Best Practices for Managing PFAS Associated with AFFF

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PFAS = Per- and Polyfluorinated Alkyl Substances

Perfluorinated-carbon tail hydrophobic interactions

Functional group head electrostatic interactions

PFOS linear isomer

Many different types and structures of PFAS.
Potential Sources of PFAS

- Fire-Fighting
- Industrial Components in Aviation and Aerospace
- Metal Machine Operations
- Hydraulic Lubricants
- Biocides
- Construction Products
- Consumer Products
Many PFAS are highly persistent in the environment.
PFAS with longer perfluorinated-carbon tails have greater tendency to bioaccumulate.
Shorter-chained PFAS are more likely to be found in the aqueous phase; longer-chained PFAS are more likely to be sorbed to solid matrices and can displace shorter molecules from their soil binding sites.
Sulfonated compounds bind more with soil in comparison to carboxylated compounds.
Pre-Cursors

• Pre-cursors degrade to intermediate compounds (e.g., PFOS and PFOA) in the environment.
• Degradation is associated with weaker bonds.
• Precursors include fluoro-telomer compounds, longer chain PFAS with additional/different functional groups.
• Most current AFFF formulations contain precursors.
### PFAS Mobility

| Concentrations observed in bedrock (fractured) |
| Elevated concentrations at surface (potential for HH risks, leaching) |
| Elevated concentrations at greater depths (indicates pathway to groundwater) |
| On-going source (e.g., unlined lagoon) |
| 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) * |

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Zhao et al., 2014. Chemosphere, 114:51-8
Potential Risks

- Fully fluorinated compounds have the potential to bioaccumulate and biomagnify in wildlife.
- Fully fluorinated 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.

<table>
<thead>
<tr>
<th>Location</th>
<th>Potential Receptors</th>
<th>Preliminary Estimate of Risk</th>
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</thead>
<tbody>
<tr>
<td>Soil</td>
<td>Human receptors, Terrestrial ecological receptors, Aquatic ecological receptors</td>
<td>Moderate, Moderate, Moderate</td>
</tr>
<tr>
<td>Groundwater</td>
<td>Human receptors, Terrestrial ecological receptors, Aquatic ecological receptors</td>
<td>Moderate/High, Low, Moderate</td>
</tr>
<tr>
<td>Surface Water</td>
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<td>Moderate/High, Low, Moderate/High</td>
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</tbody>
</table>
Regulations

The regulatory environment around PFAS is changing as it adapts to new studies and data on human health and ecotoxicological impacts. Between the years 2000 and 2015, countries including the US, Canada, 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.

Updated Environmental Interim Quality Guidelines for Federal Site Owners and Stakeholders Released October 2015 (PFOS).
Fighting fire with Foam Applicator (Sontake and Wagh, 2014).
AFFF formulations containing fluorinated surfactants are used to extinguish hydrocarbon-fueled fires.

Fire-fighting foams such as AFFF, alcohol-resistant aqueous film-forming foams (AR-AFFF), fluoroprotein foam (FP) and film forming fluoroprotein (FFFP) are used to extinguish fires of petroleum and other flammable liquids.

Pre-cursors account for 41-100% of the total PFAS concentration in archived AFFF formulations (on a molar basis). (Houtz et al., 2013)
PFOS one of many types of PFAS

PFOS-free AFFF may still contain other types of PFAS.
Has AFFF been used between 1960 and 2010 at your site?

A firefighter walks through a mountain of bubbles after gallons of firefighting foam were accidentally released inside a hangar at the Long Beach Airport in California.

Picture: AP
AFFF “Life Cycle”

- Procurement
- Storage
- Use/Testing
- Training
- Discharge to Environment
- Disposal
Returning to PFAS-impacted sites

- Guidelines and regulations have been updated since the site was last assessed/remediated.
- Some PFAS are recalcitrant, bioaccumulative, and known to pose risk to human health and/or ecological health.
- PFAS can vary in mobility compared to other co-contaminants.
- Traditional remediation techniques (such as for petroleum hydrocarbons) are ineffective for PFAS.
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Co-Contaminant Fate & Transport

• Fate and transport mechanisms for PFAS are complex.
  - Dependent on soil and groundwater geochemistry.
  - Look for sorption sites, colloidal particles and interfaces.
• PHCs can help to facilitate low-level, long distance PFAS transport in groundwater.
• PHCs can also increase ‘sorption’ in soil, as they provide another surface to ‘stick’ to.
Managing Legacy PFAS Sites

- Good Data Collection is Paramount: Apply established and specialized field sampling methods to collect representative samples.

- Sound Laboratory Analysis is Critical: Use laboratories who have proven track record and appropriate certifications in PFAS analysis. Understand PFAS chemistry and know what to analyze for.

- Develop Adequate CSM: Environmental fate and transport (synergistic) mechanisms relatively unknown, for both primary compounds and transformation products.

- Understand there is no simple remedial solution: Proven remediation technologies are limited to sorption (GAC/resin/mineral surfaces), immobilization and water treatment (reverse osmosis).
Screening Tool for Site Owners

- Being developed as part of on-going research for the North American airport industry.
- Objective: Identify Areas of Concern and Screen for Prioritization
- Limitations: Based on Available Knowledge.
- Considerations: Potential Receptors, Exposure Pathways and Site Features Salient to PFAS Fate and Transport, Characterization of Source.
Key Considerations

- PFAS are more than PFOS and PFOA (and PFCs).
- PFOS-Free (AFFF) doesn’t mean PFAS and PFOS-Precursor Free.
- The regulatory environment around PFAS is evolving rapidly.
- Best practices have been established for Sampling and Laboratory Analysis.
- PFAS risks can be effectively managed with knowledge of PFAS chemistry and environmental fate and transport properties of PFAS and co-contaminants.
- The State of the Practice is changing rapidly.
Questions?

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