Technical Challenges and Solutions for PFAS at Brownfield Sites
March 11, 2020

Troy Conrad, PADEP
Colleen Costello, GHD
Duane Luckenbill, Eurofins
Brie Sterling, PADEP
Agenda

• PFAS Overview – Troy Conrad, PADEP

• PFAS Challenges and Solutions for PFAS at Brownfield Sites – Colleen Costello, GHD

• PFAS Analysis in Environmental Samples; Current Status and What’s to Come- Duan Luckenbill, Eurofins

• PFAS Toxicity Overview – Brie Sterling, PADEP
PFAS Overview

PA Brownfields Conference
March 11, 2020
Troy Conrad

Tom Wolf, Governor
Patrick McDonnell, Secretary
Background

• Per- and polyflouroakyl substances
• 3,000+ manmade chemicals since 1940’s
• Shed water, repel stains and reduce friction
• Fire fighting foam, textiles, paper and food packaging, non-stick cookware and personal care items
• Teflon, Scotchguard, Gore-Tex
• Persistent and bioaccumulates
• Perflourooctanoic acid (PFOA) and perflurooctane sulfonate (PFOS)
• Blood serum
• Half-life
• High cholesterol, thyroid disorders and increased risk of cancer
• Largely unregulated
• Executive Order - Sept. 19, 2018
• DEP, DOH, PDA, DCED, DMVA, PennDOT and State Fire Marshal
• Chaired by Secretary McDonnell
• Identify and eliminate sources
• Ensure drinking water is safe
PFAS Action Team

• Phase out and disposal of AFFF
• Reduce PFAS from commerce
• Open and closed meetings
  – Gather and share information
  – Discuss data gaps
  – Oversight authority
PFAS Sampling Plan

• Plan is available on DEP website
• 400 samples
  – 360 samples near known or potential sources
  – 40 samples used as control group
• UCMR3...PFOS, PFOA, PFNA, PFHxS, PFHpA & PFBS
• Follow-up action for > PFOA/PFOS 70 ppt
• Review/evaluate human health effects and toxicity data for PFOA and PFOS
• Prepare final report with recommendation for appropriate MCL
• Work is expected to take one year
• Contract will be extended if needed
• DOH has also hired a toxicologist
Remediation Standards

• EPA Maximum Contaminant Level (MCL) or Lifetime Health of Level (HAL) = Act 2 Statewide Health Standard

• Combined EPA Lifetime HAL / Act 2 standard for PFOA/PFOS is 70 ng/L

• Proposing soil and/or groundwater Medium Specific Concentrations for PFOA/PFOS and PFBS
Challenges

• Still in use
• Occurrence data
• Analytical methods
• Laboratory capability
• Toxicity information
• Standards
• Treatment & disposal options
PFAS
Considerations and Challenges

Colleen Costello, PG | GHD
Ryan Thomas, PhD | GHD

March 11, 2020
Agenda for Today

PFAS Pathways

Sampling Challenges

Treatment Challenges
PFAS Pathways
Emerging Awareness

SOURCE: ITRC’s History of Use of Per- and Polyfluoroalkyl Substances (PFAS) – Fact Sheet

*Common regulatory criteria or health advisories

†Sum of informal poll (NJ, NH, MN)
Where do PFAS come from?

PFAS exposure may:

- Affect development in children
- Lower pregnancy chance
- Interfere with hormones
- Increase cholesterol levels
- Affect immune system
- Increase risk of cancer

SOURCE: CDC/ATSDR PFAS Health Effects; http://evocra.com.au
Sources from Manufacturing

- Manufacture of military vehicles, RVs, and construction equipment
- Manufacture of fluorinated pesticides/herbicides
- Manufacture, testing, or use of firefighting pumps and equipment
- Landfill leachate and WWTP effluent
- Airports
- Firefighting training facilities

Chrome plating historically used PFOS as a fume suppressant
Potential for products or precursors to degrade to PFAS
Use of fire fighting foams for emergencies and training
Use of fire fighting foams
Potential Exposure Pathway

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)

SOURCE: www.atsdr.cdc.gov/pfas

SOURCE: ITRC – History and Use of PFAS Fact Sheet 2017
PFAS Potential Pathways to Water Sources

**FACTORY**
(For example, Tyco Fire Products in Marinette)

**WASTEWATER TREATMENT PLANT**

PFAS moves through drains and sewer system

PFAS runoff enters streams, lakes and groundwater

**CONTAMINATION SITE**
(For example, firefighting foam at Truax Air Nation Guard Base)

**Stream**

Treated wastewater is discharged into streams

**Lakes**

Drinking water can come from lakes

**Aquifer**

Fertilizer enters groundwater and seeps into aquifer

PFAS seeps through soil to the aquifer

Public and private well water is drawn from aquifer

**Public water utility**

Water to homes

**Homes**

Wells deliver water to faucets

**Private wells**

**Farm fields**
Fertilizer sludge is spread on farm fields

**Wastewater from homes goes to the treatment plant**

SOURCE: Michigan Department of Environmental Quality, Environmental Working Group, State Journal research
**PFAS** in Wastewater

**PFAAs: Effluent >> Influent**

*Biotransformation of precursors during aerobic wastewater treatment*

PFAS in Commercial Fertilizers

*PFAA concentration in < 2mm fraction (36-80%) normalized to total mass (assumes PFAA is negligible in the fraction > 2 mm)

SOURCE: Lazcano et al., Manuscript in preparation
Sampling Challenges
Sampling Challenges

- PFAS are ubiquitous
- Can be on samplers clothing, gloves, sampling equipment
- Waterproof field note books
- Glass bottles can cause loss of analyte
- Water for blanks (must be certified-PFAS free)
# Sampling Challenges

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<th>Acceptable Items</th>
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<td><strong>Field Equipment</strong></td>
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<tr>
<td>Teflon® containing materials (tubing, bladders, o-rings, caps)</td>
<td>High-density polyethylene (HDPE) materials</td>
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<td>Low density polyethylene (LDPE) materials</td>
<td>Acetate Liners</td>
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<td>Silicon Tubing</td>
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<td>Waterproof field books</td>
<td>Loose paper (non-waterproof)</td>
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<td>Plastic clipboards, binders, or spiral hard cover notebooks</td>
<td>Metal field clipboards or with Masonite</td>
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<td>Post-it Notes®, Sharpies®</td>
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<td>Chemical (blue) ice packs</td>
<td>Regular ice</td>
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<td><strong>Field Clothing and PPE</strong></td>
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<td>New cotton clothing or synthetic water resistant, waterproof, or stain-treated</td>
<td>Well-laundered clothing made of natural fibers</td>
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<td>clothing containing Gore-Tex™</td>
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<td>Clothing laundered using fabric softener</td>
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<td>Tyvek®</td>
<td>Powder-free nitrile gloves</td>
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<td>No cosmetics, moisturizers, hand cream, or other related products as part of</td>
<td><strong>Sunscreens</strong> - Alba Organics Natural Sunscreen, Yes</td>
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<td>personal cleaning/showering routine on the morning of sampling</td>
<td>To Cucumbers, Aubrey Organics, Jason Natural Sun</td>
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<td>Block, Kiss my face, Baby sunscreens that are “free” or</td>
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<td>“natural”</td>
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<td><strong>Insect Repellents</strong> - Jason Natural Quit Bugging Me,</td>
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<td>Repel Lemon Eucalyptus Insect repellent, Herbal Armor,</td>
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<td>California Baby Natural Bug Spray, BabyGanics</td>
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<td><strong>Sunscreen and insect repellent</strong> - Avon Skin So</td>
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Treatment Challenges
# Evaluation of Treatment Technologies

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<th>COAG/ FLOC/SED/ G- or M-FIL</th>
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<th>AIX</th>
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*Treatment performance is assumed based on PFAA size/charge and/or known removal data of shorter or longer chain homologues

**SOURCE:** Dickenson and Higgins (2016) Water Research Foundation “Treatment Mitigation Strategies for Poly- and Perfluoroalkyl Substances”
Ion Exchange

- Dual removal mechanism
  - PFOS/PFOA negatively charged at the pH of typical natural water
  - Hydrophobic end of PFAS can adsorb to hydrophobic surface of resin
- Co-contaminants
  - Ionic contaminants will compete for IX sites
  - Organics can foul resin and require pretreatment

- Single use disposed through landfilling or incineration
- Regenerable
  - Typically done on site
  - Must dispose of regenerant solution
- Full scale systems in place in the last year or so
- Technology providers
  - Purolite
  - Evoqua
    - Dow resin developed for perchlorate
Activated Carbon

- Treatment systems for PFAS operating for 15+ years
- PFOS removal capacity greater than PFOA
- No conversion of precursors to PFAS

Considerations
- Organic concentrations can be 10-100x PFAS and drive carbon usage
- Adsorption media can be thermally reactivated to destroy PFAS
- Each supplier has ~3 locations for incineration
- Some studies show reduced effectiveness with regenerated GAC
- Uncertain if regenerated GAC could be used for drinking water treatment

Technology Providers
- Calgon
- Evoqua
**Incineration** of PFAS

- Limited scientific literature
- Fluorinated byproducts may be formed when incinerating PFOS (Yamada & Taylor 2003)
  - At 600°C, incineration of PFOS-contaminated material resulted in many byproducts
  - At higher temperatures (750°C and 900°C), these byproducts were not observed
- Current best practice disposal routes for spent PFAS adsorption media are incineration at temperatures >1000°C
Case Study PFAS Impacted Groundwater

- Target parameters initially phosphorus, iron, and oil and grease
- Permanent treatment system design completed 2017/2018
- Monitoring to better define design basis
- Focus on PFAS in Michigan
- PFAS detected, original design scrapped
- Continue discharging to the potw
- Design for a direct discharge
# Case Study
## Groundwater Characterization

<table>
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<tr>
<th>Parameters</th>
<th>Units</th>
<th>Max</th>
<th>Avg</th>
<th>% Detected</th>
<th>Potential Limits</th>
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<tr>
<td>Phosphorus</td>
<td>ug/L</td>
<td>160</td>
<td>107</td>
<td>39%</td>
<td>15,000</td>
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<td>PFOA</td>
<td>ng/L</td>
<td>38</td>
<td>31</td>
<td>100%</td>
<td>No limit (currently)</td>
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<td>PFOS</td>
<td>ng/L</td>
<td>390</td>
<td>383</td>
<td>100%</td>
<td>420</td>
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<td>Ammonia-N</td>
<td>mg/L</td>
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<td>1.0</td>
<td>61%</td>
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<td>mg/L</td>
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<td>Calcium</td>
<td>mg/L</td>
<td>140</td>
<td>121</td>
<td>61%</td>
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<td>COD</td>
<td>mg/L</td>
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<td>89%</td>
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<td>Ferrous Iron</td>
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<td>1.7</td>
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<td>TOC</td>
<td>mg/L</td>
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<td>17.3</td>
<td>100%</td>
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<td>TSS</td>
<td>mg/L</td>
<td>11</td>
<td>6.5</td>
<td>67%</td>
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Technology Evaluation

Bench Testing Conducted:
- Granular Activated Carbon (GAC)
- Anion Exchange (AIX)
- Adsorbents
- Alkaline Ozonation
Granular Activated Carbon Results
Anion Exchange Results
Alkaline Ozonation Results

Thomas, Jenkins, Landale, Trigger et al., 2020 Remediation Journal (submitted).
Developing Technologies

- Reverse Osmosis or Nanofiltration
  - Bench/pilot studies, limited full scale installations
  - Concentrating the PFAS and other constituents
  - Would require further treatment or solidification/stabilization
- Adsorbents
  - Rembind® - Mixture of Powdered Activated Carbon, kaolinite and amorphous aluminum hydroxide
  - Zeolite/clay adsorption
  - Many other under development
- Advanced oxidation/Advanced reduction
- Electrochemical oxidation
- Plasma
Questions

Ryan Thomas, PhD | ryan.thomas@ghd.com
PFAS Analysis in Environmental Samples; Current Status and What’s to Come

Duane Luckenbill, Technical Director
Charles Neslund, Scientific Officer
Eurofins Lancaster Laboratories Environmental, LLC
Per- and Polyfluorinated Alkyl Substances (PFAS)

• Have been in use since the late 1940’s, early 1950’s

• Perfluorinated – all carbons in the chain are fully bonded to fluorine, forming a strong bond that is challenging to break

• Polyfluorinated – not all carbons in the chain are only bonded to fluorine

6:2 Fluorotelomer sulfonate (6:2 FTS)  Perfluorooctanoic acid (PFOA)
The General Classes of Per- and Polyfluoroalkyl Substances (PFAS)

PFAS

Non-polymer

Perfluorinated

- PFAAs
- PFCAs
- PFSAs
- FASAs

Polyfluorinated

- Perfluoroalkyl acids
  - Carboxylates
  - Sulfonates

Polymer

- Fluoropolymers
- Perfluoropolyethers (PFPE)
- Side-chain fluorinated polymers

Fluorotelomers:

- Sulfonates
- Carboxylates
- Alcohols

Source: ITRC Naming Conventions and Physical Chemical Properties fact sheet
Current Methods - EPA 537.1 (2018)

- Matrix
  - Potable Water
- 14 +4 Compounds – Prescriptive
- Added in the 4 “replacement” compounds
  - GenX
  - Adona
  - F53b (major and minor)
- Styrene divinylbenzene solid phase extraction cartridge for the compounds listed
- Internal Standard quantitation
- Most other aspects of method are the same as 537 ver 1.1 (2009)
- Like 537 ver 1.1, intended for DW with low TSS and low TDS
Legacy and Emerging Perfluoroalkyl Substances Are Important Drinking Water Contaminants in the Cape Fear River Watershed of North Carolina

Mei Sun,*†‡ Edna Arevalo,* Mark Strynar,§ Andrew Lindstrom,§ Michael Richardson,‖ Ben Kearns,‖ Adam Pickett,⊥ Chris Smith,∥ and Detlef R. U. Knappe‡
Current Methods – PFAS by Isotope Dilution

- **Matrices**
  - Potable water
  - Nonpotable water
  - Soil/sediment
  - Tissue/biota
  - Dust wipes
  - Landfill leachate
  - AFFF Formulations

- **36 Compounds**
- **Solid Phase Extraction/Cleanup using weak anion exchange**
- **Isotope Dilution quantitation**
  - 25 isotopically labeled internal standards
- **Injection Standards for monitoring instrument vs extraction performance**

- **Advantages**
  - Isotope Dilution offers the highest degree of quantitative accuracy and precision
  - Broadest list of compounds and widest range of matrices
  - Lowest reporting limits across matrices
  - Used for TOP Assay
Isotope Dilution

C13-PFOA
Spiked into Sample prior to Extraction

PFOA
Target Analytical Compound
Per- and Polyfluorinated Compounds

Perfluorobutanoic acid | Perfluorobutanesulfonate
Perfluoropentanoic acid | Perfluoropentanesulfonate
Perfluorohexanoic acid | Perfluorohexanesulfonate
Perfluoroheptanoic acid | Perfluoroheptanesulfonate
Perfluorooctanoic acid | Perfluoroctanesulfonate
Perfluorononanoic acid | Perfluorononanesulfonate
Perfluorodecanoic acid | Perfluorodecanesulfonate
Perfluoroundecanoic acid | Perfluorododecanesulfonate
Perfluorododecanoic acid | Perfluorooctanesulfonamide
Perfluorotridecanoic acid | Methylperfluoro-1-octanesulfonamide
Perfluorotetradecanoic acid | Ethylperfluoro-1-octanesulfonamide
Perfluorohexadecanoic acid | 4:2 Fluorotelomer sulfonate
Perfluorooctadecanoic acid | 6:2 Fluorotelomer sulfonate
N-methylperfluoro-1-octanesulfonamidoacetic acid | 8:2 Fluorotelomer sulfonate
N-ethylperfluoro-1-octanesulfonamidoacetic acid | 10:2 Fluorotelomer sulfonate
2-(N-methylperfluoro-1-octanesulfamido)-ethanol | HFPO-DA (GenX)
2-(N-ethylperfluoro-1-octanesulfamido)-ethanol | ADONA
F53b (major and minor)

EPA 537.1 list
## Compound Lists

<table>
<thead>
<tr>
<th>Compound</th>
<th>Full List of 36</th>
<th>DW List</th>
<th>DOD List of 24</th>
<th>NY List of 21</th>
<th>UCMR List of 6</th>
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<td>PFHpS</td>
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<td>PFNS</td>
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<td>PFDS</td>
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</tr>
<tr>
<td>PFOSA</td>
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<tr>
<td>PFhxDA</td>
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<td>X X</td>
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<td>NePFOSAE</td>
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<td>X X</td>
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<tr>
<td>11Cl-PF3OuDS</td>
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<td>X X</td>
<td></td>
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</tr>
</tbody>
</table>
1600 Series/SW-846 Method 8328

- Uses SPE for extraction of non-potable water samples
- Solvent extraction for solids, biosolids and tissues
- Isotope dilution so recovery correction for analyte concentrations
- List of 28 compounds, performance based
- Would be DoD QSM Version 5.3 Table B-15 compliant
- Sensitivity to <10 ng/l
- Single lab validation to be submitted to OW for publication as 1600 series method
- Publication by OW should result in OLEM’s publication as SW-846 method
New/Additional Drinking Water Method

**EPA Method 533**

- New drinking water method
- SPE but designed to accommodate short chain acids (WAX)
- Employs isotope dilution so recovery correction for analyte concentrations
- List of compounds is 14 of 18 from 537.1 plus short chain acids and several precursor compounds
- Method published December 19, 2019 without any public comment period
- States still working through listing in their accreditation tables
Draft Method

SW-846 Method 8327

- variation of ASTM 7979-17
- Direct aqueous injection after dilution with methanol (no SPE)
- Intended for non-potable waters
- External standard calibration
- List of 24 compounds, performance based
- Documented issues with 6:2 Fluorotelomer sulfonate
- Sensitivity of 10 ng/l – 50 ng/l
- Has been referred to as a screening method (although that is not intent
- Draft released summer 2019, public comments in by 8/23/19
- Final version not yet released
Advisory Limits

- EPA Office of Water established Health Advisory Levels
  PFOS = 70 ng/l  PFOA = 70 ng/l

- Minnesota regulatory action limits
  PFOS = 15 ng/l  PFBS = 2000 ng/l  PFHxS = 47 ng/l
  PFOA = 35 ng/l  PFBA = 7000 ng/l

- New Jersey MCL** and proposed MCLs
  PFOS = 13 ng/l  PFNA = 13 ng/l **(MCL)
  PFOA = 14 ng/l

- Massachusetts and Vermont Enforcement Standard
  PFOA/PFOS/PFHxS/PFHpA/PFNA = 20 ng/l

- North Carolina Health Advisory
  GenX = 140 ng/l

- Connecticut
  PFOA/PFOS/PFHxS/PFHpA/PFNA = 70 ng/l
Proposed Limits

• New Hampshire
  PFOA = 12 ng/l  PFOS = 15 ng/l
  PFHxS = 18 ng/l  PFNA = 11 ng/l
  Surface water criteria coming in January of 2020

• Michigan
  PFOA = 8 ng/l  PFOS = 16 ng/l
  PFHxS = 51 ng/l  PFNA = 6 ng/l
  PFBS = 420 ng/l  GenX = 370 ng/l
  PFHxA = 400,000 ng/l
  Surface water criteria in place

• Vermont
  Requiring survey of all drinking water supplies in state by 12/1/19
  Surface water criteria by January 2021
In absence of an accepted EPA method, QSM 5.3 has detailed and relatively prescriptive criteria for the analysis of PFAS compounds.

- Calibration
- Order and concentration of CCVs
- Prescription for clean-up of samples
- Sensitivity monitoring and checks
- LCS control limits
- Retention time criteria added
- Mass calibration is different
- > 1% solid may need filtering
- Criteria for ion transitions and their ratios
- Use of internal standard removed
- IDAs controlled by their area response
- Inline SPE is acceptable
Future Methods - Other

Other EPA Initiatives

• Air method
• TOP Assay
• Total Organic Fluorine (TOF)
• Non-Targeted Analysis
Advisory Limits

- Eurofins keeps an up-to-date newsfeed regarding all things PFAS at: EurofinsUS.com/PFAS
- Interstate Technology Regulatory Council (ITRC) keeps an updated listing of pending advisories, regulation, and guidance: ITRC Table 4-1 (https://pfas-1.itrcweb.org)
Eurofins Capacity

- Isolated PFAS laboratory
- 6 dedicated systems over multiple shifts
- Data meets or exceeds all EPA Public Health Advisory limits and state drinking water guidance
Eurofins Capacity

• Capacity
  - ELLE
  - EEA (Monrovia and South Bend)
  - ETA facilities (West Sacramento, Denver, Burlington)

• Technical Expertise

• Analytical offerings
  - drinking water method 537
  - Isotope dilution method (NPW, solids, tissue)
  - DoD compliant isotope dilution
  - Replacement compounds (GenX, Adona)
  - TOP Assay
Questions

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717-587-5863

charlesneslund@eurofinsus.com
717-799-0439
PFAS Toxicity Overview

PA Brownfields Conference
March 11, 2020
Brie Sterling

Tom Wolf, Governor
Patrick McDonnell, Secretary
Health Effects of PFOA and/or PFOS

• Animal
  - Liver effects
  - Immunological effects
  - Developmental effects
  - Endocrine effects (thyroid)
  - Reproductive effects
  - Hematological (blood) effects
  - Neurobehavioral effects
  - Tumors (liver, testicular*, pancreatic*)

• Human (possible links)
  - Liver effects (serum enzymes/bilirubin, cholesterol)
  - Immunological effects (decreased vaccination response, asthma)
  - Developmental effects (birth weight)
  - Endocrine effects (thyroid disease)
  - Reproductive effects (decreased fertility)
  - Cardiovascular effects (pregnancy induced hypertension)
  - Cancer* (testicular, kidney)

*PFOA ONLY
## Health Effects of PFOA and/or PFOS

<table>
<thead>
<tr>
<th>Serum half-life</th>
<th>PFBS (C4)</th>
<th>PFHxS (C6)</th>
<th>PFOS (C8)</th>
<th>PFBA (C4)</th>
<th>PFHxA (C5)</th>
<th>PFOA (C8)</th>
<th>PFNA (C9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouse</td>
<td>NA</td>
<td>26-29 days</td>
<td>34-40 days</td>
<td>2.9-13 hours</td>
<td>~1 hour</td>
<td>17-19 days</td>
<td>26-69 days</td>
</tr>
<tr>
<td>Humans</td>
<td>26 days*</td>
<td>4.7-7.4 years</td>
<td>3.4-7.4 years</td>
<td>3-3.6* days</td>
<td>32 days*</td>
<td>2.3-4.6 years</td>
<td>2.5-12 years</td>
</tr>
</tbody>
</table>
Toxicology of Other PFAS

• Information for small number of other PFAS in peer-reviewed literature, National Toxicological Program studies; chemical registration information (REACH dossiers, TSCA submittals); and EPAs CompTox program files

• Most focus on PFCAs and PFSAs, the perfluoroalkyl acid “families” to which PFOA and PFOS belong, also GenX. Some information on ADONA, fluorotelomer alcohols

• Long-chain PFAAs appear to have generally similar effects in animal studies (developmental, immune, liver, etc.)

• Animal data for short-chain PFAAs also show effects similar to long-chain although at higher doses
<table>
<thead>
<tr>
<th># of Carbon</th>
<th>Liver</th>
<th>Developmental</th>
<th>Reproductive</th>
<th>Immune</th>
<th>Hematologic</th>
<th>Thyroid</th>
<th>Neurobehavioral</th>
<th>Tumors</th>
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<tbody>
<tr>
<td>PFBA 4</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>□</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>□</td>
</tr>
<tr>
<td>PFPeA 5</td>
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<td>□</td>
<td>□</td>
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<td>□</td>
</tr>
<tr>
<td>PFHxA 6</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>□</td>
<td>■</td>
<td>■</td>
<td>□</td>
<td>(Negative)</td>
</tr>
<tr>
<td>PFHpA 7</td>
<td>■</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>PFOA 8</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>PFNA 9</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>□</td>
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<td>PFDA 10</td>
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<td>■</td>
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<td>■</td>
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<td>■</td>
<td>■</td>
<td>■</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>

**Perfluoroalkyl Sulfonates**

| PFBS 4      | ■     | ■             | ■            | ■      | ■           | ■       | □              | □      |
| PFHxS 6     | ■     | ■             | □            | □      | ■           | □       | □              | □      |
| PFOS 8      | ■     | ■             | ■            | ■      | ■           | ■       | □              | □      |

**Per- & Polyfluoroalkyl Ether Replacements**

| ADONA 6     | ■     | ■             | □            | □      | ■           | □       | □              | □      |
| HFPO-DADGenX 6 | ■     | ■             | ■            | ■      | ■           | ■       | □              | ■      |
Carcinogenic Potential of PFAS

- **PFOA**
  - IARC - “Possibly carcinogenic to humans” (Group 2B)
  - USEPA - “Suggestive evidence of carcinogenic potential in humans” Oral cancer slope factor (SF) for PFOA of 0.07 (mg/kg-day)^{-1}

- **PFOS**
  - USEPA – “Suggestive evidence of carcinogenic potential in humans”. Data insufficient for quantitative assessment

- **GenX**
  - USEPA (draft) – “Suggestive evidence of carcinogenic potential in humans”. Data insufficient for quantitative assessment

- **PFHxA**
  - Did not induce tumors in male or female rats (Klaunig et al., 2015)
# Example Toxicity Values (Noncancer)

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Type</th>
<th>Value (ng/kg-day)</th>
<th>Source</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFOA</td>
<td>Oral RfD</td>
<td>20</td>
<td>USEPA 2016 (May)</td>
<td>Mice: developmental - reduced ossification, accelerated puberty</td>
</tr>
<tr>
<td></td>
<td>Oral RfD</td>
<td>0.45</td>
<td>OEHHA 2019 (August)</td>
<td>Mice: hepatic mitochondrial membrane potential changes and increased apoptosis and oxidative DNA damage</td>
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<td></td>
<td>Oral MRL</td>
<td>3</td>
<td>ATSDR 2018 (June)</td>
<td>Mice: altered activity and skeletal alterations in offspring</td>
</tr>
<tr>
<td>PFOS</td>
<td>Oral RfD</td>
<td>20</td>
<td>USEPA 2016 (May)</td>
<td>Rat: reduced pup body weight</td>
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<td></td>
<td>Oral RfD</td>
<td>1.8</td>
<td>OEHHA 2019 (August)</td>
<td>Mice: decreased plaque forming cell response</td>
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<tr>
<td></td>
<td>Oral MRL</td>
<td>2</td>
<td>ATSDR 2018 (June)</td>
<td>Rat: delayed eye opening, decreased pup body weight, UF immune effects</td>
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<tr>
<td>PFNA</td>
<td>Oral RfD</td>
<td>0.74</td>
<td>NJDEP 2015 (June)</td>
<td>Mice: increased maternal liver weight</td>
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<tr>
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<td>Oral MRL</td>
<td>3</td>
<td>ATSDR 2018 (June)</td>
<td>Mice: decreased offspring body weight and developmental delays</td>
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<tr>
<td>PFHxS</td>
<td>Oral MRL</td>
<td>20</td>
<td>ATSDR 2018 (June)</td>
<td>Rat: thyroid follicular cell damage</td>
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</table>
### Comparison: PFOA and PFOS

#### Noncancer toxicity values for human health risk assessment

<table>
<thead>
<tr>
<th>Source</th>
<th>PFOA</th>
<th>Basis</th>
<th>PFOS</th>
<th>Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>USEPA (2016)</td>
<td>20</td>
<td>Delayed bone development and accelerated male puberty in mice (following developmental exposure)</td>
<td>20</td>
<td>Reduced growth of offspring (following developmental exposure)</td>
</tr>
</tbody>
</table>
| ATSDR (2018) DRAFT | 3    | Behavioral and skeletal effects in mice (following developmental exposure) USEPA reviewed but did not select the study on behavioral effects; skeletal effects data published after USEPA analysis | 2    | Used same study as USEPA as the main basis
|                   |      |                                                                       |      | Added a 10X uncertainty factor to protect for immunotoxicity         |
Questions?

bsterling@pa.gov