General Sources and Structures of PFAS

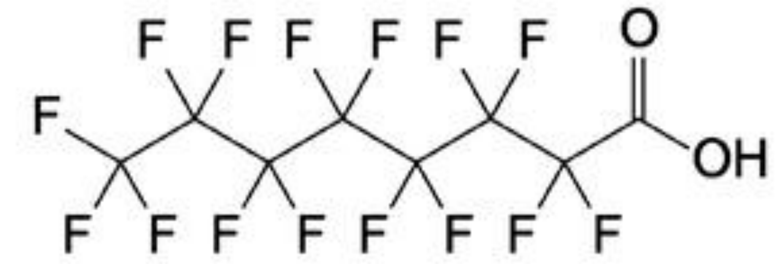
Sandra M. Goodrow, Ph.D.
NJ Department of Environmental Protection
Division of Science, Research, and Environmental Health

Panel 1- CVP/SRAG Meeting

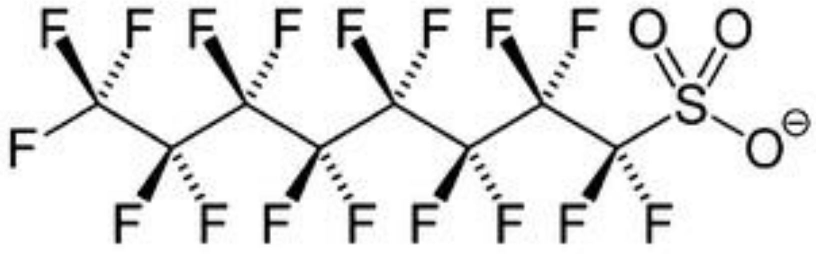
June 2017

What are PFAS?
Per- and Polyfluoroalkyl Substances

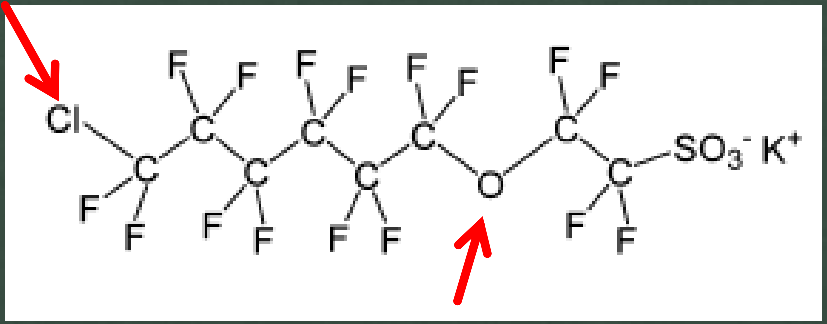
- **Class of manmade chemicals**
  - Commercial and industrial uses
  - Produced and used for over 60 years
- Chemical Structure
  - Totally fluorinated carbon chain
  - Charged functional group
    - Carboxylates (COOH)
    - Sulfonates (SO_3-)



Perfluorooctanoic acid (PFOA)



Perfluorooctanesulfonate (PFOS)



Important Properties

- Repels oil and water
  - Hydrophobic/oleophobic fluorinated carbon chain
  - Useful for commercial applications
- Highly water soluble
  - Hydrophilic charged functional group
  - Occurs in groundwater, surface water, and finished drinking water
- Chemically and thermally non-reactive
  - Extremely strong C-F bond
  - Useful for commercial and industrial applications
- Does not break down in the environment.

Uses

- Processing aid in the production of fluoropolymer plastics (e.g. PTFE, PVDF)
  - Non-stick cookware
  - Waterproof/breathable clothing
  - Chemical/heat resistant industrial uses.
- Water and stain resistant coatings for carpets and upholstery
- Grease-proof food packaging
- Aqueous fire fighting foam

…and more!

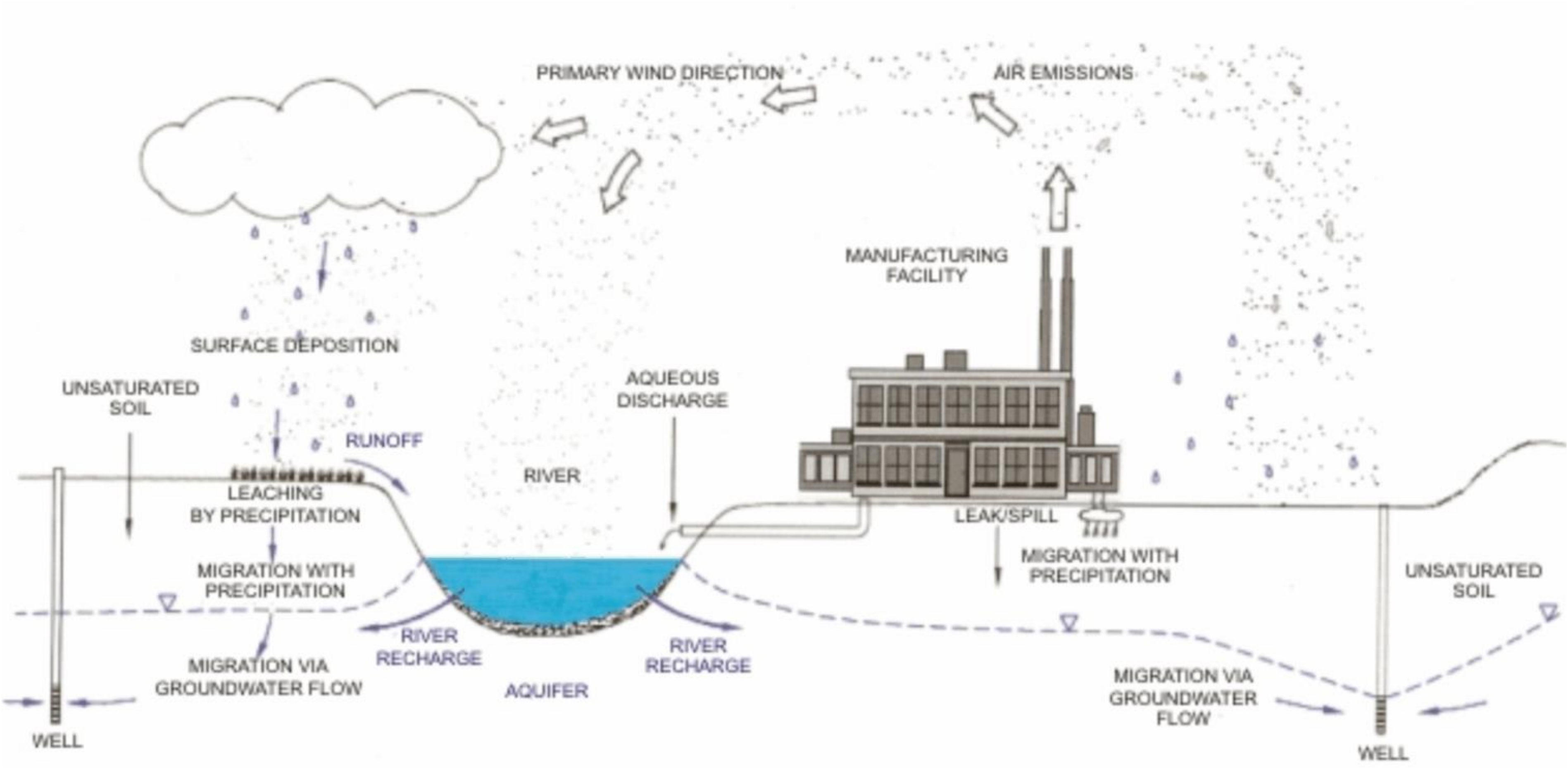
Sources

- Industrial facilities where they are made or used
- Release of aqueous fire fighting foams
  - Fire fighter training sites
  - Military bases and airports
- Wastewater treatment plants
  - Effluent discharges
  - Land application of sludge
- Disposal of products used by small businesses
- Municipal landfill leachates
- Formation from precursors in atmosphere, and by bacteria in soil, sludge, and wastewater.

Transport

Two major pathways for industrial releases to get to groundwater:

1. Migration of groundwater plume
2. Air emissions to Soil Deposition (up to miles away) to Migration to groundwater



Phase-out of Long-Chain PFAS

- **PFOA, PFNA, PFOS, PFHxS, and other long chain-homologues:**
  - Production by major U.S. manufacturers has been voluntarily ended.
  - Phased out due to concerns about biological persistence and potential health effects.
  - Shorter chain PFCs and other types of PFAS have been introduced as replacements (next slide).

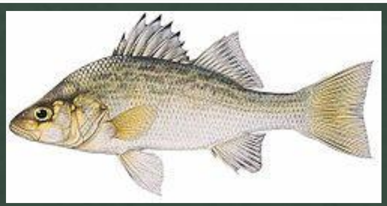
- **However, environmental contamination from these long-chain PFCs is expected to continue due to:**
  - Extreme environmental persistence.
  - Continued formation from precursors in the environment.
  - Continued production by non-participating manufacturers, especially overseas.

Environmental Fate & Transport of PFAS

- Persistent, Bioaccumulative, and Toxic…

  - BUT very different from "classic" PBT chemicals

	PFCs	Dioxins & PCBs
Highly water soluble	YES	NO
Bind well to soil & sediments	NO	YES
Degrades in environment to some extent	NO	YES
Bioaccumulates in fish	NO/YES*	YES
Bioaccumulates in lipids	NO	YES
Drinking water is major exposure route	YES	NO



* **NO** - Less than 8 fluorinated carbons (e.g. *PFOA, PFHxS*).

YES – 8 or more fluorinated carbons (*PFOS, PFNA, and higher*).

For Questions or More Information:

Sandra Goodrow, Ph.D.
NJDEP, Division of Science, Research and Environmental Health

Sandra.Goodow@dep.nj.gov

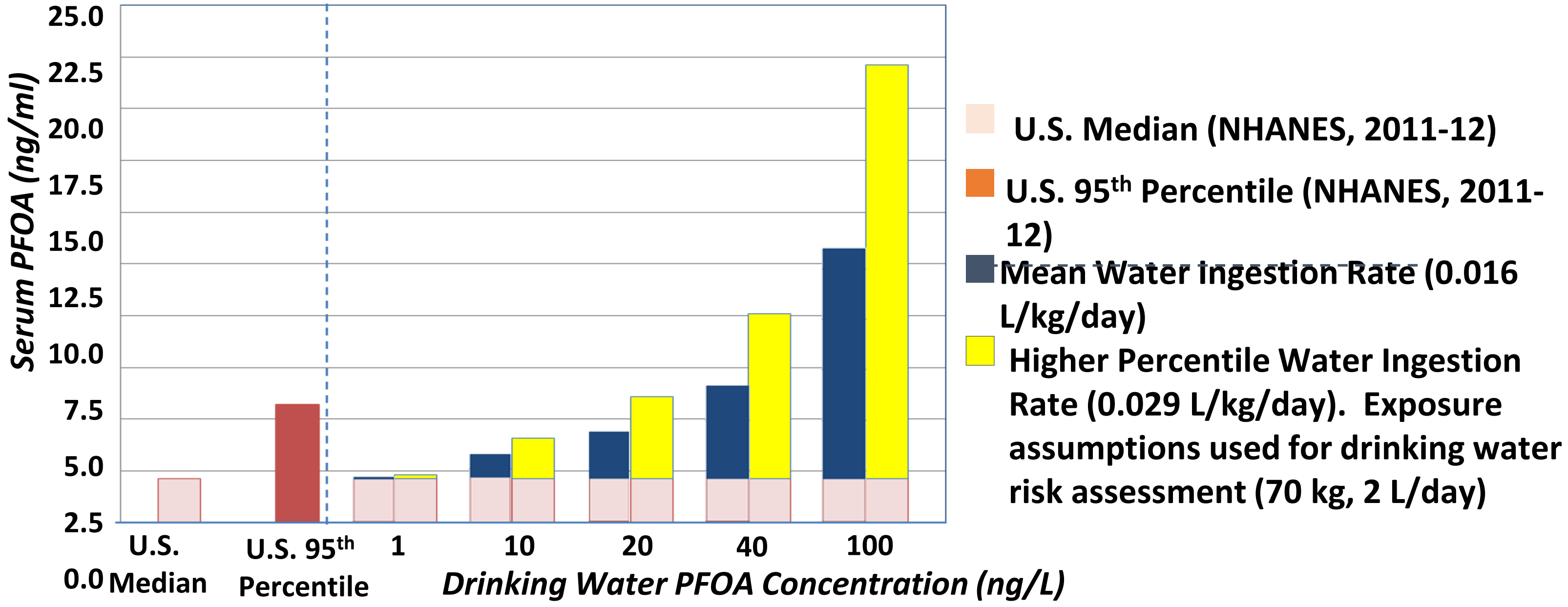
PFAS Health Effects Overview

Long-chain PFAS are Biologically Persistent

- Human half-lives are several years. (Shorter-chain PFAS have shorter half-lives.)
  - Blood serum level is indicator of long term exposure
  - Not metabolized and slowly excreted
  - Elevated body burdens remain for many years after exposure ends
- Several long-chain PFAS found at low ppb levels in blood serum of virtually all U.S. residents.
  - Perfluorooctanoic acid (PFOA; C8)
  - Perfluorononanoic acid (PFNA; C9)
  - Perfluorooctane sulfonate (PFOS; C8-S)
  - Perfluorohexane sulfonate (PFHxS; C6-S)
- Accumulate in liver, blood serum, and kidneys - not fat
  - Bind to proteins in these tissues
  - In contrast to other well known persistent, bioaccumulative, and toxic (PBT) chemicals (e.g. dioxins, PCBs) that accumulate in fat.
- Higher blood serum level (internal dose) from same administered dose in humans versus animals.
  - Human-to-animal comparison based on serum levels (internal dose), not administered dose.

Long-chain PFAS in Drinking Water Substantially Increase Total Human Exposure

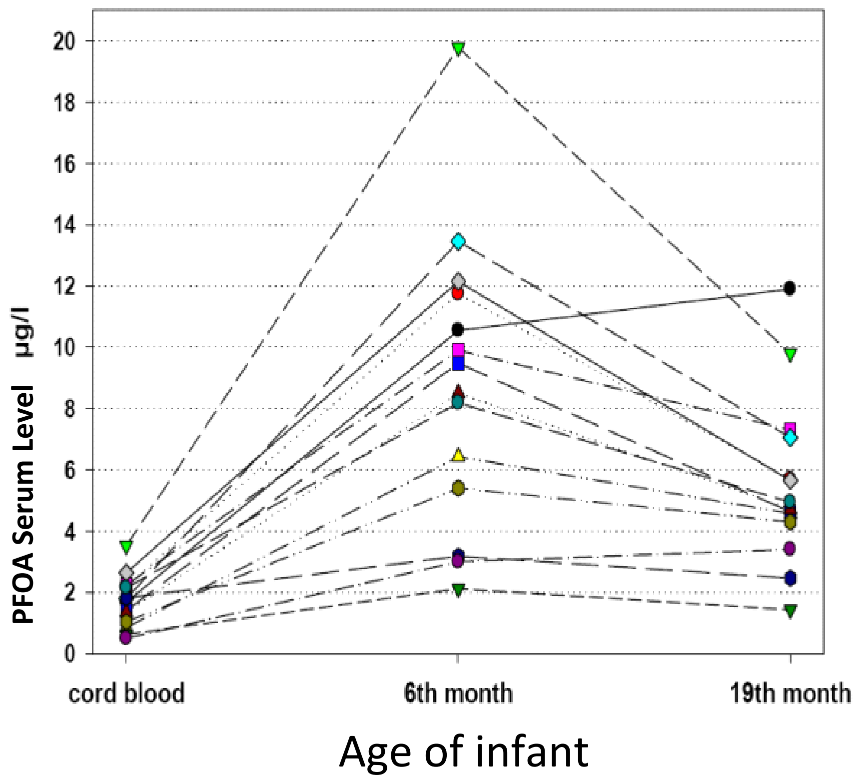
- Non-drinking water exposure sources include diet, consumer products, and house dust.
  - Drinking water, even with low levels of long chain PFAS, is a major exposure source.
- *Example – PFOA:* Blood serum levels increase, on average, by **greater than 100-fold the drinking water concentration**, with ongoing exposure.
- Compared to median general population serum PFOA level**:**
  - **20 ng/L** in drinking water increases serum levels by **more than 2-fold,** on average.
  - **100 ng/L** in drinking water increases serum levels by **more than 6-fold,** on average.



Developmental Exposures to PFAS are Important

- Of concern because early life effects are sensitive endpoints for PFC toxicity.
- Prenatal exposure to fetus
- Infants & young children have **higher exposures** than adults.
  - Blood serum levels at birth are similar to maternal serum levels.
  - Increase several fold during first few months of life.
- From breast milk or formula prepared with contaminated water.
  - Breast milk concentrations similar or higher than in maternal drinking water.
  - Infants consume much more fluid on body weight basis than older individuals.
- Exposures via other routes also higher for infants and young children:
  - Hand-to-mouth behavior: House dust.
  - More time on floors: Treated carpets.

Serum PFOA Increases in Breastfed Infants



Fromme et al., 2010

PFAS Toxicology & Mode of Action Overview

- There are similarities and differences in toxicological effects among PFAS
  - Longer-chain PFAS generally more toxic & biologically persistent than shorter chain PFAS.
- Modes of action - Overall NJDEP/DWQI conclusion is that toxicological effects of PFAS in animal studies are considered relevant to humans.
  - PFAS interact with multiple receptors that regulate expression of genes which control many biological pathways.
  - Not genotoxic.
  - Several other potential modes of action.
  - Modes of action are not fully characterized.
- Carcinogenicity evaluations (based on human, animal, and mode of action data):
  - PFOA:
    - USEPA SAB (2006) - “likely carcinogen”.
    - IARC (2015) - “possibly carcinogenic”.
    - USEPA Office of Water (2016) - “suggestive carcinogen”.
  - PFNA:
    - No animal or human carcinogenicity data.
    - European Chemical Agency (ECHA; 2014) classified as “suspected of causing cancer” based on “read-across” from PFOA

PFOA: Human Epidemiology

- Much more human data for PFOA than for other PFAS or most other drinking water contaminants.
- PFOA is associated with cancer and non-cancer effects in humans.
  - ↑ cholesterol
  - ↑ uric acid
  - ↑ liver enzymes
  - ↓ birth weight
  - ↓ vaccine response
  - Testicular and kidney cancer
  - …and others
- Notable features of human data:
  - <u>Consistency</u> of results in different populations for most of these endpoints.
  - <u>Concordance</u> with effects in animal toxicology studies for most endpoints.
  - Use of serum concentrations as measure of <u>internal exposure</u>.
  - Associations found at <u>low exposure levels</u> - in general population and communities with drinking water exposure.

PFOA: Toxicology

- Studies have been conducted in non-human primates (monkeys) and rodents.
- PFOA causes multiple toxicological effects in laboratory animals
  - Weight loss
  - Liver toxicity
  - Multiple effects on pregnancy and on development of fetus and neonate
  - Immune system suppression
  - Neurobehavioral effects
- Carcinogenicity
  - Two chronic rat studies - Liver, testicular, and pancreatic tumors
  - Human data – associations of drinking water exposure with kidney and testicular cancer
  - Evaluations by authoritative groups:
    - USEPA Science Advisory Board (2006) - “likely carcinogen”
    - International Agency for Research on Cancer (IARC; 2015) - “possibly carcinogenic”
    - USEPA Office of Water (2016) - “suggestive carcinogen”
- Toxicological endpoints are generally consistent with associations with human health effects.
- Some effects (delayed mammary gland development; liver toxicity after developmental exposures) occur at very low doses.

PFNA: Human Epidemiology

- Much less data than for PFOA:
  - Most studies are from general population.
  - No studies in communities with drinking water exposure.
  - One occupational study.
- Evidence strongest for associations with increased serum cholesterol and the liver enzyme ALT.
  - Consistent with PFOA data for these endpoints
- Most other endpoints evaluated in only one or a few studies.
- Cancer has not been studied.

PFNA: Toxicology

- Studies have been conducted in rats and mice.
- Profile of toxicity is generally similar to PFOA
  - PFNA is more persistent in the body than PFOA.
  - Causes generally similar effects but at lower doses than PFOA.
- Toxicological effects include:
  - Weight loss
  - Liver toxicity
  - Kidney toxicity
  - Immune system suppression
  - Multiple effects on pregnancy and on development of fetus and neonate
    - Decreased weight gain in offspring persists into adulthood (in contrast to PFOA)
  - Male reproductive system toxicity
- Chronic toxicity/carcinogenicity not studied

PFOS: Human Epidemiology

- Considerable epidemiology data:
  - Most studies are from general population.
  - No studies in communities with specific sources of drinking water contamination.
  - Several occupational studies.
- Evidence strongest for associations with decreased vaccine response and increased serum uric acid/hyperuricemia.
- Associations with cancer are equivocal.

PFOS: Toxicology

- Studies have been conducted in rats, mice, monkeys and rabbits
- PFOS is more persistent in the body than PFOA.
  - Some significant differences with the health effects of PFOA.
- Toxicological effects in adults include:
  - Neurological effects
    - changes in learning, memory, activity, and habituation
  - Effects on thyroid hormones
  - Liver toxicity
  - Immune system suppression
- Effects on reproduction and fetal development include:
  - Increased mortality
  - Decreased body weight
  - Developmental delay
  - Developmental neurotoxicity
  - Endocrine effects

PFOS: Toxicology (cont'd)

- Carcinogenicity
  - Chronic bioassay in rats
  - Tumors of
    - Liver
    - Thyroid
    - Mammary glands
  - USEPA Office of Water (2016) – "Suggestive evidence of carcinogenic potential"

ITRC PFAS Team

Developing Concise Technical Resources to Support Regulators and Improve Understanding of the Current Science of PFAS Compounds

CVP/SRAG Meeting

June 14, 2017

What is ITRC?

ITRC is a state-led coalition working to advance the use of innovative environmental technologies and approaches.

ITRC translates good science into better decision making

ITRC Purpose & Mission

- **ITRC Purpose**

  To advance innovative environmental decision making

- **ITRC Mission**

  Develop information resources and help break down barriers to the acceptance and use of technically sound innovative solutions to environmental challenges through an active network of diverse professionals

What ITRC Does

ITRC uses a proven, cost-effective approach to develop guidance documents and training courses

Select Projects

Form Teams

Develop Documents and Training

Conduct Training

Implement Solutions

Since 1995:
115 documents
74 training courses

Power of ITRC's Unique Network

- Environmental Council of the States (ECOS)
- Federal Government
- State Government
- Public/Tribal Stakeholders
- IAP ITRC Industry Affiliates Program — Industry
- Academia

PFAS Team Goal

- Understanding in the scientific community of PFAS sources, site characterization, fate and transport and remediation is growing rapidly
- PFAS compounds in the environment have become an emerging, worldwide priority
- The ITRC PFAS team will produce concise technical resources for project managers – regulators, consultants, responsible parties, and stakeholders
  - Six Fact Sheets
  - Web-based Technical and Regulatory Guidance Document
  - Internet-based Training

Overview

- The ABCs of PFAS
  - **Background**
  - **History**
  - **Use**

- **Status of ITRC PFAS Efforts**

PFAS: Background

- **What are per- and poly-fluoroalkyl substances (PFAS)?**
  - Very large class of fluorinated surfactants (200+, 1,000+, ??)
  - Used for many years in a wide range of products that resist heat, stains, water, oil and grease.
  - Have many specialized industrial applications.
- **Why do we care about PFAS?**
  - Persistent and widely dispersed in the environment
  - Bioaccumulate
  - Mounting evidence of health concerns at environmentally relevant concentrations

The Wide World of PFAS

- Non-stick coatings
- Water, oil, and stain repellents
- **Fire-fighting foams**
- Pesticides/insecticides
- **Aviation hydraulic fluid**
- **Metal plating baths (CrVI; Ni, Sn,…)**
- Antifogging & antistatic agents
- **Semiconductor industry**
- Paints & adhesives
- Fluoro-elastomers
- Mining & oil surfactants
- Personal care & sports

ITRC PFAS Team

- Team membership total = 265
  - Academics – 8
  - Stakeholders – 3
  - Federal (DOD, DOE, EPA, Other) – 41
  - State and local – 61
  - Industry and consulting – 146
  - International - 6
- Leading experts from all sectors
- State representatives from 29 states (including Wash DC)

Project Overview

- Produce concise technical resources for PFAS compounds
- Start with six Fact Sheets synthesizing key information
  - History and Use
  - Nomenclature Overview and Physicochemical Properties
  - Regulatory Summary
  - Fate and Transport
  - Site Characterization Tools, Sampling Techniques and Laboratory Analytical Methods
  - Remediation Technologies and Methods

Project Overview

- Following the release of the Fact Sheets in 2017, develop a detailed, web-based technical and regulatory guidance document and Internet –based training (IBT) course.
  - Technical information
    - Necessary breadth and depth not given by Fact Sheets
  - Links to scientific literature
  - Regulatory information and links
  - Stakeholder perspectives
  - Other related information as determined by the team
- Work on outreach opportunities
- Team to complete its work by December 2019

Developing Fact Sheets

- Six writing subgroups
- Led by one state regulator and one other team member
- All team members will be able to participate through comments and review
- Fact sheets expected to be 10 pages or less
- Identify key information for the fact sheets and accumulate content for the more in-depth web-based document
- Evaluate the potential for updatable resources such as Excel files with chemical and physical properties and regulatory levels that could be made available on the ITRC web site as the project progresses

Fact Sheet Writing Subgroup Leaders

- History & Use
  - Kate Emma Schlosser, NH
  - Jeff Hale, Kleinfelder
- Nomenclature and Phys-Chem
  - Tracie White, CO
  - Elizabeth Denly, TRC Solutions
- Regulatory Summary
  - Brie Sterling, PA
  - Linda Hall, GSI
- Fate & Transport
  - Sandra Goodrow, NJ
  - Sarah Gewurtz, GHD
- Site Char., Sampling Tech., Lab Methods
  - Bob Delaney, MI
  - Janice Willey, Navy
- Remediation Technologies
  - Jamie Wallerstedt, MN
  - Bill DiGuiseppi, CH2M

Target Users for Fact Sheets

- Primary – state personnel of regulatory programs, project mangers for remediation, drinking water, waste management and other programs
- Additional – consultants, industry, and federal project managers; stakeholders

Fact Sheet Writing Schedule

- First 3 fact sheet drafts to the editor by June 15
- Start external review for first 3 fact sheets July 17 (30-day review)
- Review complete August 16
- Possible team meeting end of August, early September
- Publish first 3 fact sheets September 8
- Second 3 fact sheet drafts to the editor by September 15
- Define scope and goals for web-based document by September 15
- Start external review for second 3 fact sheets October 16 (30-day review)
- Review complete November 15
- Publish second 3 fact sheets December 8
- Annotated outline for web-based document by December 13

ITRC PFAS Contacts

- Patricia Reyes, ITRC Director
  - preyes@ecos.org
- Bob Mueller, NJ DEP, PFAS Team Leader
  - Bob.Mueller@dep.nj.gov
- Ginny Yingling, MN Dept of Health, PFAS Team Leader
  - virginia.yingling@state.mn.us
- Lesley Hay Wilson, ITRC Program Advisor PFAS Team
  - lhay_wilson@sagerisk.com