PFAS Sources

PFAS Technical Advisory Subgroup Meeting

April 9, 2019

Agenda

- Overview
- ITRC Update
  - Fact Sheets
  - Upcoming Tools
  - Regulatory Update
- ITRC History/Sources
- Resource Information
- Lists of PFAS Sources
- Evaluation Methods
  - Michigan Model
  - Minnesota Model
  - California Model
- Technical Advisory Group Objectives
- Next Steps

Per- and Polyfluoroalkyl Substances (PFAS)

- Large class of surfactants with unique chemical & physical properties that make many of them extremely persistent and mobile in the environment
- Unique physical and chemical properties impart oil and water repellency, temperature resistance, and friction reduction.
- Used since 1940s in wide range of consumer and industrial applications.





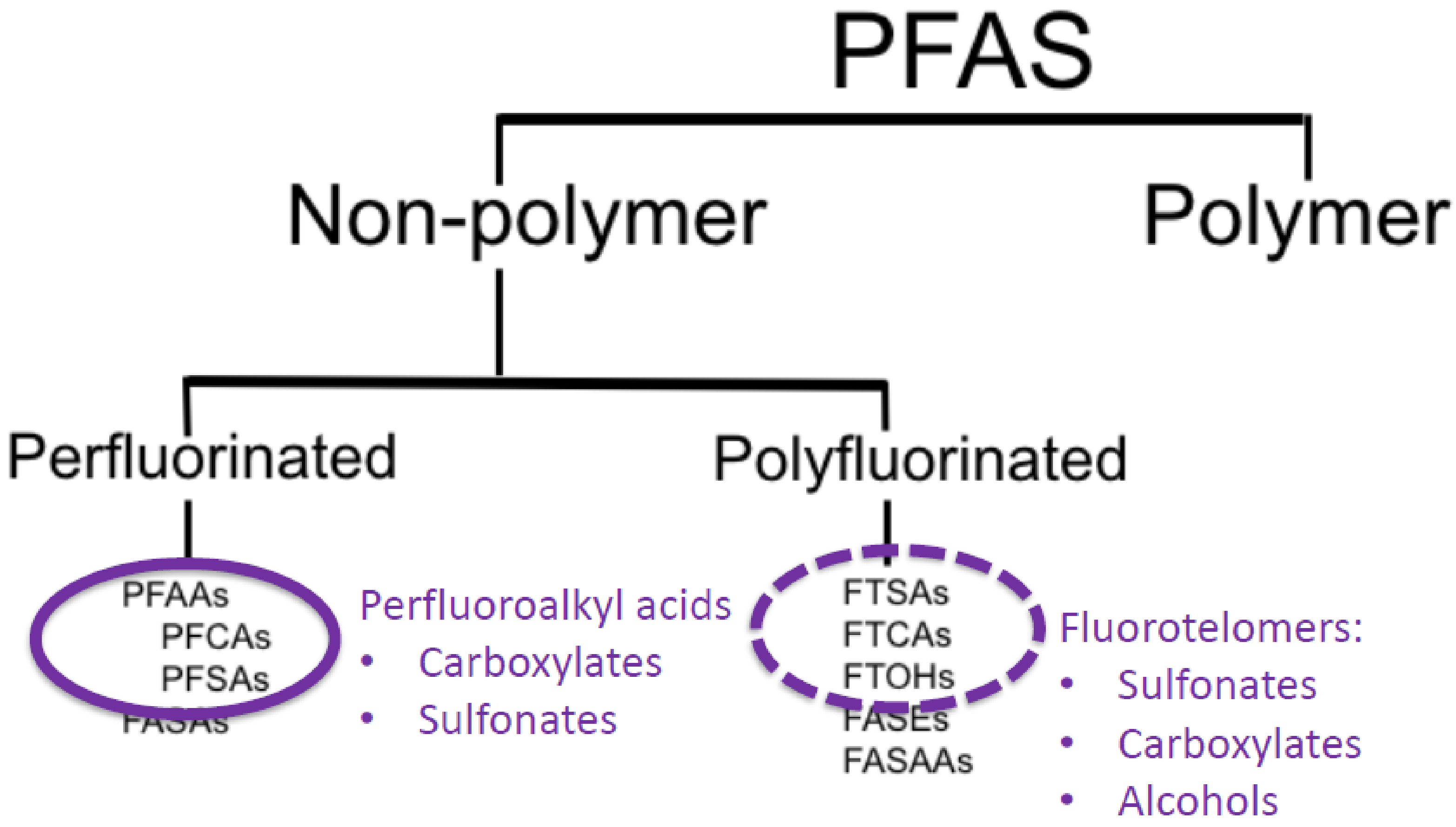






Source: open access images – bing.com

General Classes of PFAS



ITRC Fact Sheets - https://pfas-1.itrcweb.org

- History and Use (Nov. 2017)
- Naming Conventions & Physical and Chemical Properties (March 2018)
- Regulations, Guidance, and Advisories (January 2018)
- Fate & Transport (March 2018)
- Site Characterization, Sampling Techniques, and Lab Analytical Methods (March 2018)
- Remediation Technologies (March 2018)
- AFFF (October 2018)

ITRC Tools in Development

Coming soon from ITRC

- Web-based, updated information tables
- Online training development in 2019
- Publication of the Risk Communication Toolkit in 2019
- Publication of the web-based *Technical and Regulatory Document* early 2020

ITRC Tech/Reg Document - Sections

1. History of Use
2. Detection Technologies/Analytical
3. Fate and Transport
4. Risk Communication
5. AFFF
6. Remediation Technologies
7. Regs/Toxicology/Risk
8. Stakeholders
9. Training

ITRC Tech/Reg Document - Sections

1. History of Use – Includes
   - Source Information – industrial use affiliations
   - Naming conventions

ITRC Tech/Reg Document - Sections

2. Detection Technologies

- Analytical Procedures
- Some Sampling Information
  - Analyze entire sample due to bottle effects
  - Importance of blanks

ITRC Tech/Reg Document – Sections

3. Fate and Transport
   - Physical and Chemical Properties
   - Site Characterization – Design Implications
   - General PFAS site characterization approaches
     - Conceptual Site Models
     - Discharge mechanisms
     - Transport pathways

ITRC Tech/Reg Document - Sections

4. Risk Communication

- Includes engagement tools
- Generic for other emerging contaminants

ITRC Tech/Reg Document - Sections

5. AFFF

ITRC Tech/Reg Document - Sections

6. Remediation Technologies
    - Field Implemented Technologies
    - Limited Application Technologies
    - Developing Technologies

ITRC Tech/Reg Document - Sections

7. Regs/Toxicology/Risk
8. Stakeholders
9. Training

Regulatory Update – March 2019

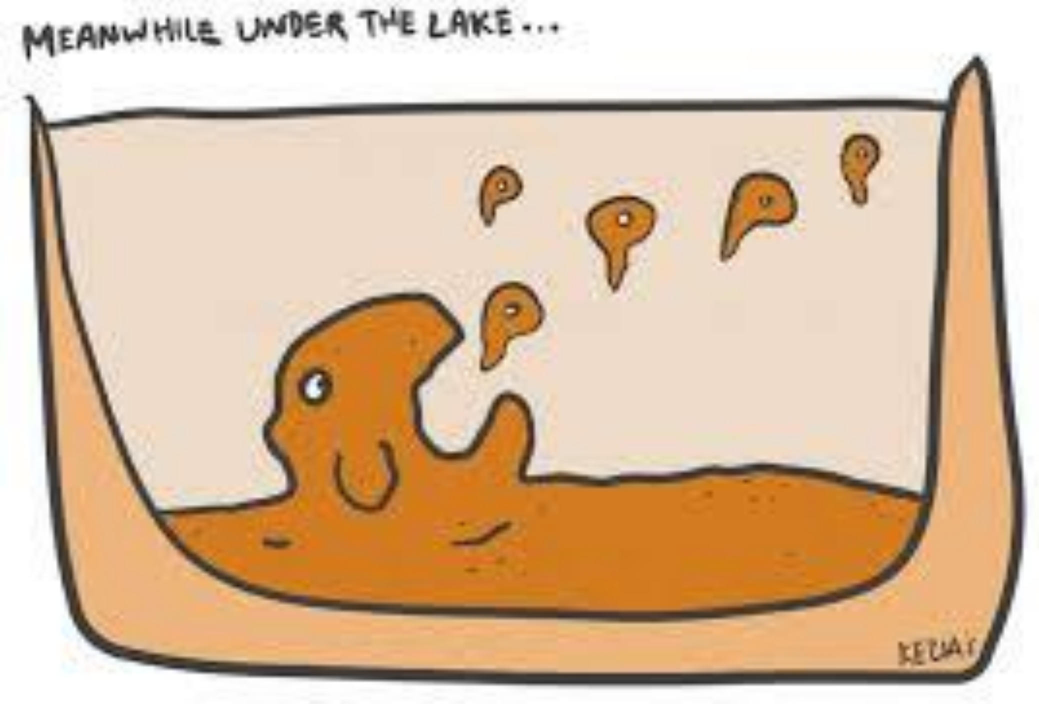
State Standards

- 19 states have criteria in Water
- 6 states have criteria different than USEPA HALs for Drinking Water
- 6 states have criteria for PFAS other than PFOA and PFOS
- ITRC summary spreadsheet is updated frequently https://pfas-1.itrcweb.org/

Regulatory Update – March 2019

Federal Regulatory Authority for PFAS

- Federal authority as Pollutant or Contaminant under Clean Water Act
- Allows for identification as Recognized Environmental Condition (REC)
- Not Federal Hazardous Substance



ITRC Tech Reg Updates

- Wisconsin DNR participated in the PFAS Tech Reg Document preparations by:
  - Preparing written comments to ITRC on Site Investigation components – January 2019
  - Attending work sessions to incorporate and respond to comments related to Site Investigation – March 2019

Review of History and Sources

- Data presented primarily from ITRC
  - Fact Sheets
  - Tech/Reg Document
  - Training

PFAS History and Use

- History and Use Fact Sheet (November 2017)
  - Understand the manufacturing history PFAS production, past and current uses and the possible implications for site chemical signatures
  - Be aware of the major sources of PFAS releases to the environment, possible release mechanisms, and associated pathway-receptor relationships.

Manufacturing History

- Complex family of more than 3,000 manmade fluorinated organic chemicals
- Produced since the mid-20th century, although not all may be currently in use or production.
- Potential health and environmental concerns, particularly for more bioaccumulative “long-chain” PFAS

Short-chain PFCAs				Long-chain PFCAs				
PFBA	PFPeA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA
PFBS	PFPeS	PFHxS	PFHpS	PFOS	PFNS	PFDS	PFUnS	PFDoS
Short-chain PFSAs		Long-chain PFSAs						

Manufacturing History

- PFAS are produced using several different processes.
- Two major processes have been used to manufacture fluorosurfactants (includes PFAAs) and side-chain fluorinated polymers:

1. Electrochemical fluorination (ECF) and telomerization. ECF was licensed by 3M in the 1940s, and used by 3M until 2001. ECF produces a mixture of even- and odd- numbered carbon chain lengths of approximately 70% linear and 30% branched substances.
2. Telomerization was developed in the 1970s, and yields mainly even numbered, straight carbon chain isomers.

Manufacturing History

- **2002-2008:** 3M voluntarily phased out production of PFOS, PFHxS, PFOA, and related precursors
- **2010-2015:** U.S. manufacturers eliminated production of PFOA and longer-chain PFCAs
- **Exemptions:** USEPA SNURs allow continued, low-volume use in specific applications
- Production shifted to parts of Asia and Eastern Europe

What are SNURs?

- **Significant New Use Rules (SNURs)**
- Toxic Substances Control Act (TSCA) Section 5(a) Significant New Use Rules (SNURs) can be used to require notice to EPA before chemical substances and mixtures are used in new ways that might create concerns.
- EPA can determine that a use of a chemical substance is a “significant new use.” after considering all relevant factors, including :
  - Projected volume of manufacturing and processing of a chemical substance.
  - Extent to which a use changes the type or form of exposure of humans or the environment to a chemical substance.
  - Extent to which a use increases the magnitude and duration of exposure of humans or the environment to a chemical substance.
  - Reasonably anticipated manner and methods of manufacturing, processing, distribution in commerce, and disposal of a chemical substance.

SNURs

- USEPA issued SNURs to restrict any future use or production of 183 PFAS, which include 88 of the PFOS-related chemicals phased-out by 3M.
- The SNURs allowed for continued, low-volume use of some of these PFAS in certain industries:
  - photographic/imaging,
  - semiconductor,
  - etching,
  - metal plating, and
  - aviation.
- Also, PFOS-based fire-fighting foams have a long shelf-life and may still be stored and in use at various facilities.
- SNURs for some long-chain PFCAs and PFSAs have been proposed.

Table 2-1. Discovery and manufacturing history of select PFAS

PFAS[1]	Development Time Period							
	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s
PTFE	Invented	Non-Stick Coatings			Waterproof Fabrics			
PFOS		Initial Production	Stain & Water Resistant Products	Firefighting foam				U.S. Reduction of PFOS, PFOA, PFNA (and other select PFAS[2])
PFOA		Initial Production	Protective Coatings					
PFNA					Initial Production	Architectural Resins		
Fluoro-telomers					Initial Production	Firefighting Foams		Predominant form of firefighting foam
Dominant Process[3]		Electrochemical Fluorination (ECF)						Fluoro-telomerization (shorter chain ECF)
Pre-Invention of Chemistry /			Initial Chemical Synthesis / Production			Commercial Products Introduced and Used		

Notes:
1. This table includes fluoropolymers, PFAAs, and fluorotelomers. PTFE (polytetrafluoroethylene) is a fluoropolymer. PFOS, PFOA, and PFNA (perfluorononanoic acid) are PFAAs.
2. Refer to Section 3.4.
3. The dominant manufacturing process is shown in the table; note, however, that ECF and fluorotelomerization have both been, and continue to be, used for the production of select PFAS.

Sources: Prevedouros et al. 2006; Concawe 2016; Chemours 2017; Gore-Tex 2017; US Naval Research Academy 2017

Timeline, Production and Products

ITRC November 2017

Environmental Awareness

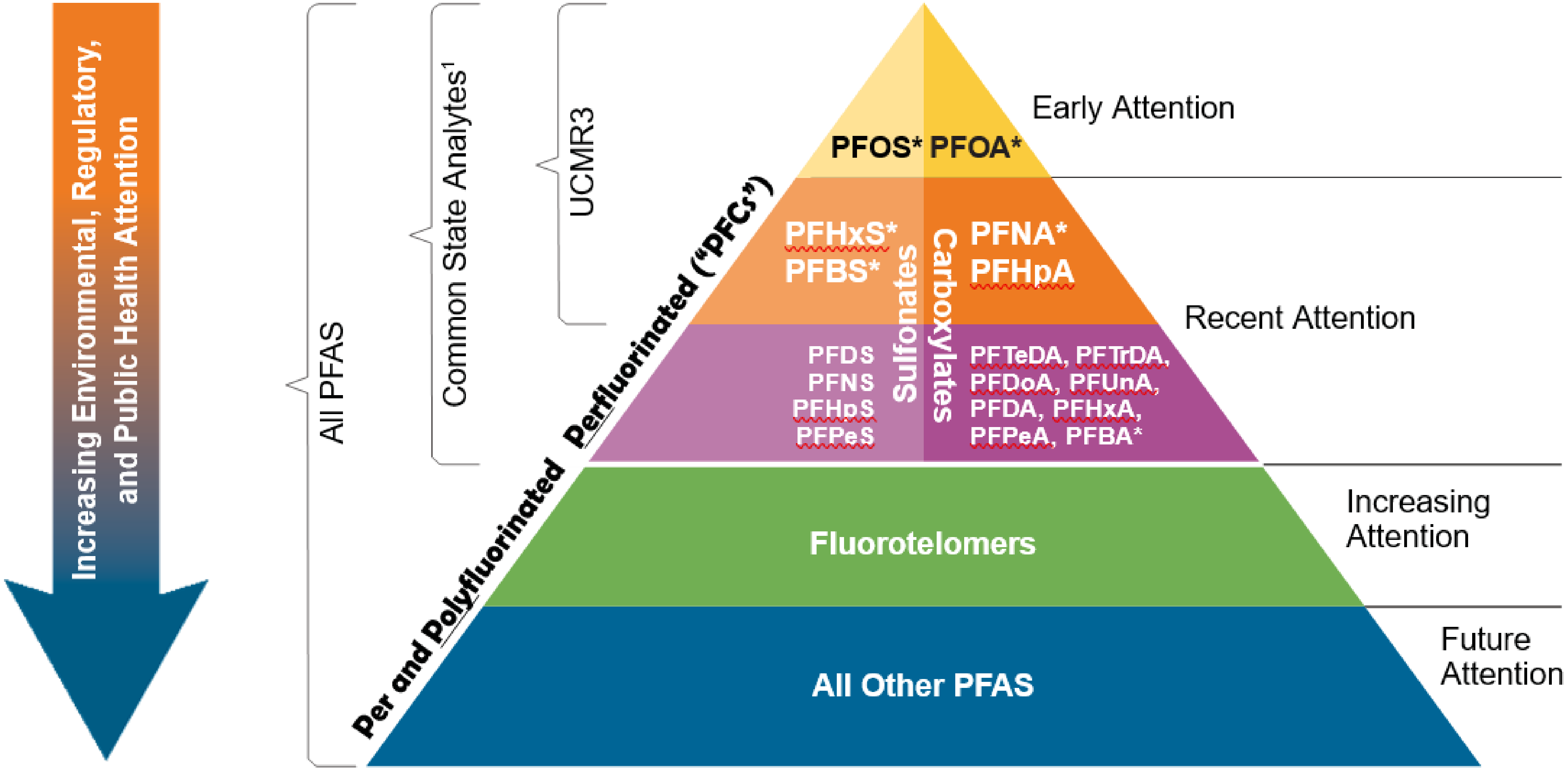
- Some PFAS have been manufactured for more than 50 years, but were not widely documented in environmental samples until the early 2000s.
- Early detection at low reporting limits was hindered due to analytical capability challenges arising from the unique surface-active properties of PFAS.

Environmental Awareness

- Now much data showing widespread distribution of certain PFAS, such as PFAAs, in various matrices including:
  - sediments
  - surface and groundwater
  - wildlife
  - human blood (whole, plasma, and serum)
- Some PFAS (such as PFAAs) are found in many places throughout the globe, even in areas well beyond where they were initially used or manufactured.

Environmental Awareness

- Six additional PFAAs have recently gained attention after their inclusion in the USEPA Unregulated Contaminant Monitoring Rule (UCMR).
- The third round of monitoring, or UCMR3, was promulgated in 2012 for tracking chemicals suspected to be present in drinking water, but do not have health-based standards set by the Safe Drinking Water Act.
- A summary of the occurrence data is included in ITRC's *Regulations, Guidance, and Advisories Fact Sheet*.



*Common regulatory criteria or health advisories
[1]Sum of informal poll (NJ, NH, MN)

Thematic and not proportional.
Bottom of triangle indicates additional number of compounds; not a greater quantity by mass, concentration, or frequency of detection.

Figure 3-1. Emerging awareness and emphasis on PFAS occurrence in the environment
(Source: J. Hale, Kleinfelder, used with permission)

Long-Chain PFAS Phase-Out

- In January 2006, USEPA initiated the PFOA Stewardship Program.
- The eight major manufacturing companies committed to reducing PFOA, other longer-chain PFCAs, and related precursors that could be converted to these PFCAs from their global facility emissions and product content.
- USEPA indicates all eight companies successfully satisfied the program goals, meeting a 95% reduction by 2010, and elimination by 2015.
- Even though the program goals were met, materials imported to the United States may contain these PFCAs and related precursors.

Global PFAS Production

- Recent increased production of PFOA and related PFAS in China, India, and Russia have potentially offset the global reduction anticipated with the U.S. phase-out.
- PFAS manufacture began in China in the 1980s, and PFOS production in China increased with the long-chain PFAA phase-out in the United States.
- In 2016, PFOS and its derivatives were still being produced in Germany, Italy, and China.
- By early 2017, China was the only known producer of PFOS.
- China has ratified the Stockholm Convention on Persistent Organic Pollutants (POPs) and a grant from Global Environment Facility (GEF) was approved in 2017 to support the reduction of PFOS in China.

Replacement Chemistry

- Manufacturers have been developing replacement technologies, including reformulating or substituting longer-chain substances with shorter-chain perfluoroalkyl or polyfluorinated substances.
- Many long-chain PFAS alternatives are structurally similar to their predecessors and manufactured by the same companies.
- It is not clear if some of these chemicals can achieve the same performance effectiveness as their predecessors.

Replacement Chemistry

- Publicly available information on most replacement chemicals is limited.
- Replacement PFAS less hazardous than the long-chain predecessors?
- TSCA New Chemicals Program had USEPA's review of hundreds of "shorter chain-length PFAS telomeric" substitutes for long-chain PFAS.
- Other documentation regarding replacement chemistries is available from the FluoroCouncil (2017).

Replacement Chemistry

- Information on environmental contamination by replacement PFAS is limited.
- Most are not detected by standard analytical methods.
- Treatment processes used to remove these chemicals from waste streams may not be as effective as with longer-chain PFAS.
- The nature of PFAS source material at locations with discharges to the environment has likely changed over time as the PFAS compounds used a the facility changed.

Major Sources of PFAS

1. **Aqueous Film Forming Foam**
   - Military installations
   - Civilian airports
   - Petroleum Refineries
   - Fire Fighting Training Areas
2. **Production and Manufacturing**
   - Surfactants, resins, molds, plastics
   - Textiles and leather
   - Paper products
3. **Waste Water Treatment Plants**
   - Industrial or domestic products in influent may not be treated (or may be transformed) and end up in effluent
   - Biosolids created in treatment process may contain PFAS
4. **Landfills**
   - Consumer products
   - Industrial waste
   - Biosolids from WWTP applied as cover

ITRC November 2017

1. Firefighting Foams - Use

- Class B fluorine-containing firefighting foams (firefighting foam) for extinguishing flammable liquid fires include
  - aqueous film forming foam (AFFF),
  - fluoroprotein (FP), and
  - film forming fluoroprotein foam (FFFP).
- These foams have been stored and used for fire suppression, fire training, and flammable vapor suppression at
  - military installations
  - civilian airports,
  - petroleum refineries and storage facilities, and
  - chemical manufacturing plants.

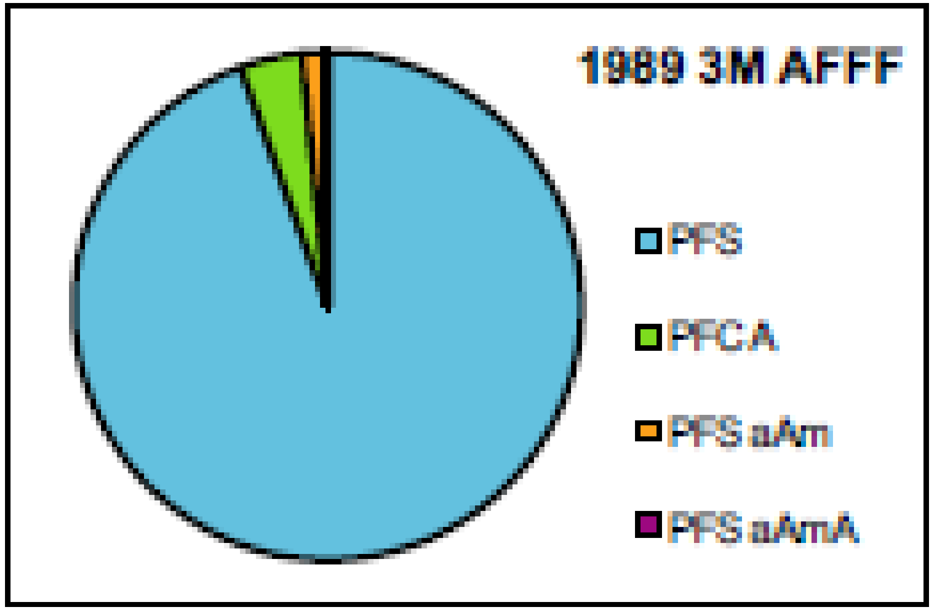
1. Firefighting Foams - Use

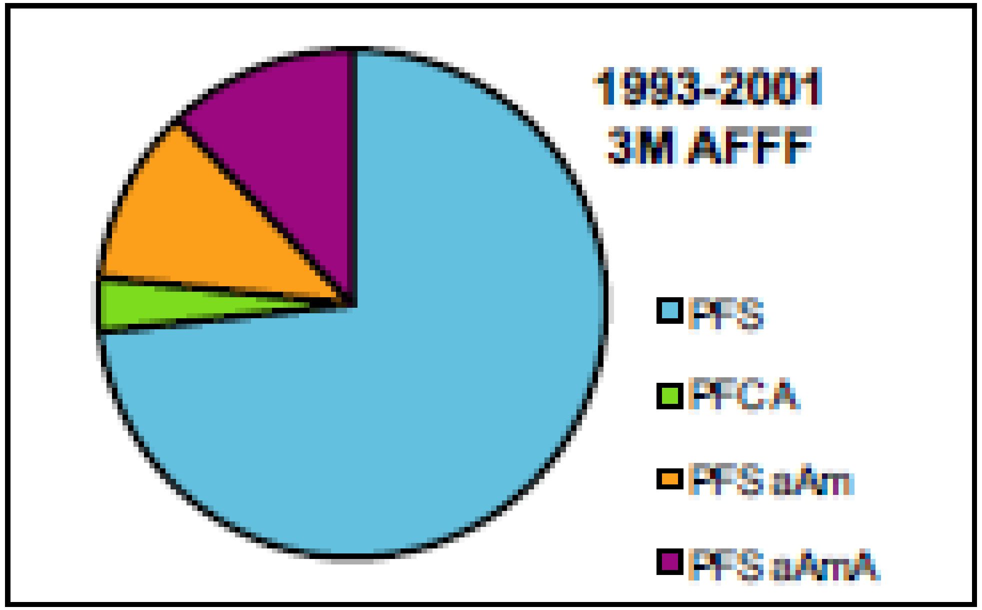
- Local fire departments in communities have used and maintained quantities of firefighting foam in their inventories.
- Despite the phase-out of longer-chain PFAAs, these products still have long-chain PFAA constituents in firefighting foam due to the long shelf-life of these products.
- Facilities that manufactured firefighting foams are also potential sources.

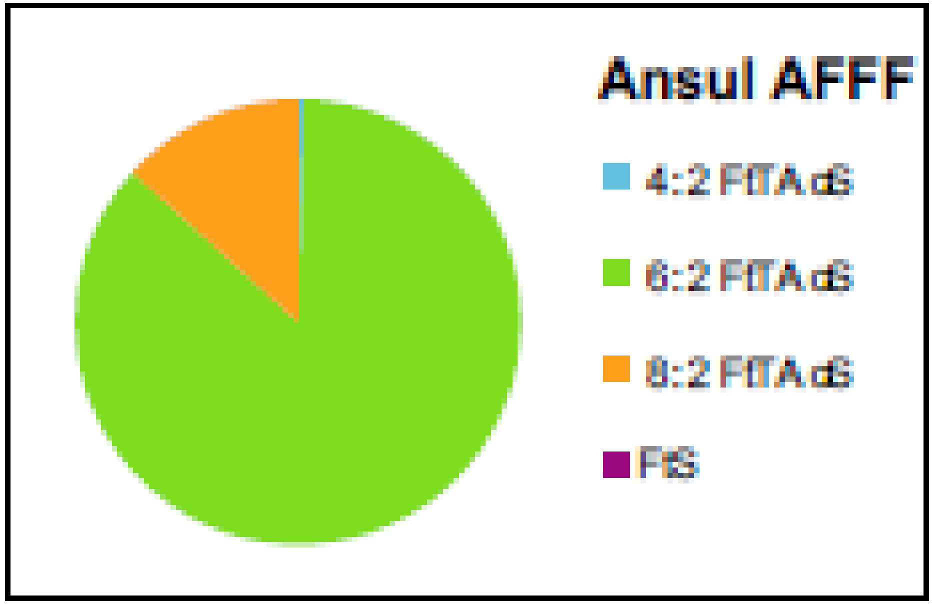
1. Firefighting Foams – Contents and History

- Firefighting foams are a complex mixture of both known and unidentified PFAS of differing molecular structures present in varying proportions.
- Foams were produced to meet firefighting specifications, rather than formulated to contain a specified mixture of PFAS.
- These types of firefighting foams have been in use since the 1960s following development by the United States Naval Research Laboratory leading to advancements in performance and increased safety.
- Fluorotelomer foams have been in use since the 1970s and became the predominant foam after 2001 when long-chain ECF-based foams were discontinued.

Important to consider AFFF has consisted of different mixtures over time







ITRC March 2019

1. Firefighting Foams – Release Mechanisms

- Firefighting foams are released into the environment through a variety of practices and mechanisms:
  - low volume releases of foam concentrate during storage, transfer or equipment calibration
  - moderate volume discharge of foam solution for apparatus testing
  - occasional, high-volume, broadcast discharge of foam solution for firefighting and fire suppression/prevention
  - periodic, high volume, broadcast discharge for fire training
  - leaks from foam distribution piping between storage and pumping locations

1. Firefighting Foams – Evaluation

- The U.S. Department of Defense (USDOD) has undertaken an evaluation of potential firefighting foam contamination at its facilities nationwide.
- Similar efforts have been undertaken by some states.
  - Minnesota Pollution Control Agency (MPCA) conducted a state-wide survey of firefighting foam use at training sites. Working with the State Fire Chief Association, the MPCA identified more than two dozen locations where Class B foams were likely used in firefighting training.
  - California – mandated sampling at airports

2. Production and Manufacturing

- PFAS are used in many industrial and consumer applications.
- PFAS have been used in
  - coatings for textiles,
  - paper products,
  - cookware and
  - some firefighting foams
- Industrial uses include:
  - aerospace,
  - photographic imaging,
  - semiconductor,
  - automotive,
  - construction,
  - electronics, and
  - aviation.

ITRC November 2017

Potential Major Manufacturing Sources of PFAS releases to the Environment

Sector	Example Uses
Textiles & Leather	Factory- or consumer-applied coating to repel water, oil, and stains. Applications include protective clothing and outerwear, umbrellas, tents, sails, architectural materials, carpets, and upholstery.
Paper Products	Surface coatings to repel grease and moisture. Uses include non-food paper packaging (for example, cardboard, carbonless forms, masking papers) and food-contact materials (for example, pizza boxes, fast food wrappers, microwave popcorn bags, baking papers, pet food bags).
Metal Plating & Etching	Corrosion prevention, mechanical wear reduction, aesthetic enhancement, surfactant, wetting agent/fume suppressant for chrome, copper, nickel and tin electroplating, and post-plating cleaner.
Wire Manufacturing	Coating and insulation.
Industrial Surfactants, Resins, Molds, Plastics	Manufacture of plastics and fluoropolymers, rubber, and compression mold release coatings; plumbing fluxing agents; fluoroplastic coatings, composite resins, and flame retardant for polycarbonate.
Photolithography, Semiconductor Industry	Photoresists, top anti-reflective coatings, bottom anti-reflective coatings, and etchants, with other uses including surfactants, wetting agents, and photo-acid generation.

ITRC November 2017

2. Production and Manufacturing Facilities

- Both in the United States and abroad, primary manufacturing facilities produce PFAS and secondary manufacturing facilities use PFAS to produce goods.
- Due to the solubility and persistence of many PFAS, environmental release mechanisms associated with these facilities include air emission and dispersion, spills, and disposal of manufacturing wastes and wastewater.
- Potential impacts to air, soil, surface water, stormwater, and groundwater are present not only at release areas but potentially over the surrounding area.

3. Wastewater Treatment

- Consumer and industrial use of PFAS-containing materials, including disposal of landfill leachate and firefighting foam, results in the discharge of PFAS to WWTPs.
- WWTPs, particularly those that receive industrial wastewater, are possible sources of PFAS release.

3. WWTP Operations

- Conventional sewage treatment methods do not efficiently remove PFAAs.
- Evaluation of full-scale WWTPs indicates conventional primary (sedimentation and clarification) and secondary (aerobic biodegradation of organic matter) treatment processes, can result in changes in PFAS concentrations and classes (for example, an increase in the concentrations of PFAAs in effluent, presumably from degradation of precursor PFAS).
- Some PFAS are frequently detected in WWTP effluent (for example, PFOA and PFBS), with concentrations of some PFAS ranging up to hundreds of ng/L.
- WWTP effluents are believed to be major point sources of PFAS chemicals in surface water.

3. WWTP Operations

- PFOS and PFOA are two of the most frequently detected PFAS in wastewater.
- PFAS distribution (primarily PFAAs and FTOH, with higher concentrations of FTOH) changes based on the specific PFAS sources in the effluent and the type of treatment methods employed at the WWTP.
- Lagoon systems contain a greater fraction of PFAAs.

3. WWTP - Biosolids

- PFAS (measured as PFCAs and PFSAs) have been found in domestic sewage sludge.
- USEPA states that more than half of the sludge produced in the United States is applied to agricultural land as biosolids, which can be a source of PFAS to the environment.
- The most abundant PFAS found in biosolids (PFOS and PFOA) are the same as in WWTP effluent; however, biosolids may also contain other long- chain PFAS.

3. WWTP - Biosolids

- Application of biosolids as a soil amendment can result in a transfer of PFAS to soil.
- These PFAS can then be available for uptake by plants and soil organisms.

3. WWTP - Biosolids

- There are indications that PFAAs can enter the food chain through the use of biosolids-amended soil.
- PFAS concentrations can be elevated in surface and groundwater in the vicinity of agricultural fields that received PFAS contaminated biosolids for an extended period of time.

4. Waste Disposal

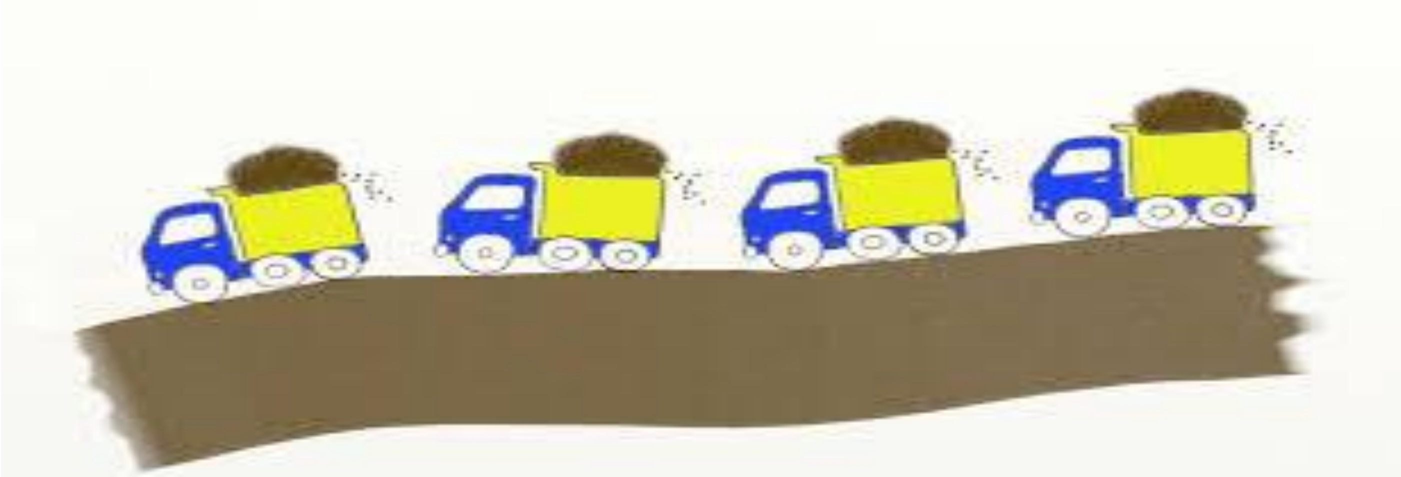
- Disposal of wastes generated during primary PFAS production and secondary manufacturing using PFAS can be sources of PFAS environmental contamination.

4. Waste Disposal

- As PFAS manufacturing processes change with time, the resulting type and composition of waste streams also change.
- PFAS production and use began several decades before the enactment of federal and state regulations governing waste disposal.
- Environmental impacts, including impacted drinking water supplies, from disposal of legacy PFAS industrial waste have been documented.

4. Waste Disposal

- Leachate from some municipal solid waste landfills has been shown to be a source of PFAS release to the environment, with the presence of some PFAS reportedly due to the disposal of consumer goods treated with hydrophobic, stain- resistant coatings.
- PFAS composition and concentration in leachates vary depending on waste age, climate, and waste composition.



ITRC November 2017

4. Waste Disposal

- The evolution of waste reduction and landfill technology has provided significant protection to human health and the environment.
- Leachate collection systems are essential to providing systematic transport of leachate to a central location for recirculation, treatment, or offsite treatment.
- Leachate treatment by wastewater treatment plants (WWTPs) is common prior to discharge to surface water, or distribution for agricultural or commercial use.
- Standard WWTP technologies may do little to reduce or remove PFAS and discharge of landfill leachate treated at WWTPs represents a secondary source of certain PFAS release to the environment.

Other Sources of PFAS – Use of Commercial and Consumer Products

- PFAS are widely used in consumer products and household applications, with a diverse mixture of PFAS found in daily use in varying concentrations.
- Environmental releases associated with the use of commercial and consumer products are primarily related to management of solid waste (disposal of used items in a municipal solid waste landfill), and wastewater disposal (discharge to WWTPs, private septic systems, or other subsurface disposal systems).

Other Sources of PFAS – Use of Commercial and Consumer Products

- Physical degradation of some consumer products (such as PFAS-treated paper, textiles, and carpets) may be a source of PFAS in house dust.
- Professional ski wax technicians may have significant inhalation exposures to PFAS and snowmelt and surface waters near ski areas may have measurable PFAS impacts.
- As increased environmental sampling for PFAS occurs, it is likely that additional sources may emerge.



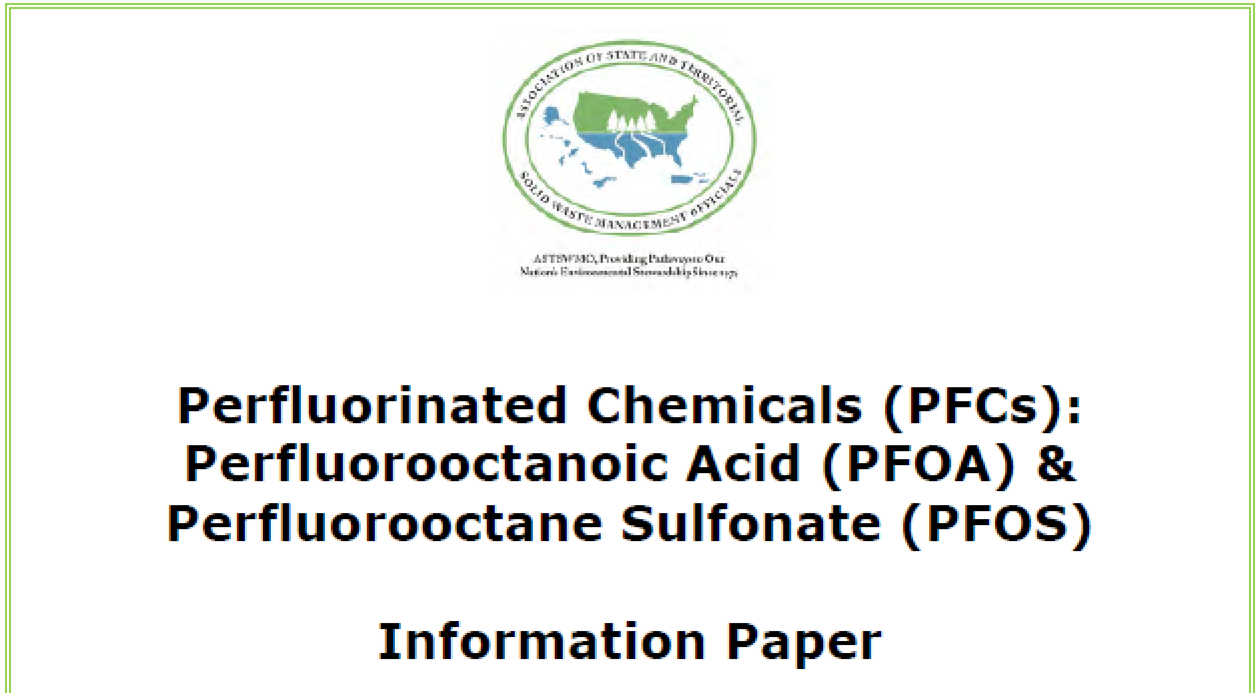


Commercial and Consumer Products Containing PFAS

- paper and packaging
- clothing and carpets
- outdoor textiles and sporting equipment
- ski and snowboard waxes
- non-stick cookware
- cleaning agents and fabric softeners
- polishes and waxes, and latex paints
- pesticides and herbicides
- hydraulic fluids
- windshield wipers
- paints, varnishes, dyes, and inks
- adhesives
- medical products
- personal care products (for example, shampoo, hair conditioners, sunscreen, cosmetics, toothpaste, dental floss)

ITRC November 2017

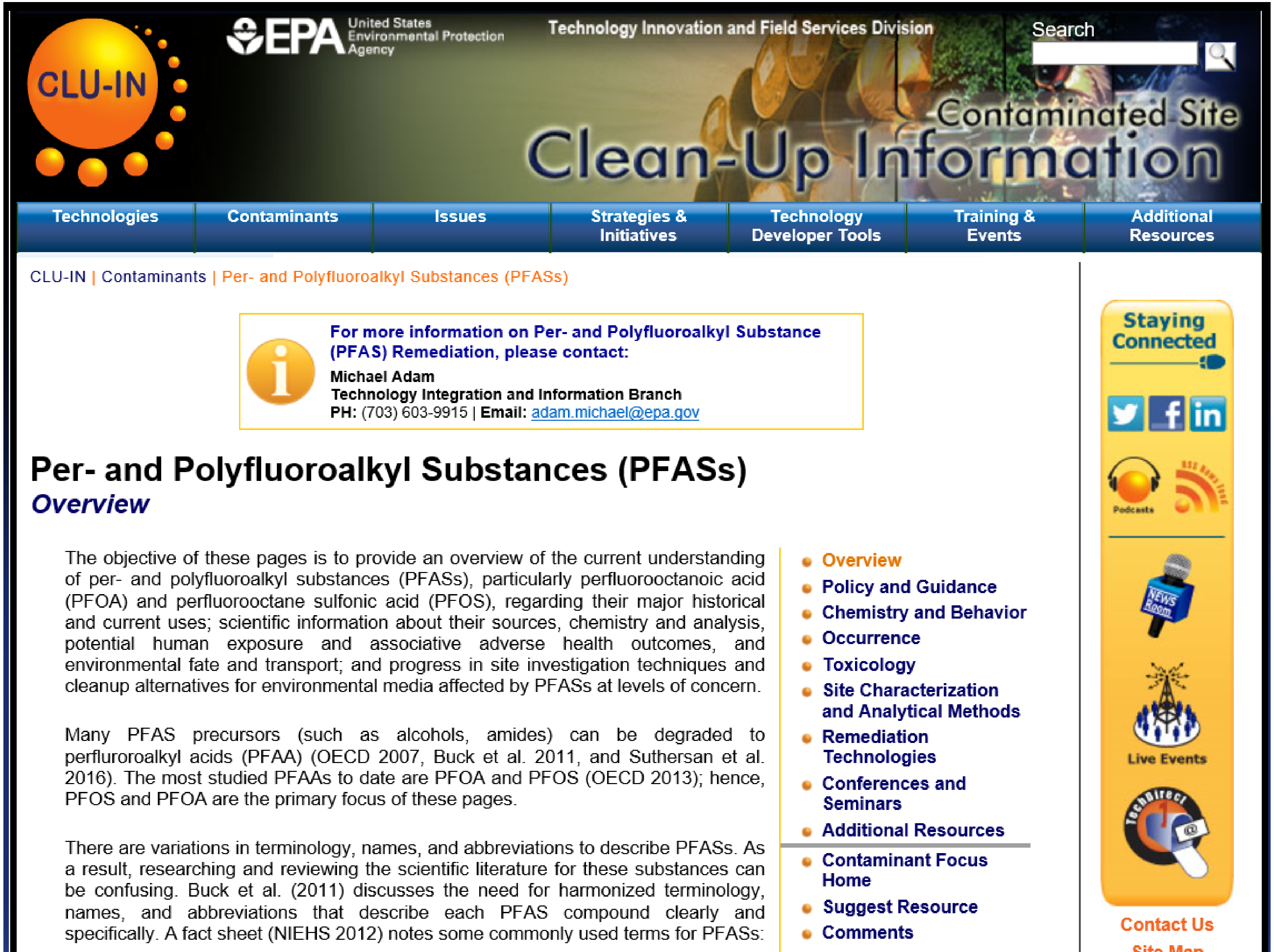
Resources



Perfluorinated Chemicals (PFCs): Perfluorooctanoic Acid (PFOA) & Perfluorooctane Sulfonate (PFOS)

Information Paper

- ASTSWMO (Association of State and Territorial Solid Waste Management Officials), 2015. Perfluorinated Chemicals (PFCs): Perfluorooctanoic Acid (PFOA) & Perfluorooctane Sulfonate (PFOS) — Information Paper. 68 pp.



CLU-IN

EPA United States Environmental Protection Agency

Technology Innovation and Field Services Division

Search

Contaminated Site Clean-Up Information

Technologies | Contaminants | Issues | Strategies & Initiatives | Technology Developer Tools | Training & Events | Additional Resources

CLU-IN | Contaminants | Per- and Polyfluoroalkyl Substances (PFASs)

For more information on Per- and Polyfluoroalkyl Substance (PFAS) Remediation, please contact:

Michael Adam
Technology Integration and Information Branch
PH: (703) 603-9915 | **Email:** adam.michael@epa.gov

Per- and Polyfluoroalkyl Substances (PFASs)

Overview

The objective of these pages is to provide an overview of the current understanding of per- and polyfluoroalkyl substances (PFASs), particularly perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS), regarding their major historical and current uses; scientific information about their sources, chemistry and analysis, potential human exposure and associative adverse health outcomes, and environmental fate and transport; and progress in site investigation techniques and cleanup alternatives for environmental media affected by PFASs at levels of concern.

Many PFAS precursors (such as alcohols, amides) can be degraded to perfluroroalkyl acids (PFAA) (OECD 2007, Buck et al. 2011, and Suthersan et al. 2016). The most studied PFAAs to date are PFOA and PFOS (OECD 2013); hence, PFOS and PFOA are the primary focus of these pages.

There are variations in terminology, names, and abbreviations to describe PFASs. As a result, researching and reviewing the scientific literature for these substances can be confusing. Buck et al. (2011) discusses the need for harmonized terminology, names, and abbreviations that describe each PFAS compound clearly and specifically. A fact sheet (NIEHS 2012) notes some commonly used terms for PFASs:

- Overview
- Policy and Guidance
- Chemistry and Behavior
- Occurrence
- Toxicology
- Site Characterization and Analytical Methods
- Remediation Technologies
- Conferences and Seminars
- Additional Resources
- Contaminant Focus Home
- Suggest Resource
- Comments

Staying Connected

Podcasts

Live Events

Contact Us

U.S. EPA Training and Information

Other Good Resources

Commentary

A Section 508–conformant HTML version of this article is available at https://doi.org/10.1289/EHP2727.

Evaluation and Management Strategies for Per- and Polyfluoroalkyl Substances (PFASs) in Drinking Water Aquifers: Perspectives from Impacted U.S. Northeast Communities

Jennifer L. Guelfo,[1] Thomas Marlow,[2] David M. Klein,[3] David A. Savitz,[4] Scott Frickel,[2] Michelle Crimi,[5] and Eric M. Suuberg[1]

[1]School of Engineering, Brown University, Providence, Rhode Island, USA
[2]Department of Sociology and Institute at Brown for Environment and Society, Brown University, Providence, Rhode Island, USA
[3]Department of Pathology and Laboratory Medicine, Brown University, Providence, Rhode Island, USA
[4]Departments of Epidemiology and Obstetrics and Gynecology, Brown University, Providence, Rhode Island, USA
[5]Department of Engineering and Management, Clarkson University, Potsdam, New York, USA

Environmental Health Perspectives 065001-1 126(6) June 2018

Table 1. Groundwater concentrations, compounds, relevant groundwater pathways, and affected receptors resulting from groundwater PFAS source types summarized from peer-reviewed literature and regulatory reports.

Source type	Magnitude of [PFAS] (μg/L)	Max PFAS	PFASs detected	Ground water pathways	Receptors impacted	Ref. cited
PFAS/FP manufacturing	10^{-2}–10^{3}	PFOA	PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFBS, PFHxS, PFOS	VZ to GW Atm SW to GW	DW, GW, SW, B	MDOH 2012; Davis et al. 2007; Bach et al. 2017; Dauchy et al. 2012; Weston Solutions 2009
AFFF use (DoD)[a]	10^{-3}–10^{4}	6:2 FtS	PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnA, PFDoA, PFEtS, PFPrS, PFBS, PFPeS, PFHxS, PFHpS, PFOS, PFDS, 4:2 FtS, 6:2 FtS, 8:2 FtS, FHxSA, FOSA, 4:2 FtTAoS, 6:2 FtTAoS, PFBSaAm, PFPeSaAm, PFHxSaAm, PFHxSaAmA	VZ to GW	DW, GW, SW, B	Houtz et al. 2013; McGuire et al. 2014; Schultz et al. 2004; Moody et al. 2003; MDHHS 2016; Hull et al 2017; Moody and Field 1999; Barzen-Hanson and Field 2015; Backe et al. 2013
AFFF use (airport)	10^{-3}–10^{2}	PFOA	PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFBS, PFHxS, PFOS	VZ to GW	DW, GW, SW, B	Ahrens et al. 2015; Awad et al. 2011; Yingling 2016; Antea Group 2011; Delta Consultants 2010; Horsley Witten Group, Inc., 2016
AFFF use (fire training area)[b]	10^{-3}–10^{2}	PFOS	PFBA, PFPeA, PFHxA, PFOA, PFDoA, PFTriA, PFTreA, PFBS, PFHxS, PFOS, EtFASE, MeFASE	VZ to GW	DW, GW, SW	Antea Group 2011; Cape Cod Commission 2016
AFFF use (petroleum)	10^{-3}–10^{1}	PFOS	PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnA, PFBS, PFHxS, PFOS, FOSA	VZ to GW	DW, GW	Antea Group 2011
FP coating (e.g. plastics, textiles, metals)	10^{-3}–10^{1}	PFOA	PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFBS, PFHxS, PFHpS, PFOS, FOSA, 6:2 FtS, 8:2 FtS	Not specified	DW, GW	U.S. EPA 2016c; NHDES 2017a
Electronics	10^{-3}–10^{1}	PFOA	PFHpA, PFOA, PFOS	Not specified	DW, GW	Unicorn Mgmt. Consultants 2016
Waste streams (landfills)	10^{-3}–10^{3}	PFBA	PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFBS, PFHxS, PFOS, 6:2 FtS	VA to GW Atm	DW, GW	NHDES 2017a; Weston Solutions 2016; VTDEC 2016; Oliaei et al. 2006; Oliaei et al. 2013
Waste streams (biosolids)	10^{-2}–10^{0}	PFOA	PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFBS, PFHxS, PFOS	VZ to GW	DW, GW, SW, B	Lindstrom et al. 2011
Waste streams (septic systems)	10^{-3}–10^{-2}	PFHxS	PFHxA, PFHpA, PFOA, PFBS, PFHxS, PFOS	VZ to GW	DW, GW	Schaider et al. 2016

Sources, Magnitude, Specific PFAS Compounds, References

Risk Scores

Table 2. Risk scores utilized for calculation of the PFAS source hazard index (HI).

PFAS source	Upper magnitude (μg/L)	No. PFASs	Risk score	Table 1 source type
DoD facilities	10,000	28	100	AFFF use (DoD)
Chemical manufacturing	1,000	13	100	PFAS/FP manufacturing
Landfills	1,000	11	100	Waste streams (landfills)
Airports	100	28	75	AFFF use (Airports)[a]
Fire training areas	100	28	75	AFFF use (fire training areas)[a]
Petroleum refineries	10	28	75	AFFF use (petroleum refineries)[a]
Textiles	10	13	50	FP coating (plastics, textiles, metals)
Furniture	10	13	50	FP coating (plastics, textiles, metals)
Paper	10	13	50	FP coating (plastics, textiles, metals)
Rubber/plastics	10	13	50	FP coating (plastics, textiles, metals)
Fire Stations	N/A	28	25	N/A[a,b]
Fabricated metal	N/A	11	25	N/A[c]

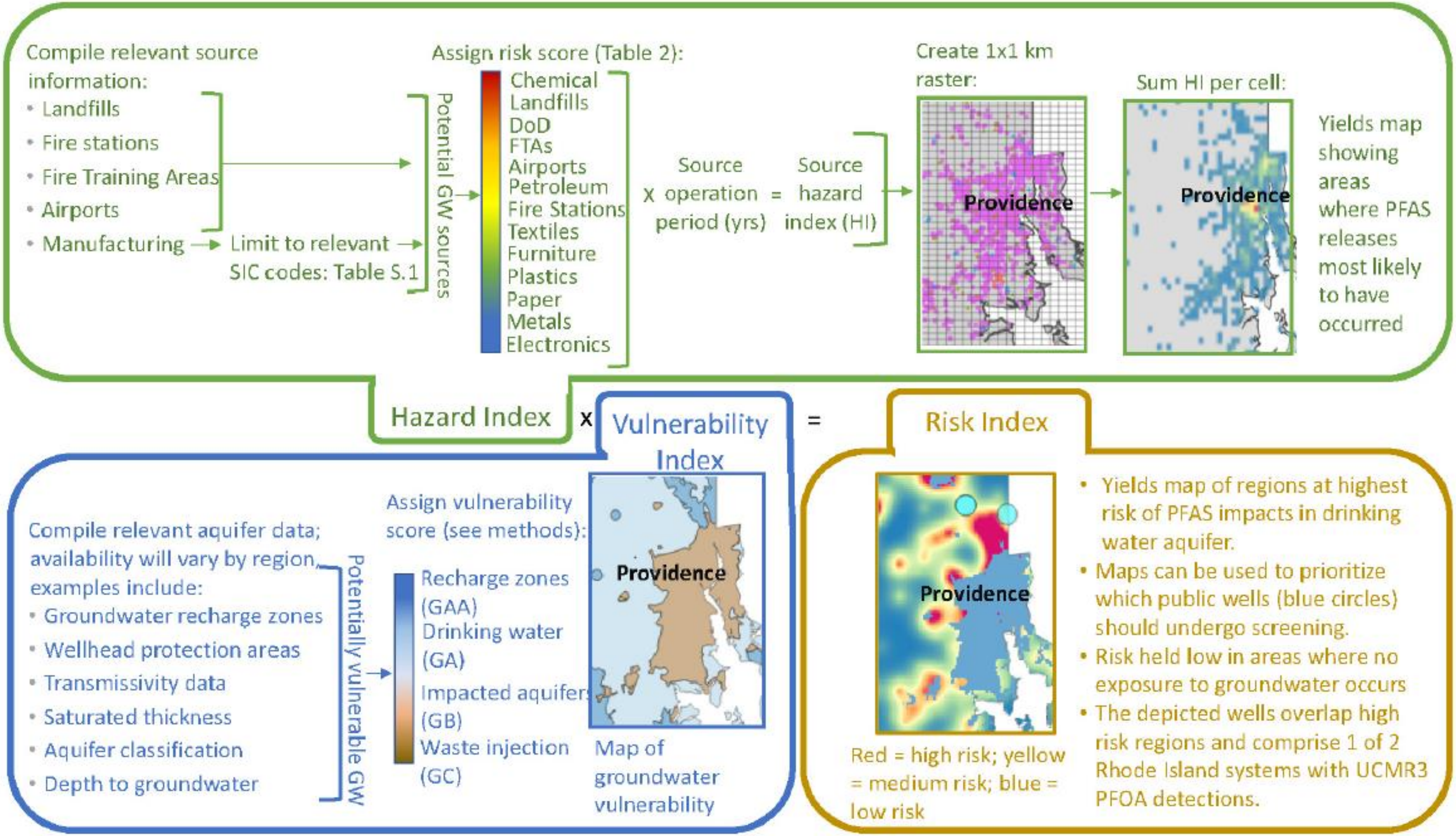
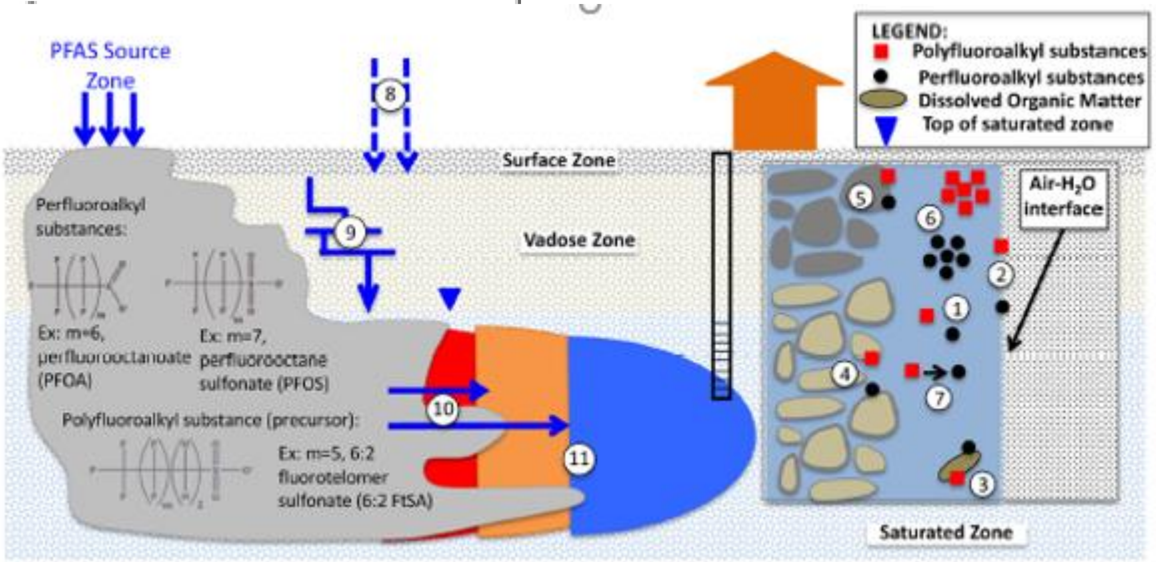


Figure 1. Overview of Rhode Island case study that utilizes a systematic approach to conduct a geospatial risk assessment of potential PFAS impacts in drinking water aquifers. Wells are shown with 1-mile buffers.

Description	Key Knowledge Gaps
(1) Dissolved PFAS (see Table 1 for current state of science)	Total PFAS composition at key points (surface, vadose, saturated zones) at PFAS-impacted facilities
(2) PFAS air-water partitioning[1,2]	Impact of PFAS water-air surface activity on partitioning in unsaturated media
(3) PFAS sorption to dissolved organic matter	Potential for PFAS to partition to DOM and exhibit facilitated transport, similar to other contaminants
(4) PFAS sorption to solids[3-10]	Potential for PFAS sorption hysteresis, polyfluoroalkyl sorption, impacts of soil/solution chemistry on polyfluoroalkyl sorption
(5) PFAS sorption to solids altered by co-contaminants or remedial activity[10–13]	Impact of co-contaminants, remediation on sorption/desorption of polyfluoroalkyl substances
(6) PFAS micelle/hemimicelle formation	Potential formation of PFAS micelles or hemimicelles as concentrations increase and saturation decreases
(7) Precursor biotransformation to perfluoroalkyl substances[14-16]	Transformation pathways, applicability of laboratory precursor transformation rates at the site level
(8) Infiltration	Impacts of infiltration and resulting changes in saturation on PFAS transport through the surface and vadose zones
(9) Vadose zone hydrogeology	Influence of fractures, root zone, low permeability zones, or capillary zone on PFAS migration to the satura
(10) Saturated zone hydrogeology	Impact of variable hydraulic conducti subsurface conditions on saturated PF
(11) Transition from reducing to oxic conditions[7,10]	Potential for redox conditions caused degradation products (e.g. CH_4) to inf transformation

Conceptual Model of Micro and Macro Scale PFAS Fate and Transport



PFAS Sources – Lists of Industries that used PFAS

- U.S. EPA
- Other states

- North American Industry Classification System (NAICS)
- Standard Industrial Classification (SIC) Code

New Hampshire Potential Commercial and Industrial Products that Use PFCs

SIC Code	Manufacturer	NAICS Code
2221	Broadwoven Fabric Mills, Manmade Fiber and Silk	313210
2262	Finishers of Broadwoven Fabrics of Manmade Fiber and Silk	313310
2273	Carpets and Rugs	314110
2295	Coated Fabrics, Not Rubberized	313320
2297	Non-woven Fabrics	313230
2299	Textile goods, Not Elsewhere Classified	313110
2385	Waterproof Outerwear	314999
2392	House furnishings, Except Curtains and Draperies	314999
2621	Paper Mills	322121
2656	Sanitary Food Containers, Except Folding	322219
2671	Packaging Paper and Plastics Film, Coated and Laminated	322220
2672	Coated and Laminated Paper, Not Elsewhere Classified	322220
2673	Plastics, Foil, and Coated Paper Bags	322220
2752	Commercial Printing, Lithographic	323111
2796	Platemaking and Related Services	323120
2824	Manmade Organic Fibers, Except Cellulosic	325220
2842	Specialty Cleaning, Polishing, and Sanitation Preparations	325612
2844	Perfumes, Cosmetics, and other Toilet Preparations	325611
2851	Paints, Varnishes, Lacquers, Enamels, and Allied Products	325510
2869	Industrial Organic Chemicals, Not Elsewhere Classified	325193
2899	Chemicals and Chemical Preparations, Not Elsewhere Classified	325199
2911	Petroleum Refining	324110
2992	Lubricating Oils and Greases	324191
3081	Unsupported Plastics Film and Sheet	326113
3082	Unsupported Plastics Profile Shapes	326121
3083	Laminated Plastics Plate, Sheet, and Profile Shapes	326130
3089	Plastics Products, Not Elsewhere Classified	326121
3471	Electroplating, Plating, Polishing, Anodizing, and Coloring	332813
3497	Metal Foil and Leaf	332999
3589	Service Industry Machinery, Not Elsewhere Classified	333318
3841	Surgical and Medical Instruments and Apparatus	333249
3861	Photographic Equipment and Supplies	333316
5169	Chemicals and Allied Products, Not Elsewhere Classified	424690
5719	Miscellaneous Home Furnishings Stores	442291
7217	Carpet and Upholstery Cleaning	561740

Minnesota NAICS List

Primary NAICS	Primary NAICS Description	Rank
324110	Petroleum Refining	4
324110	Oil Refineries	4
488119	Airports	4
928110	National Security (DoD sites)	4
323120	Platemaking and Related Services	3
324191	Lubricating Oils and Greases	3
325510	Paints, Varnishes, Lacquers, Enamels, and Allied Products	3
332813	Electroplating, Plating, Polishing, Anodizing, and Coloring	3
562212	Landfills	3
313210	Broadwoven Fabric Mills, Manmade Fiber and Silk	2
313310	Finishers of Broadwoven Fabrics of Manmade Fiber and Silk	2
314110	Carpets and Rugs	2
314999	Waterproof Outerwear	2
316110	Leather & Hide Tanning & Finishing	2
316998	All Other Leather Good & Allied Product Mfg	2
322219	Sanitary Food Containers, Except Folding	2
322220	Packaging Paper and Plastics Film, Coated and Laminated	2
323111	Commercial Printing, Lithographic	2
326113	Unsupported Plastics Film and Sheet	2
333318	Service Industry Machinery, Not Elsewhere Classified	2
334413	Semiconductor and Related Device Manufacturing	2
424690	Chemicals and Allied Products, Not Elsewhere Classified	2
561740	Carpet and Upholstery Cleaning	2
322121	Paper Mills	1
325611	Perfumes, Cosmetics, and other Toilet Preparations	1
325612	Specialty Cleaning, Polishing, and Sanitation Preparations	1
332999	Metal Foil and Leaf	1
333249	Surgical and Medical Instruments and Apparatus	1

NAICS and SIC Codes

- Challenging to use – location based filing system
- References only current activities; No legacy actions indicated.
- Business specific – not location specific
  - Headquarters?
  - Former or current manufacturing?
  - No specifics of operations at plant

Evaluation Methods

- Michigan Model – Water Supply Well Sampling
- Minnesota Model – Industry Identification – Fire Dept and Landfill studies
- California Model – Airport and Landfill Testing

Other Resources

- Open Forum to discuss other resources on PFAS sources

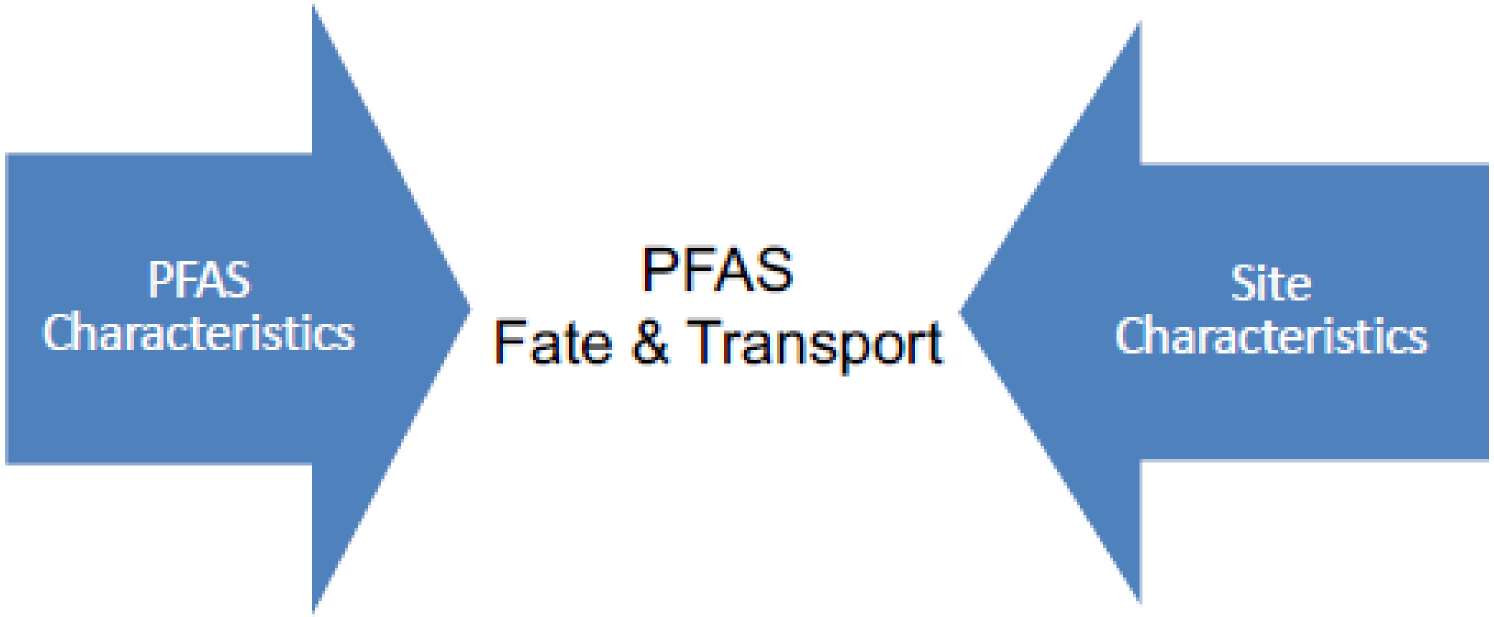
Technical Advisory Group Objectives

- Needs
  - Fact Sheets
  - Guidance
  - Training
  - Policy Development
  - Other
- Resources
- Data Gaps
- Deliverables
- Report out

Questions?

Site Characterization – April 18th

- Review of ITRC information and other sources



Site Characterization – April 18th

- Review of ITRC information and other sources

- General PFAS site characterization approaches
  - Conceptual Site Models
    - Discharge mechanisms
    - Transport pathways
  - Target Compounds
- Assessing different PFAS sources
  - Fire Training/Fire Response Sites
  - Industrial Sites
  - Landfills
  - WWTPs/Biosolids
- Identify data gaps

Interest Survey

- Review of other ITRC Fact Sheets and Tech/Reg Document information?
- Prioritize future subgroup assignments based on interest

ITRC Tech/Reg Document - Sections

1. History of Use
   - Naming Conventions
   - Precursors
   - Replacement Chemistry
2. Detection Technologies/Analytical
3. Fate and Transport
   - Site Investigation
   - Physical and Chemical Properties
   - Sample Collection
4. Risk Communication
5. AFFF
6. Remediation Technologies
   - Drinking water
   - Soil
   - Groundwater
7. Regs/Toxicology/Risk
8. Stakeholders
9. Training

Thank You!