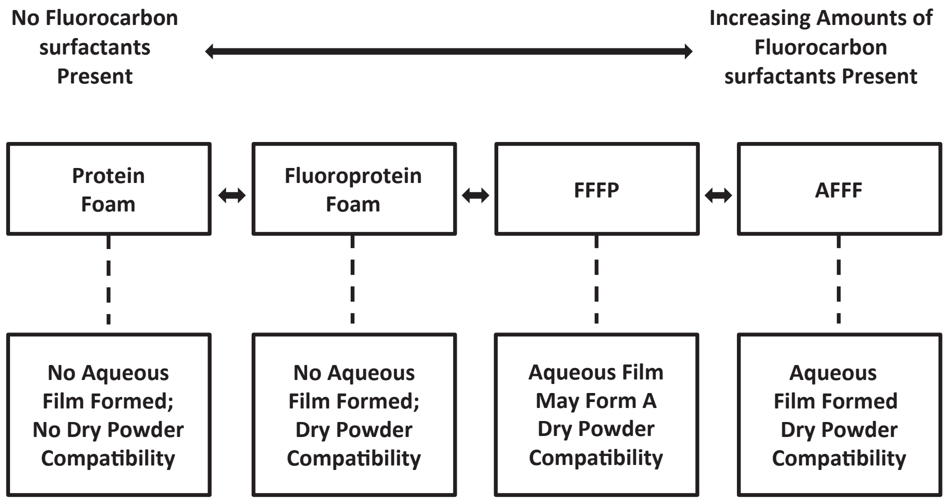

Figure B-1. Relationship of different types of foam agents with respect to fluorocarbon surfactant content, film formation capabilities, and dry powder compatibility. Source: Scheffey and Wright, 1994.

Information on alternatives may also be protected by trade secrets or is not peer-reviewed (UNEP 2011). This document looks specifically at the evolution from the PFOS-based AFFF, provides alternatives to AFFF (and PFOS-based AFFF), and outlines some advantages and disadvantages, as suggested from a variety of sources, associated with each.

Types of Firefighting Foams

Firefighting foams that are commonly used range in their fluorocarbon surfactant content. Fluorine based foams differ in their content of fluorocarbon surfactants (as shown on Figure B-1) making different types of foam agents vary in their performance with regard to knockdown, heat resistance, fuel tolerance and vapor suppression. Table B-1 provides further detail on the different types of firefighting foams used to combat Class B fires.

Alternatives

History

AFFF was developed in the 1960s for use in aviation, marine and shallow pit fires (UNEP 2010). Fluorochemicals in early AFFF formulations were the result of one of two processes, electrochemical fluorination or telomerization. The electrochemical fluorination process was dominated by 3M, a major manufacturer of firefighting foam, with AFFF containing fluorochemicals synthesized by electrochemical fluorination accounting for 75% of the total AFFF stockpiled on US military bases (Place et al. 2012). The remaining stockpiled AFFF in the US contains fluorochemicals produced by telomerization.

In 2002, 3M voluntarily removed an entire class of AFFF which contained and/or degraded into PFOS due to human health and environmental concerns. Regulations in numerous jurisdictions followed, placing restrictions on or banning the production and/or use of AFFF containing PFOS and/or PFOS precursors and/or other PFASs. Regulations in the US, Canada, European Union (EU), Australia and Japan currently ban all new production of PFOS-based products. In the US, Australia and Japan, these regulations do not currently restrict the use of existing stocks of PFOS-based foam. In the EU and Canada, existing stocks of PFOS-based foam were removed

Table B-1. Types of firefighting foams for Class B fires.

	Fluorine-Free Foams (F3)	Protein Foam (PF)	Fluoroprotein Foam (FP)	Film Forming Fluoro-Protein (FFFP)	Aqueous Film Forming Foam (AFFF)	Alcohol-Resistant AFFF (AR-AFFF)
Type	Synthetic	Protein Based	Protein Based	Protein Based	Synthetic	Synthetic
Description	• Formulated without the use of fluorochemicals.	• Mechanical foam produced by proportioning foam concentrate with water at specific rations and using and discharging the resulting solution through an aspirating device.	• Manufactured from protein foam concentrates with added fluorocarbon surfactants.	• Based on protein foam formulations but are produced by increasing the quality and quantity of fluorocarbon surfactants.	• Synthetically formed by combining fluorine-free hydrocarbon foaming compounds with highly fluorinated surfactants.	• Uses plain AFFF concentrate as a base with the addition of a high molecular weight polymer to protect the foam blanket from being destroyed by a polar solvent.
Use(s)	• Hydrocarbon fires. • Aircraft rescue training foam.	• Hydrocarbon fires.	• Hydrocarbon fires. • Hydrocarbon storage tank firefighting.	• Hydrocarbon fires.	• Hydrocarbon fires. • Aircraft rescue.	• Used by city and industrial fire departments due to the effectiveness on both hydrocarbons and polar solvents.
Characteristics	• Re-healing for burn back resistance. • Good heat resistance. • Do not break down to PFOS or PFOA. • Does not form an aqueous film.	• Acts to exclude the air from the fuel vapors to prevent the creation of a combustible mixture. • Relatively slow moving due to its stability when used to cover the surface of a flammable liquid. • Require gentle foam application to avoid contamination if plunged directly onto the fuel surface. • Does not form an aqueous film.	• Provides for vapor suppression and reduced fuel pick up. • More resistant to fuel contamination/pickup. • More mobile foam blanket when discharged onto the flammable liquid. • Does not form an aqueous film.	• Ability to form a vapor sealing film similar to AFFF due to the higher concentrations of fluorochemicals than FP. • Has the quick knockdown of AFFF with the added burn back resistance of standard fluoroprotein foam. • Does not have knockdown as rapid as AFFF when used on a spill fire.	• Forms an aqueous film on the surface of a flammable liquid. • Creates a barrier to exclude air or oxygen, and is capable of suppressing the evolution of fuel vapors.	• Addition of the polymer allows the foams to not be destroyed by polar solvents. • Forms a membrane to separate the polar solvent from the foam blanket.

(continued on next page)

Table B-1. (Continued).

	Fluorine-Free Foams (F3)	Protein Foam (PF)	Fluoroprotein Foam (FP)	Film Forming Fluoro-Protein (FFFP)	Aqueous Film Forming Foam (AFFF)	Alcohol-Resistant AFFF (AR-AFFF)
Materials	• Water-soluble non-fluorinated polymer additives. • Hydrocarbon surfactants.	• Hydrolyzed protein (i.e., hoof and horn meal) • Foam stabilizers. • Preservatives (to prevent bacterial decomposition and corrosion).	• Protein Foam. • Fluorocarbon surfactants.	• Protein Foam. • Increased quantity of fluorocarbon surfactants.	• Synthetic foaming agents (hydrocarbon surfactants). • Solvents (i.e., viscosity leveler) • Fluorocarbon surfactants. • Small amount of salts. • Foam stabilizers.	• Similar inputs to AFFF concentrate. • Polysaccharide polymer.
Environmental Considerations	• Considered to be biodegradable, low in toxicity, and can be treated in sewage treatment plants.	• Considered to be biodegradable and low in toxicity.	• Contains stable, environmentally persistent fluorinated degradation products. • May require pre-treatment prior to standard wastewater treatment plants.	• Contains stable, environmentally persistent fluorinated degradation products. • May require pre-treatment prior to standard wastewater treatment plants.	• Contains stable, environmentally persistent fluorinated degradation products. • May require pre-treatment prior to standard wastewater treatment plants.	• Contains stable, environmentally persistent fluorinated degradation products. • Requires pre-treatment prior to standard wastewater treatment plants.
North American Standards	• UL 162 (Type 3 application), Standard for Safety for Foam Equipment and Liquid Concentrates.	• UL 162 (Type 3 application), Standard for Safety for Foam Equipment and Liquid Concentrates.	• UL 162 (Type 3 application), Standard for Safety for Foam Equipment and Liquid Concentrates.	• UL 162 (Type 3 application), Standard for Safety for Foam Equipment and Liquid Concentrates. • CAN/ULC-S563	• Mil-F-24385F • CAN/ULC-S560	• UL 162 (Type 3 application), Standard for Safety for Foam Equipment and Liquid Concentrates. • CAN/ULC-S560
Application Technique	• Aspirating Device. • Non-Aspirating Device. • Sub-surface Injection Method.	• Must always be used with an air aspirating type discharge device.	• Must always be used with an air aspirating type discharge device.	• Air-aspirating or Non Air-aspirating nozzles. • Does not provide expansion ratios as good as AFFF with a non-aspirating nozzle.	• Air-aspirating or Non Air-aspirating nozzles	• Air-aspirating or Non Air-aspirating nozzles. • When used on an alcohol fire, an air-aspirating nozzle will provide better performance.
Application Rate (gpm/sq.ft)[1]	.16	.16	.16	.10	.10	.10

[1] http://www.chemguard.com/about-us/documents-library/foam-info/general.htm

from service in 2011 and 2013, respectively. Production and sale of PFOS-based AFFF in China has continued.

In the early 2000s, following 3M's decision, the US EPA indicated that some early alternatives to PFOS-based AFFF can break down into PFOA or other perfluorocarboxylic acids (PFCAs) which, like PFOS, have been observed to be persistent in the environment. As a result, in 2006, the US EPA introduced a voluntary directive through the global 2010/2015 PFOA Stewardship Program which called for a 95 percent reduction of plant emissions and product content of PFOA, PFOA precursors, and related homologue materials by 2010, and a 100 percent reduction by 2015. This global stewardship program has been adopted by other countries including Canada. Since 2006, both the US and Canada have taken steps to phase out the production and use of C_8-based fluorotelomers. This has also contributed to a shift by AFFF manufacturers toward using shorter chain (i.e., PFCAs ≤ C_6, having six or less carbon molecules) fluorinated chemicals. The 2010/2015 PFOA Stewardship Program is voluntary, and there are no restrictions banning the use of C_8-based fluorotelomers.

The implementation of regulations brought about substantial research and development to find substitutes to PFOS-based AFFF. The following sections identify alternatives to PFOS-based AFFF and AFFF that can break down into other PFASs.

Fluorine Based Foam Agents

Description

The FAA identifies the following fluorinated agents for airport firefighting involving hydrocarbon fuels:

- Aqueous Film-Forming Foam (AFFF);
- Fluoroprotein Foam (FP); and,
- Film-Forming Fluoroprotein Foam (FFFP).

Similarly, Transport Canada recognizes AFFF and FFFP foams to be the principal extinguishing agents for airports.

What gives these fluorine based foams their function and properties are the fluorocarbon surfactants. Fluorocarbon surfactants are not naturally occurring; rather, they are man-made chemicals that are used in firefighting due to their ability to reduce surface tension and form a film on top of lighter fuel (Sontake and Waugh, 2014). Since production of PFOS-based AFFF ceased, most modern AFFF (except some produced in China and India) contains fluorocarbon surfactants produced by telomerization. These are referred to as fluorotelomers. Fluorotelomers do not break down into PFOS and do not contain any chemicals currently considered to be persistent, bioaccumulative, and toxic (Melkote et al. 2012).

Although currently thought to be better practice than using PFOS-based AFFF, there is still some uncertainty with respect to potential environmental impacts associated with other types of PFASs found in fluorotelomer based foams. Early alternatives to PFOS-based AFFF that contained longer chain (C_8-based) fluorotelomers are on the path towards being phased out by producers due to their potentially hazardous and long-range transport properties. This "phase-out" has created a shift towards shorter chain C_6, C_4 and C_3-based perfluoroalkylated chemicals, which are perceived to be less problematic. The most common and most widely used are C_6-based fluorotelomers. The reformulated C_6-based fluorotelomers are used in AFFF, FFFP, and FP foams.

The predominant breakdown product from the C_6-based fluorotelomers is referred to as the 6:2 fluorotelomer sulfonate (6:2 FtS) (Cortina and Korzeniowski, 2008). A broad range of existing data suggest that 6:2 FTS is not similar to PFOS in either its physical or eco-toxicological properties (Cortina 2010). 6:2 FTS does, however, have the potential, depending on environmental conditions, to eventually degrade to PFHxA (perfluorohexane), PFPeA (perfluoropentanoic acid) and 5:3 fluorotelomer acid.

Benefits

The benefits presented in the literature and by product manufacturers on the use of fluorine based foams, specifically fluorotelomer-based foams, include:

Strong Performance—In addition to stability, a key factor in the performance of firefighting foams containing fluorocarbon surfactants is their extremely low surface tension, which has been shown to not be matched with other surfactants apart from PFOS itself (UNEP 2011). It is this stability that creates rapid surface migration to contribute to high-speed coating processes, beneficial in the event of a fire that involves hydrocarbons. Fluorocarbon surfactants in firefighting foams contribute to the strong performance in quickly and effectively extinguishing fires resulting from highly combustible and flammable materials as they provide rapid extinguishment, burnback resistance, and protection against vapor release (FFFC 2014).

Compliance—In the US, the MIL-SPEC (MIL-F-24385) specifications are known to be the most stringent standards for firefighting foams. Only fluorotelomer-based AFFF foam agents extinguished gasoline and heptane fires in less than 30 seconds, passing the test to qualify for the MIL-SPEC specification. In the US, the FAA requires all US airports to carry AFFF agents that have met the MIL-SPEC specifications. In Canada, it is required that AFFF meet the ULC Standard, CAN/ULC-S560. There are many fluorotelomer based AFFF products that meet this standard for use at airports in both the US and Canada.

Low Hazard Profile (based on current data)—Fluorotelomer based foams do not break down into PFOS (perfluorooctance sulfonate) or homologues of PFOS, nor do they break down into any chemicals that are currently listed as persistent organic pollutants (POPs) under the Stockholm Convention (FFFC 2014). Recent studies of fluorotelomers that break down into 6:2 FTS show it to have low acute, sub-chronic and aquatic toxicity, negative genetic and developmental toxicology, not to be bio-accumulative according to regulatory criteria, and to be significantly lower than PFOS in biopersistence (Seow 2013). A pilot study determined that since the phase-out of PFOS based materials in 2002, there has been a 60% decline in PFOS concentrations in serum samples collected from the Red Cross in 2006 in comparison to 2000–2001 data (Olsen et al. 2008). This is consistent with the timeline of phase-out and the half-life of PFOS.

Disadvantages

The disadvantages presented in the literature and by product manufacturers on the use of fluorine-based foams include:

Environmental Persistence—While fluorotelomers are low in biopersistance, they can be considered as environmentally persistent. All fluorinated materials are highly persistent in the environment due to their perfluorinated chains that degrade very slowly, if at all, under environmental conditions (Blum et al., 2015). Measurements made at former US military firefighting foam training sites found that 6:2 FTS has an environmental half-life of at least a decade (Seow, 2013). In addition, according to the information provided by Germany in 2011 to UNEP, due to the very limited ability of the C_6-based perfluroalkylates bodies to adsorb, it is difficult to remove these chemicals from water (UNEP 2011). More recently, the Madrid Statement on Poly-and Perfluoroalkyl Substances (2015) has come forward to suggest that the use of the entire class of PFAS (including the short chain alternatives) should be avoided due to their environmental persistence. Use of the short-chain alternatives may not reduce the amount of PFAS in the environment, and the environmental impacts may be compounded by use in larger quantities required to provide the same performance (Blum et al. 2015).

Limited Data—There are limited independent pieces of research or studies on the environmental and human health impacts of AFFF formulated with fluorotelomers, in comparison to the research done for foams that use PFOS and PFOA. In addition, there is little publicly available information on the chemical structures, properties, uses and toxicological profiles of these fluorotelomer based alternatives. As is suggested in Place et al. (2012), further research studying the fate of the fluorochemicals during biodegradation is needed as the environmental behavior and toxicity of individual fluorinated surfactants is still unknown (Place et al. 2012).

Products

There are a number of AFFF, FFFP, and FP products that are available today that use fluorochemicals, particularly C_6-based fluorotelomers as inputs. These firefighting foams are formulated using their own blends or use inputs from other manufacturers (e.g., Chemours, Dynax). Inputs currently on the market include:

- Forafac® products, with 65–95% C_6 fluorinated amphoteric telomers based on perfluorohexyl ethyl sulfonamide—Produced by Chemours (Dupont).
- Novec™ 1230 Fire Protection Fluid containing dodecafluoro-2-methylpentan-3-one—Produced by 3M.
- Dynax DX1025 – blend of C_6-based fluorocarbon surfactants – Produced by Dynax America Corporation.

Fluorine-Free Firefighting Foams

Description

Fluorine-free firefighting foams, sometimes referred to as "F3s," are formulated without the use of fluorochemicals. To be considered fluorine-free, these foams must not contain either fluorocarbon surfactants or fluoropolymers. They instead contain water-soluble non-fluorinated polymer additives and increased levels of hydrocarbon detergents (Seow 2013). In general, the approach to reformulating foams to be fluorine free has been to increase hydrocarbon surfactant levels to compensate for the removal of fluorine (Melkote et al. 2012).

Free of fluorochemicals, fluorine-free foams do not degrade into PFOS or PFOA and as such these foams are considered to be more environmentally friendly. In Norway, for example, Avinor phased out the use of AFFF containing fluorine and fluorocarbon surfactants in 2012. The fluorine-free foam used in Avinor meets the International Civil Aviation Organization standards (ICAO level B) on fire-extinguishing performance, meeting both safety and environmental requirements. The use of fluorine-free foams has been suggested as an alternative for use as training foams and as fluids/methods for system and equipment testing.

It has been noted however that some foam concentrates that degrade rapidly and completely in the environment, such as Class A and fluorine-free Class B foams containing only hydrocarbon surfactants, are likely to be more acutely toxic to aquatic organisms than Class B AFFF foams containing fluorocarbon surfactants and hydrocarbon surfactants, which degrade more slowly and incompletely because of their organo-fluorine content. Fluorine-free foams also fail to provide the same firefighting performance as the fluorinated alternatives.

Benefits

The advantages presented in the literature and by product manufacturers on the use of fluorine-free foams include:

Less Environmentally Persistent—Free of fluorochemicals, fluorine-free foams cannot break down to PFOS or PFOA. Bioaccumulation and persistence are also unlikely to be significant unless unusual additives are present (Seow 2013). Some fluorine-free foam products are also described as being substantially biodegradable.

Training—Fluorine-free foams can play an important role in training exercises where controls can be put in place to reduce environmental risks. These foams can mimic the induction performance of fluorinated foams.

Disadvantages

The disadvantages presented in the literature and by product manufacturers on the use of fluorine-free foams include:

Decrease in Performance—Fluorine-free foams have been shown to not have the same performance as their fluorinated counterparts. They are currently not able to provide the same level of fire suppression capability, flexibility, applicability, and scope of usage as AFFF firefighting foams (Industrial Fire Journal, 2013). An analysis of the performance of two available fluorine-free foams found that they would need to be replenished three times more often than AFFF to provide the same level of fire protection (Schaefer et al. 2008). In the same analysis, it was found that some fluorine-free foams offered little or no performance for the suppression of flammable vapors.

Limitations in the effectiveness of fluorine-free foams are in large part due to the oil loving properties of the hydrocarbon surfactants. Lab experiments by Dynax show that a commercial fluorine-free foam becomes flammable and degrades when contaminated with fuel in contrast to commercial fluorocarbon surfactant-based foams that do not become flammable or degrade with fuel contamination (Jho 2013). This is observed due to the oleophilicity (fuel attraction) of hydrocarbon surfactants in fluorine-free foams.

Increase in Short-Term Toxicity—In order to achieve the properties for AFFF, particularly the low surface tension, many fluorine-free foams rely on increasing the hydrocarbon surfactant levels to compensate for the removal of fluorine. While many fluorine-free foams are neither biopersistent nor bioaccumulative, the increase in hydrocarbons can cause foams to exhibit extremely high aquatic toxicity, greater than what is observed with AFFF (Melkote et al. 2012).

Higher Biochemical Oxygen Demand—Fluorine-free foams containing hydrocarbon surfactants will emulsify with oil based fuels in an aquatic environment. This creates higher biochemical oxygen demands due to the increase in required oxygen needed to degrade the foam. An increase in required oxygen reduces available oxygen for organisms in the aquatic environment.

Higher Costs—It has been difficult for fluorine-free foams to gain a firm foothold in the market, partly because of established supplier relationships with manufacturers of C_6-based fluorotelomers (UNEP 2011). In the United Kingdom, for example, it was shown that the fluorine-free alternatives to firefighting foams are 5–10% more expensive than fluorocarbon surfactant-based foams. It has been suggested, however, that as the market size for fluorine-free alternatives increases the price will fall (UNEP 2011).

Products

Fluorine-free foams have been developed by most foam manufacturers as alternatives to AFFF and are being used for some applications in Europe and Australia, particularly in environmentally sensitive areas. These products use inputs that include:

- Silicone-based surfactants;
- Hydrocarbon-based surfactants;
- Synthetic detergent foams; and,
- Protein-based foams.

As of late, these foams are used more for training purposes than for emergency response.

Conclusion

There are commercially produced alternative foam types to AFFF. Most of these alternative foam types contain PFASs (with the exception of the fluorine-free foams). However, all available firefighting foam alternatives exhibit properties that have the potential to impact the environment and/or human health, whether they are fluorotelomer-based or fluorine-free. Recognizing the importance of efficacy and safety in fire protection, these foams will continue to be used. Therefore, it is important to consider preventative approaches and best management practices that limit the discharge off firefighting foams to the environment and protect the individuals using these foams.

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APPENDIX C

Quick Guide to MAPA Screening Tool

The Managing AFFF and PFASs at Airports (MAPA) screening tool has been designed to assist airports with the identification of areas of potential environmental concern (APECs) on or near their airport.

There are two versions of the screening tool, one entitled "MAPA Screening Tool" and the other "MAPA Screening Tool Compatibility Version." If you are utilizing Microsoft Excel 97 to 2003 or 2007, please use the file entitled "MAPA Screening Tool Compatibility Version." If running a more recent version of Microsoft Excel, please use the file entitled "MAPA Screening Tool." Please note that the screening tool works best when used in Microsoft Excel 2010.

Macros Security

The MAPA Screening Tool consists of multiple worksheets and embedded macros. Macros automate frequently used tasks; the ones used in the MAPA Screening Tool are created with Visual Basic for Applications (VBA) and have been written by Dillon Consulting. When you first open the MAPA Screening Tool, macros need to be enabled for the program to function and carry out its tasks.

Some macros pose a potential security risk. A person with malicious intent can introduce a destructive macro, in a document or file, which can spread a virus on your computer. In Microsoft Office Excel™, you can change the macro security settings to control which macros run and under what circumstances when you open a workbook. The following steps discuss how to enable macros.

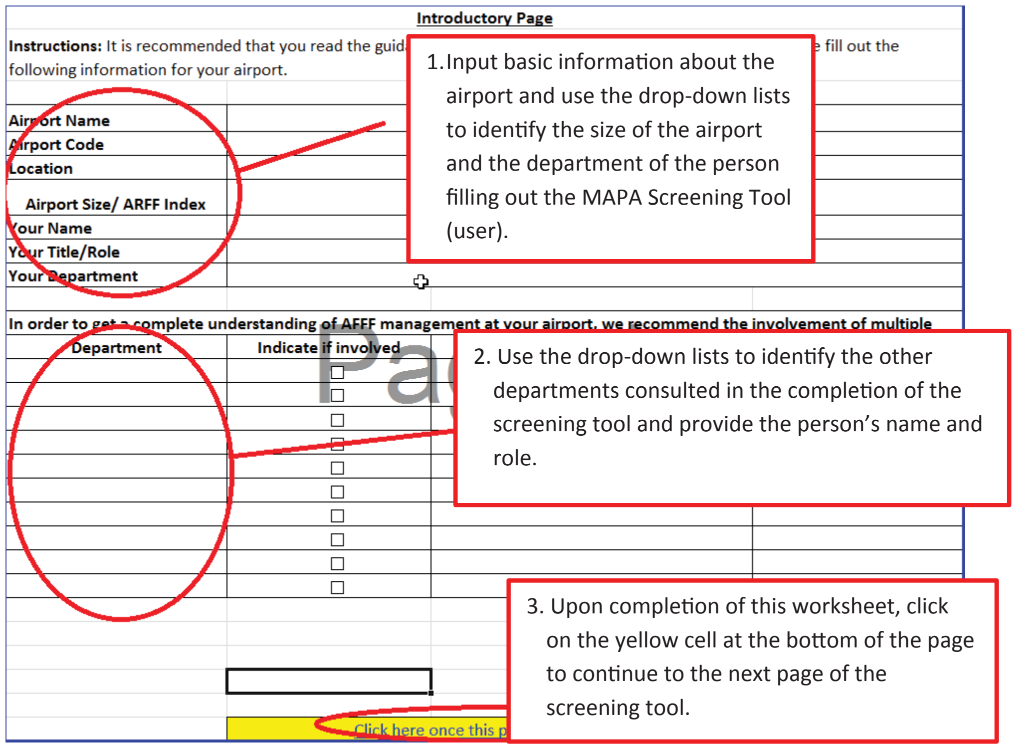
When first opening the program, a pop-up window generally provides the user with an option to enable macros. If there is no pop-up window, or if the user has accidentally clicked "do not enable macros," the user should refer to the online instructions provided by Microsoft Office for their version of Excel™: https://support.office.com/en-us/article/Enable-or-disable-macros-in-Office-files-12b036fd-d140-4e74-b45e-16fed1a7e5c6#__toc311698310

Typically, these instructions include the following steps (with variations on naming conventions, e.g., File Tab versus Microsoft Office Button). Microsoft Office provides a disclaimer on the risks associated with running unknown-source Macros.

- Click the Microsoft Office Button (or File Tab), and then click Excel Options.
- Click Trust Center, click Trust Center Settings, and then click Macro Settings.
- Click the options that you want: **Enable all macros** (not recommended, potentially dangerous code can run). Click this option to allow all macros to run. This setting makes your computer vulnerable to potentially malicious code and is not recommended.

Worksheet 1: Introductory Worksheet

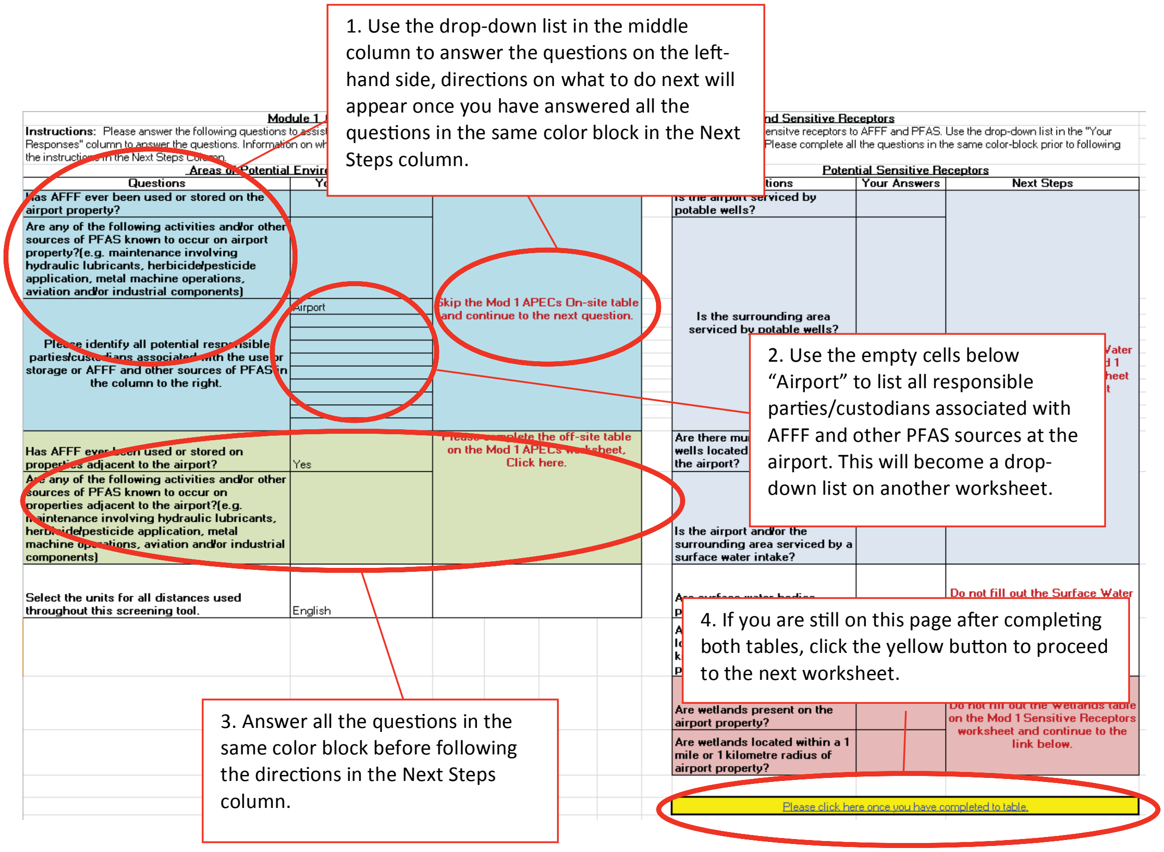
The first worksheet of MAPA collects basic information about the airport and the users involved in completing the screening tool, which will be incorporated into a cover page of the document produced as a result of completing MAPA. Users should complete the fields to the best of their knowledge; however, it is strongly recommended to include the input of various people in the completion of the MAPA Screening Tool as different departments will have different AFFF and PFAS knowledge.



Worksheet 2: Module 1 Overview Questions

The purpose of worksheet #2 is to identify areas of potential environmental concern (APECs) and potential receptors through a series of overview questions. After the introductory worksheet (Worksheet 1), the second worksheet of the screening tool, titled "Module 1 Overview Questions," consists of two tables: APECs and potential sensitive receptors. On worksheet #2, users will identify APECs, both on-site (on airport property) and off-site (in the vicinity of the airport property), and sensitive receptors (e.g., potable water, nearby surface water bodies, wetlands). The following information categories are color coded:

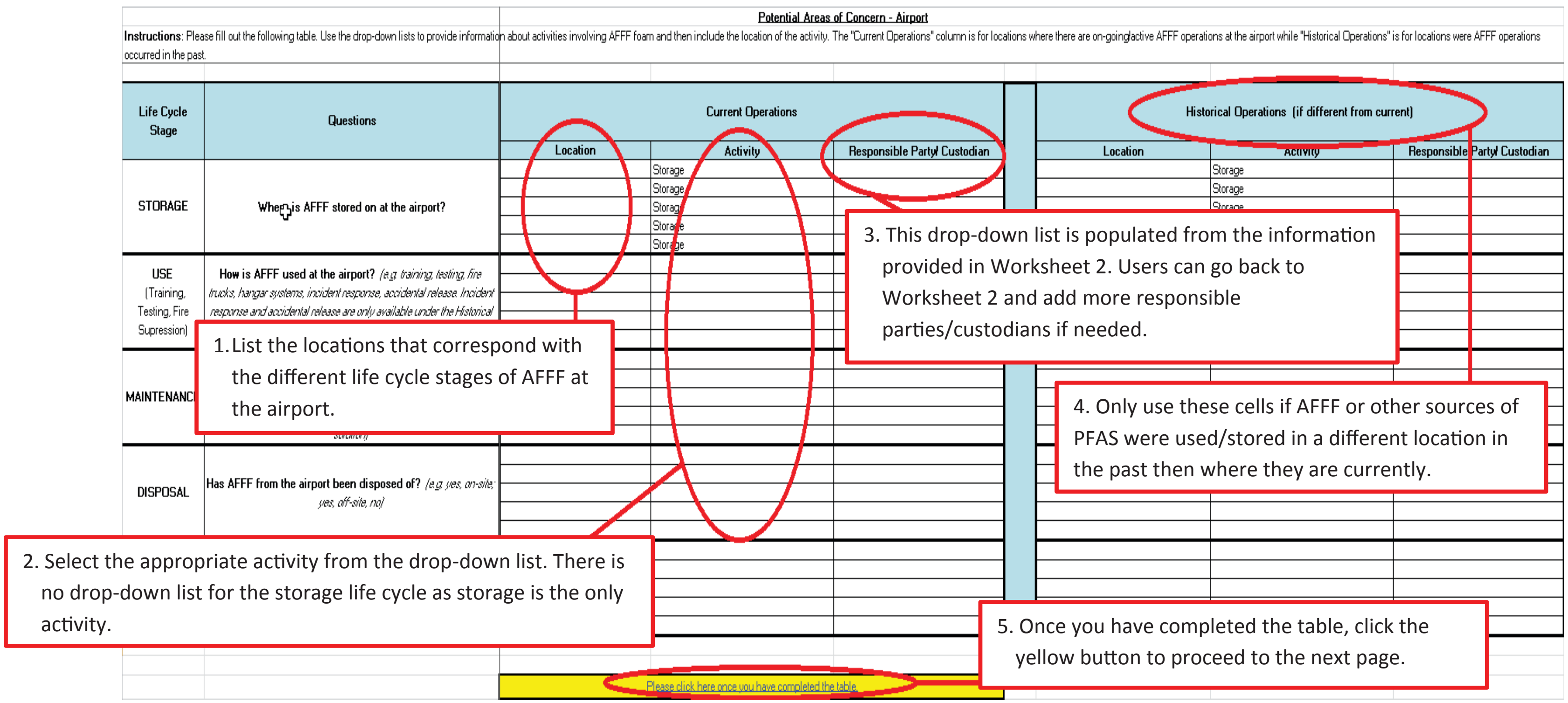
- Information associated with on-site APECs will be entered in cells colored blue;
- Information associated with off-site APECs will be entered in cells colored green; and,
- Information associated with sensitive receptors will be entered in cells colored gray.



Worksheet 3: APECs

Worksheet 3, titled “APECs,” seeks to gain a basic understanding of the life cycle of AFFF at your airport and specific locations of potential concern, if any exist. For the AFFF life cycle stages listed in the first column, provide the location, activity and responsible party associated with AFFF on the airport property.

On the same page is an identical table for APECs that are off-site, which should be filled out in the same manner. The only difference is in the place of a “Responsible Party/Custodian” column, there is a drop-down list to identify the land use type.


Potential Areas of Concern - Airport
Instructions: Please fill out the following table. Use the drop-down lists to provide information about activities involving AFFF foam and then include the location of the activity. The "Current Operations" column is for locations where there are on-going/active AFFF operations at the airport while "Historical Operations" is for locations were AFFF operations occurred in the past.
Life Cycle Stage
Questions
Current Operations
Location
Activity
Responsible Party/ Custodian
Historical Operations (if different from current)
Location
Responsible Party/ Custodian
Storage
STORAGE
Where is AFFF stored on at the airport?
USE (Training, Testing, Fire Supression)
How is AFFF used at the airport? (e.g. training, testing, fire trucks, hangar systems, incident response, accidental release. Incident response and accidental release are only available under the Historical
DISPOSAL
Has AFFF from the airport been disposed of? (e.g. yes, on-site; yes, off-site, no)
1. List the locations that correspond with the different life cycle stages of AFFF at the airport.
2. Select the appropriate activity from the drop-down list. There is no drop-down list for the storage life cycle as storage is the only activity.
3. This drop-down list is populated from the information provided in Worksheet 2. Users can go back to Worksheet 2 and add more responsible parties/custodians if needed.
4. Only use these cells if AFFF or other sources of PFAS were used/stored in a different location in the past then where they are currently.
5. Once you have completed the table, click the yellow button to proceed to the next page.
Please click here once you have completed the table.

Worksheet 4: Sensitive Receptors

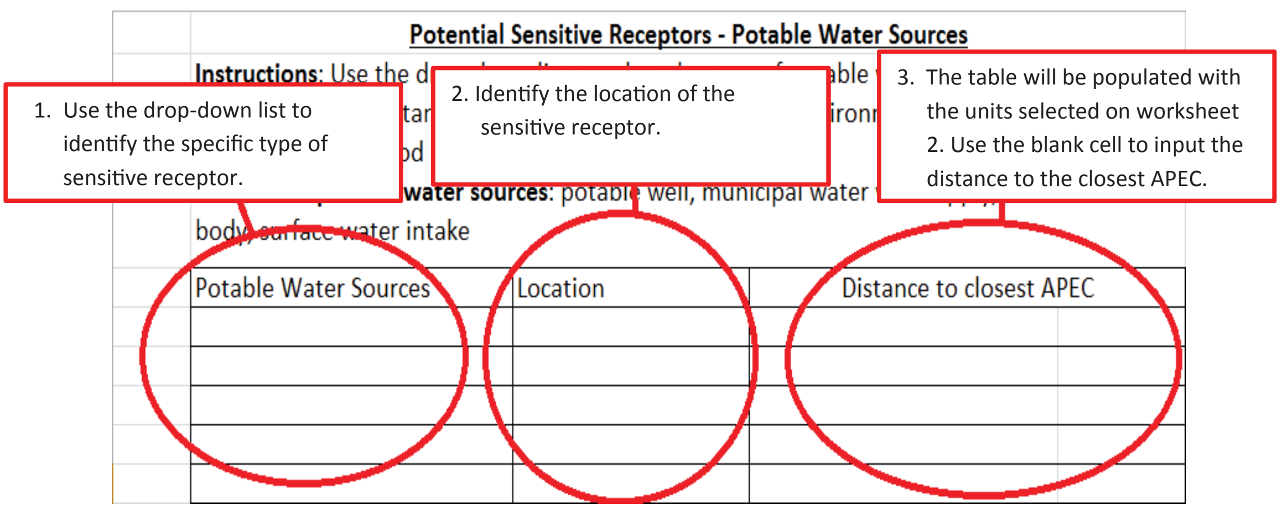
Worksheet 4: Sensitive Receptors builds on the identified potential receptors from Worksheet 2 and assists with clarifying associated potential risk. Users should ensure that they are only completing the tables that are applicable to their site, based on their entries on Worksheet 2, as the three types of sensitive receptors (potable water sources, surface water bodies, and wetlands) are included on Worksheet 4 in individual tables. The three sensitive receptor tables are to be completed in the same manner.

Potable Water Sources: Potable water (i.e., drinking water) sources, if impacted with PFASs, may present an unacceptable risk to human health via ingestion. Use the drop-down list in the first column of the Potable Water Sources worksheet to describe the type of potable water source. Options include:

- Potable well: groundwater
- Municipal water well supply: groundwater
- Surface water body: A surface water body (e.g., lake or river) that is used as a source of drinking water

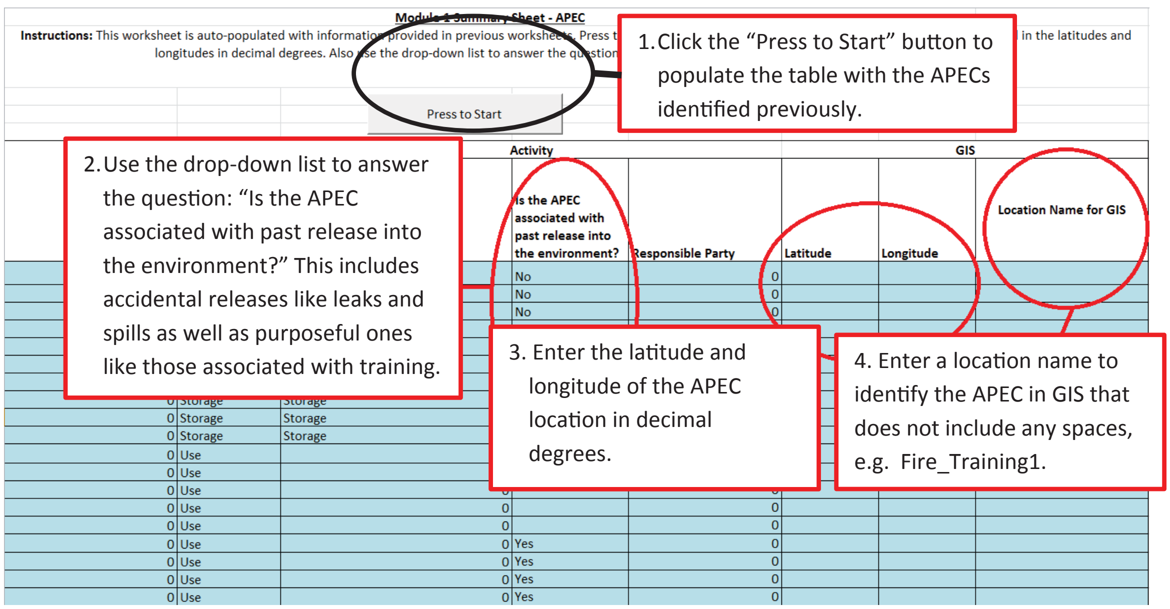
Surface Water Bodies: In addition to being a potential potable water source, surface water bodies also represent a potential habitat for sensitive receptors. Identify the type of surface water body (e.g., lake, river, stream, pond, ocean, or ditch) using the drop-down menu, assign a location name, and indicate, if known, the proximate distance to the nearest APEC previously identified.

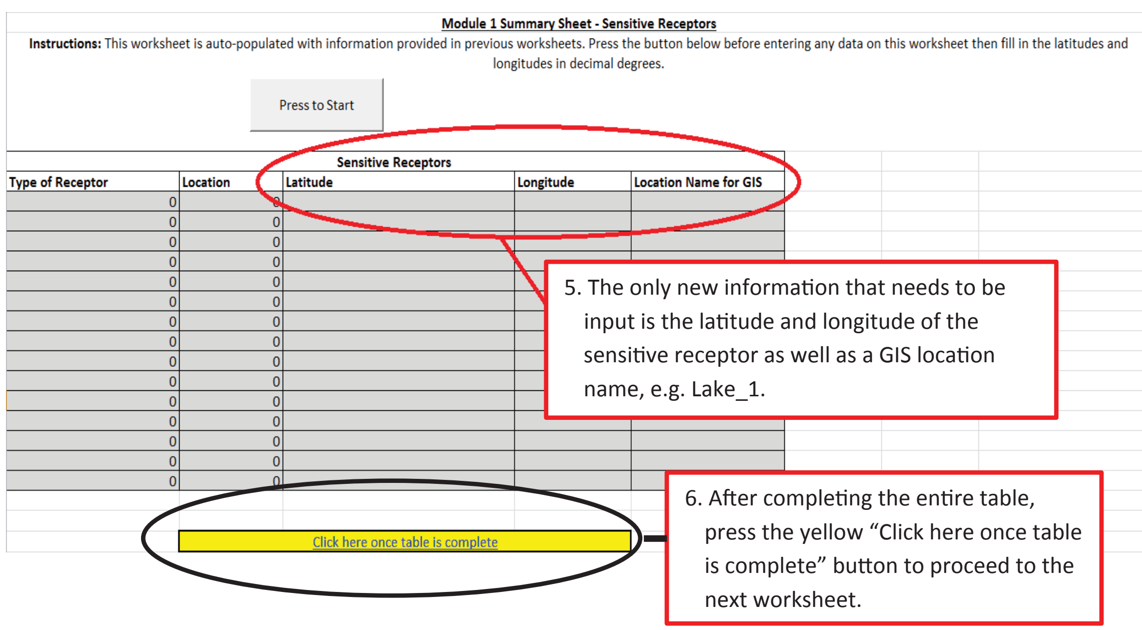
Wetlands: Wetlands, like surface water bodies, represent a potential habitat for sensitive receptors. Types of wetlands vary; the user is encouraged to characterize the type of wetland using the basic descriptions provided in the screening tool using the drop-down menu. The user should identify each wetland by assigning a location name and indicating, if known, the proximate distance to the nearest APEC previously identified.



Worksheet 5: Module 1 Summary

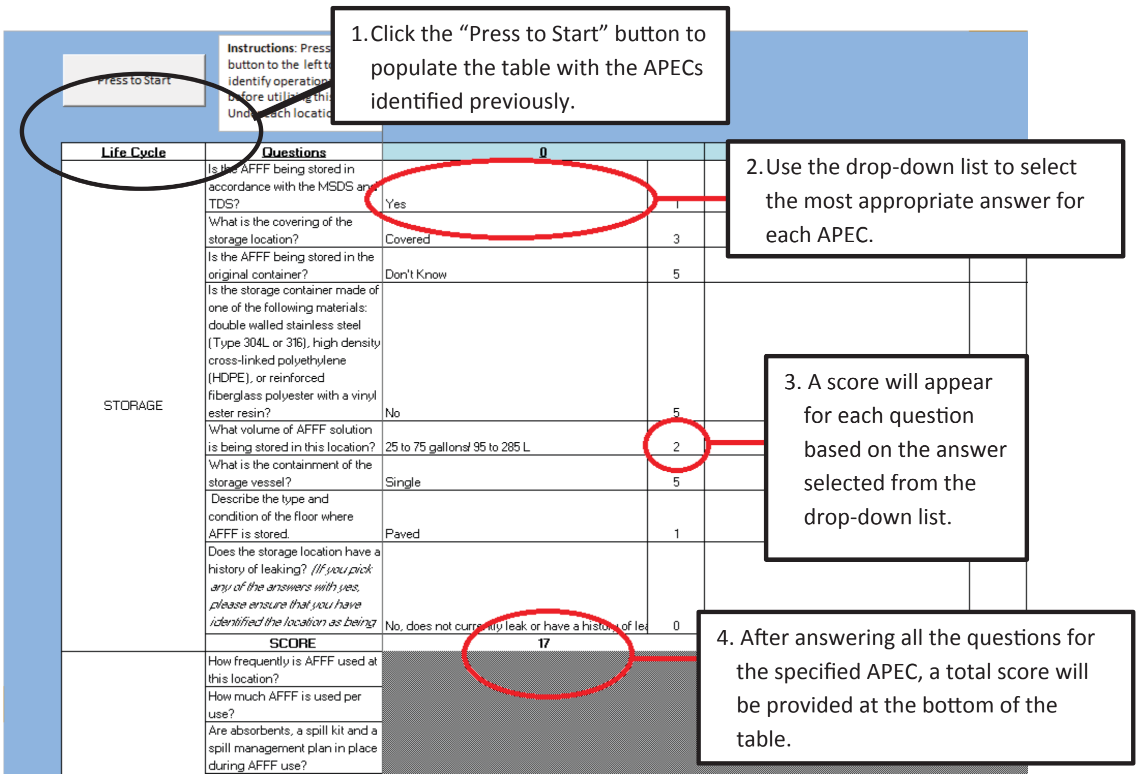
Worksheet 5: Module 1 Summary summarizes the APECs and sensitive receptors identified at the airport, based on previous worksheets. Before entering any new information, click the "**Press to Start**" button. If using the compatibility version of the tool, **press Crtl, Shift and F** to activate the macro that populates the table appropriately. Once completed, this worksheet can be used to create GIS maps, which can be useful when visualizing locations of potential concern and their interaction with potentially sensitive receptors. Press the yellow "Click here once table is complete" button upon completion of the tables.





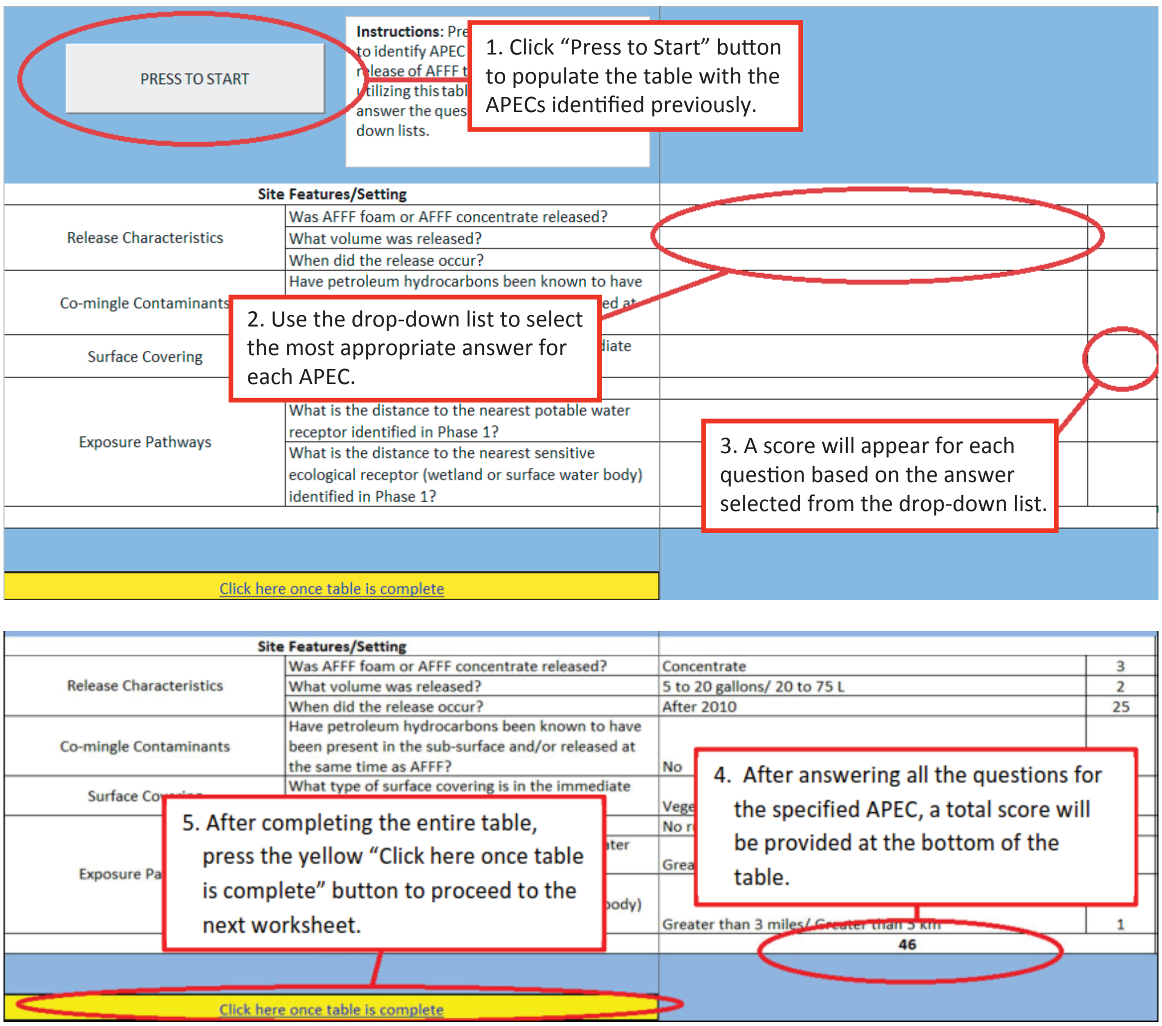
Worksheet 6: MOD 2 OPS APECS

Worksheet 6 is used to input further details on the operational life cycle of AFFF at an airport. Worksheet 6 will self-populate with the operational APECs identified in Worksheet 3. Click the "Press to Start" button in the upper left hand corner to populate the table with APEC names. If using the compatibility version of the tool, press Crtl, Shift and A to activate the macro that populates the table appropriately. Answer questions applicable to the APECs identified at the top of each column. Each response corresponds to a numerical value that will be used to score the potential risk associated with each APEC. Once the table is complete, click the yellow "Click here once table is complete" button at the bottom of the table.



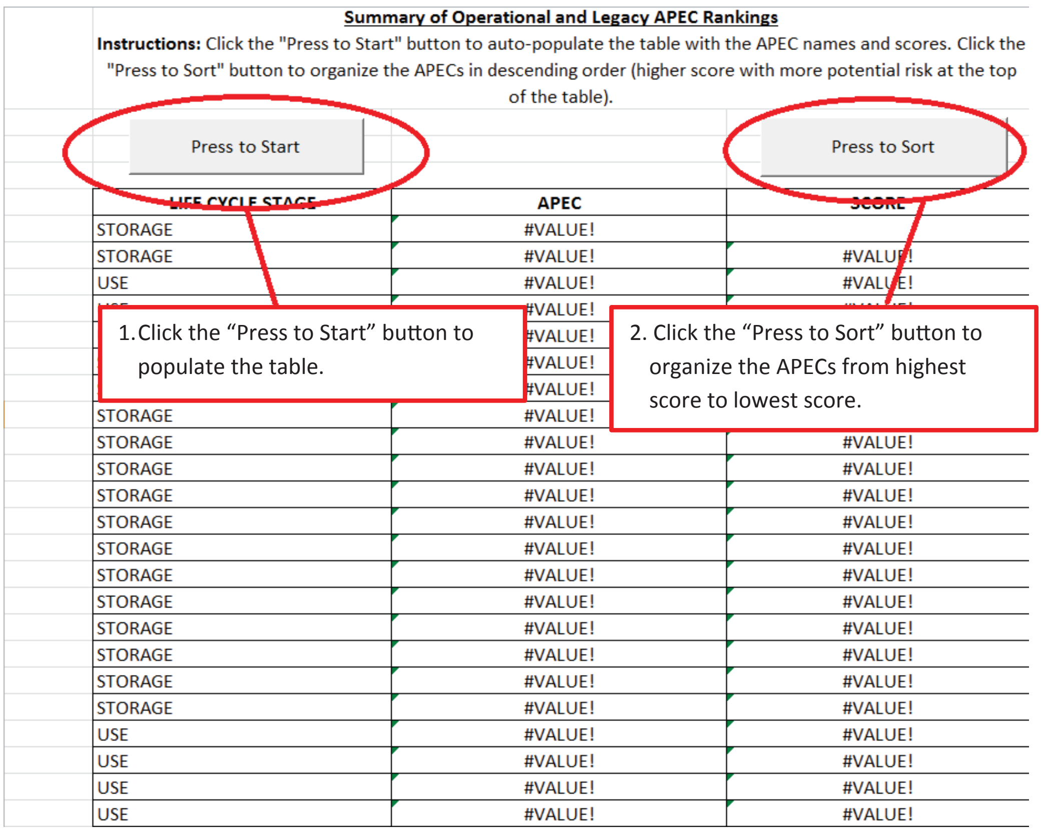
Worksheet 7: MOD 2 Legacy APECS

The table will auto-populate with the locations identified on Worksheet 5 when the "Press to Start" button is clicked. If using the compatibility version of the tool, press Crtl, Shift, and B to activate the macro that populates the table appropriately. Worksheet 7 is used to input further details associated with APECs associated with PFAS impacts in the environment. Questions are posed about the release characteristics, co-mingling of contaminants, surface covering, and exposure pathways of AFFF at each APEC. Each answer in the drop-down list is associated with a score. When all the questions for an APEC have been answered, a score for that APEC is provided at the bottom of the table. Press the yellow "Click here once table is complete" button upon completion of the table.



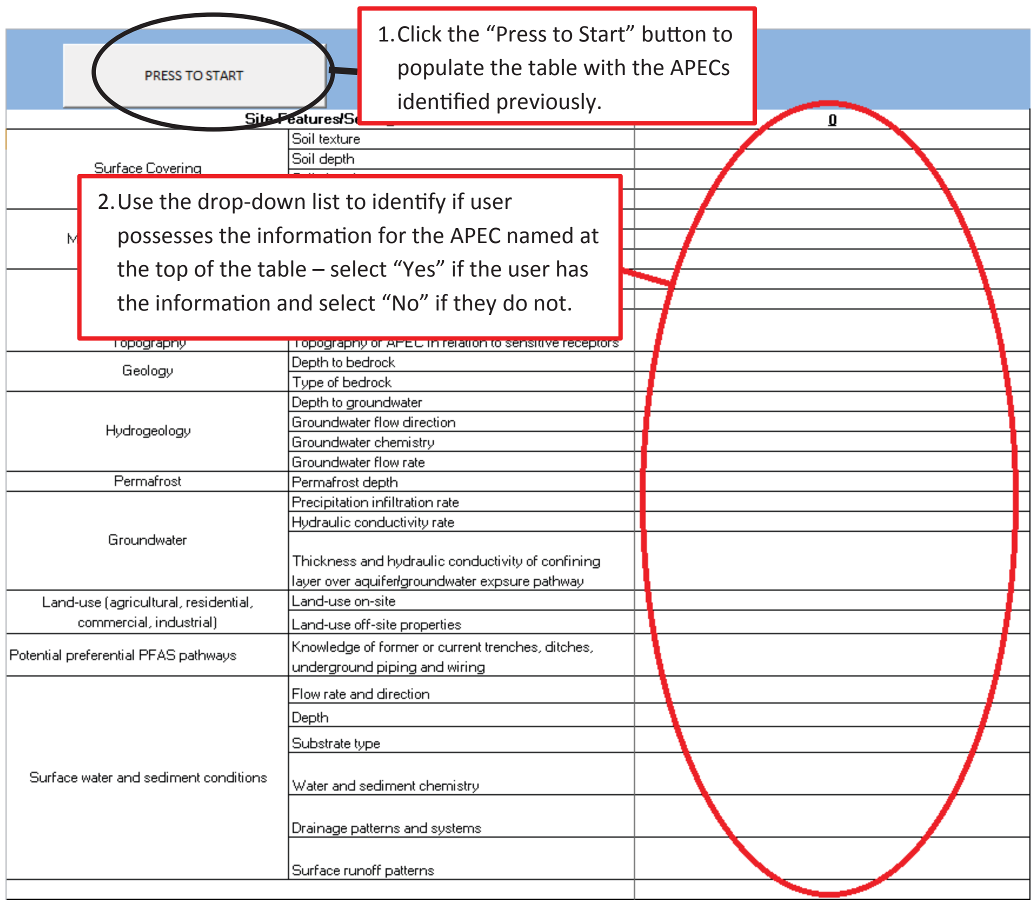
Worksheet 8: MOD 2 Ranking Summary

Worksheet 8: Ranking Summary combines operational and legacy APECs for comparison and preliminary ranking in order of potential concern. This table will auto-populate with the information input previously and lists the life cycle stage, APEC, and score for comparison. If using the compatibility version of the tool, press Crtl, Shift, and C to activate the macro that populates the table appropriately, and then press Crtl, Shift and D to sort the APECs from highest to lowest scores.



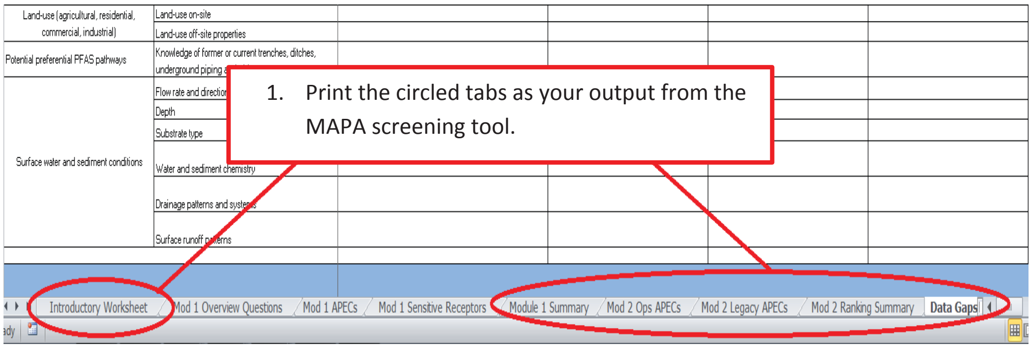
Worksheet 9: Data Gaps

Worksheet 9: Data Gaps identifies additional information that is needed for a further analysis of potential impacts associated with AFFF. Click the "Press to Start" button to populate the table with APECs previously identified. If using the compatibility version of the tool, press Crtl, Shift, and E to activate the macro that populates the table appropriately. Use the drop-down list to identify whether or not the specified information is available for the APEC. For the most part, this is not information expected to be readily on hand; instead it is, in many cases, related to intrusive environmental studies (e.g., groundwater chemistry, precipitation infiltration rate, and surface water and sediment chemistry). The identification of data gaps is important when creating a plan for locations that potentially have AFFF impacts and determining where to allocate resources.



End Product of MAPA Screening Tool

It is recommended that Worksheets 1, 5, 6, 7, 8, and 9 are printed at the completion of the screening tool as outputs for use in the management of AFFF at the airport.



Upon the completion of the nine worksheets of the screening tool, users have

- Identified APECs on and adjacent to airport property.
- Identified potential sensitive receptors on and adjacent to airport property.
- Collected the information needed to create GIS maps for visualization of APECs, sensitive receptors, and exposure pathways.
- Produced a preliminary ranking of potential concern for operational and legacy APECs.
- Identified gaps in data needed for more in-depth analysis of AFFF impacts for each APEC.

The MAPA screening tool can be used

- As a summary of information that the airport has concerning the life cycle of AFFF.
- As a first step in the assessment and remediation of APECs for future development or changes to the airport property in consultation with an AFFF environmental specialist.
- To identify operational practices that would decrease the potential environmental impacts associated with AFFF use.

A printout of Worksheet 5: Module 1 Summary should be shared with your GIS specialist for the creation of maps identifying APECs and sensitive receptors. Mapping the results of Module 1 can

- Make exposure pathways from APECs to sensitive receptors more easily identifiable.
- Allow for improved communication of MAPA screening tool results with other members of staff.
- Provide a visual representation when consulting with an AFFF environmental specialist.

If the user requires further information to complete the screening tool or more background information about the rationale behind various aspects of the screening tool, please refer to Chapter 6 of the reference document.

ATTACHMENT A

Module 2 Questions, Answer Choices, and Scores

Table 1. Operational storage.

Question	Answer Choices	Associated Score
Is the AFFF being stored in accordance with the MSDS and TDS?	Yes	1
	No	5
	Don't Know	5
What is the covering of the storage location?	Enclosed	1
	Covered	3
	Outside or exposed directly to the elements	5
Is the AFFF being stored in the original container?	Yes	1
	No	5
What is the volume of AFFF solution that is being stored in this location?	less than 95 L/ less than 25 gallons	1
	95 to 285 L/ 25 to 75 gallons	2
	285 to 945 L/ 75 to 250 gallons	4
	945 to 2,840 L/ 250 to 750 gallons	6
	2, 840 to 3,785 L/ 750 to 1,000 gallons	8
	More than 3,785 L/ more than 1,000 gallons	10
What is the containment of the storage vessel?	Double	1
	Single	5
Describe the type and condition of the floor where AFFF is stored.	Paved	1
	Slightly cracked pavement	2
	Moderately cracked pavement	3
	Heavily cracked/broken pavement	4
	Earthen	5
Does the storage location have a history of leaking?	No, does not currently or have a history of leaking	0
	Yes, on a couple of occasions	3
	Yes, substantial leaking has occurred	4
	Yes, currently leaks	5

OPERATIONAL STORAGE = MSDS + Covering + Original Container + Volume of AFFF + Containment + Flooring + Leaking

Maximum Score: 40

Table 2. Operational use.

Question	Answer Choices	Associated Score
How frequently is AFFF used at this location?	Less than once per every 5 years	1
	Between 1 and 5 years	2
	Semi-annually	3
	Annually	4
	Monthly	5
How much AFFF is used per use?	0 to 5 gallons/ 0 to 20 L	1
	5 to 20 gallons/ 20 to 75 L	2
	20 to 50 gallons/ 75 to 190 L	4
	50 to 100 gallons/ 190 to 375 L	6
	100 to 500 gallons/ 375 to 1900 L	8
	500 to 1000 gallons/ 1900 to 3800 L	10
	Greater than 1000 gallons/Greater than 3800 L	15
Are absorbents, a spill kit, and a spill management plan in place during AFFF use?	Yes	1
	No	5
	Don't Know	5
Where (ultimate receiver) does the used AFFF (or unused if returned to the manufacturer) go when used?	Sent off-site for disposal	1
	Down the drain	5
	Evaporated off of pavement	5
	Soaked into the ground	8
	Washed/runoff into surface water body	10
How many of the following types of PPE are used during the handling and use of AFFF? *(eye protection, work gloves, nitrile/single-use gloves, fire-retardant/turnout gear, well-ventilated location)*	All	0
	Four	1
	Three	2
	Two	3
	One	4
	None	5
Under current operational conditions, is there exposure contact via direct contact to humans without any of the PPE listed above?	Yes - workers during daily operations	240
	Yes - workers during weekly operations	48
	Yes - workers during monthly operations	12
	Yes - workers during emergency situations	5
	Yes – trespassers	3
	No	0
	Don't know	240

OPERATIONAL USE = (Frequency of Use x Volume of AFFF x AFFF Ultimate Receiver) + Human Exposure + Spill Management + PPE

Maximum Score: 1000

Table 3. Operational maintenance.

Question	Answer Choices	Associated Score
How frequently is the AFFF equipment checked for malfunctions/degradation (leaks, cracks, erosion, etc.)?	Monthly or more frequently	1
	Quarterly	2
	Semi-annually	4
	Annually	8
	Never	10
What is used to clean equipment that had contained AFFF?	Nothing	5
	Rinsed/flushed with water	3
	Cleaned with water and soap/detergent	2
	Rinsed/flushed with a solvent	0
How is AFFF removed from the distribution equipment (deluge systems or fire trucks) during the maintenance activities?	Mechanical pump	1
	Manual pump	3
	Gravity/drain valve	5
	AFFF not removed	10
When AFFF is removed from distribution equipment (deluge systems or fire trucks), what is done with it?	Discharged into temporary storage containers and returned to the equipment	1
	Kept in storage containers	2
	Discharged onto ground	10
	Disposed of off-site	1
What volume of AFFF is used during maintenance (lost in transportation)?	None	0
	Less than 1 gallon	1
	1 to 2 gallons	2
	3 to 5 gallons	3
	More than 5 gallons	5
What is the typical volume of rinsate that results from cleaning equipment that had contained AFFF?	Less than 200 gallons/ Less than 760 L	4
	More than 200 gallons/ More than 760 L	5
	None	0
Describe the type and condition of the floor where maintenance activities are conducted.	Paved	1
	Slightly cracked pavement	2
	Moderately cracked pavement	3
	Heavily cracked/broken pavement	4
	Earthen	5

Table 3. (Continued).

Question	Answer Choices	Associated Score
What is the ultimate receiver of the waste produced from AFFF equipment maintenance activities?	Sent off-site for disposal	1
	Down the drain	5
	Evaporated off of pavement	5
	Soaked into the ground	8
	Washed/runoff into surface water body	10
Are absorbents, a spill kit, and a spill management plan in place during AFFF use?	Yes	1
	No	5
	Don't Know	5
How many of the following procedures are required for the handling of AFFF? (Two or more people involved in the handling of AFFF (single person could do it if they had to), clear procedural standards, procedural training for those handling AFFF, ensuring fittings and connections are tight)	All	0
	Three	2
	Two	3
	One	4
	None	5

OPERATIONAL MAINTENANCE = ((Volume of AFFF + Volume of Rinsate) x Ultimate Receiver) + Equipment Checks + AFFF Removal Method + AFFF Storage during Maintenance + Cleaning Method + Handling Procedures + Spill Management + Flooring

Maximum Score: 145

Table 4. Operational disposal.

Question	Answer Choices	Associated Score
What is the frequency of disposal of AFFF?	1 to 2 years	5
	2 to 5 years	3
	More than 5 years	1
What volume of AFFF is disposed of at a time?	0 to 5 gallons/ 0 to 20 L	1
	5 to 20 gallons/ 20 to 75 L	2
	20 to 50 gallons/ 75 to 190 L	3
	50 to 100 gallons/ 190 to 375 L	6
	100 to 500 gallons/ 375 to 1900 L	8
	500 to 1000 gallons/ 1900 to 3800 L	10
	Greater than 1000 gallons/Greater than 3800 L	15
	Unknown	15
What is the ultimate receiver of the disposed AFFF?	Manufacturer	1
	Incinerator	2
	Down the drain/municipal sewer system	4
	Evaporated off of pavement	6
	Soaked into the ground	8
	Washed/runoff into surface water body	10
	Sent off-site for disposal (waste management contractor or landfill)	3
	Sent off-site for treatment	3

OPERATIONAL DISPOSAL = Frequency of Disposal x Volume of AFFF x AFFF Ultimate Receiver

Maximum Score: 500

Table 5. Legacy APEC.

Question	Answer Choices	Associated Score
Was AFFF foam or AFFF concentrate released?	Foam	3
	Concentrate	5
What volume was released?	0 to 5 gallons/ 0 to 20 L	1
	5 to 20 gallons/ 20 to 75 L	2
	20 to 50 gallons/ 75 to 190 L	4
	50 to 100 gallons/ 190 to 375 L	6
	100 to 500 gallons/ 375 to 1900 L	8
	500 to 1000 gallons/ 1900 to 3800 L	10
	Greater than 1000 gallons/Greater than 3800 L	15
	Unknown	15
When did the release occur?	Before 2010	50
	After 2010	25
	Don't know	50
Have petroleum hydrocarbons been known to have been present in the sub-surface and/or released at the same time as the AFFF?	Yes	5
	No	1
What type of surface covering is in the immediate vicinity of the release?	Paved (concrete or asphalt)	1
	Unvegetated Soil/Gravel	5
	Vegetated -Treed/forested	3
	Vegetated- Meadow/grassland	3
Where does runoff flow at this APEC?	No runoff/infiltration	10
	Overland flow via grassed ditches/swales to surface water body	10
	Overland flow via lined conveyance systems to surface water body	10
	Collected and treated on-site	1
What is the distance to the nearest potable water receptor identified in Phase 1?	0 to 500 m/ 0 to 1640 ft	100
	500 to 1 km/ 1640 to 0.6 miles	75
	1 to 5 km/ 0.6 to 3 miles	25
	Greater than 5 km/ Greater than 3 miles	1
What is the distance to the nearest sensitive ecological receptor (wetland or surface water body) identified in Phase 1?	0 to 500 m/ 0 to 1640 ft	100
	500 to 1 km/ 1640 to 0.6 miles	75
	1 to 5 km/ 0.6 to 3 miles	25
	Greater than 5 km/ Greater than 3 miles	1

LEGACY APEC = ((Concentrate vs. Foam x AFFF Volume x Petroleum Hydrocarbons) + Release Timing + Surface Covering + Runoff Flow + Distance to Potable Water + Distance to Sensitive Ecological Receptor)

Maximum Score: 650

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
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
TDC	Transit Development Corporation
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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