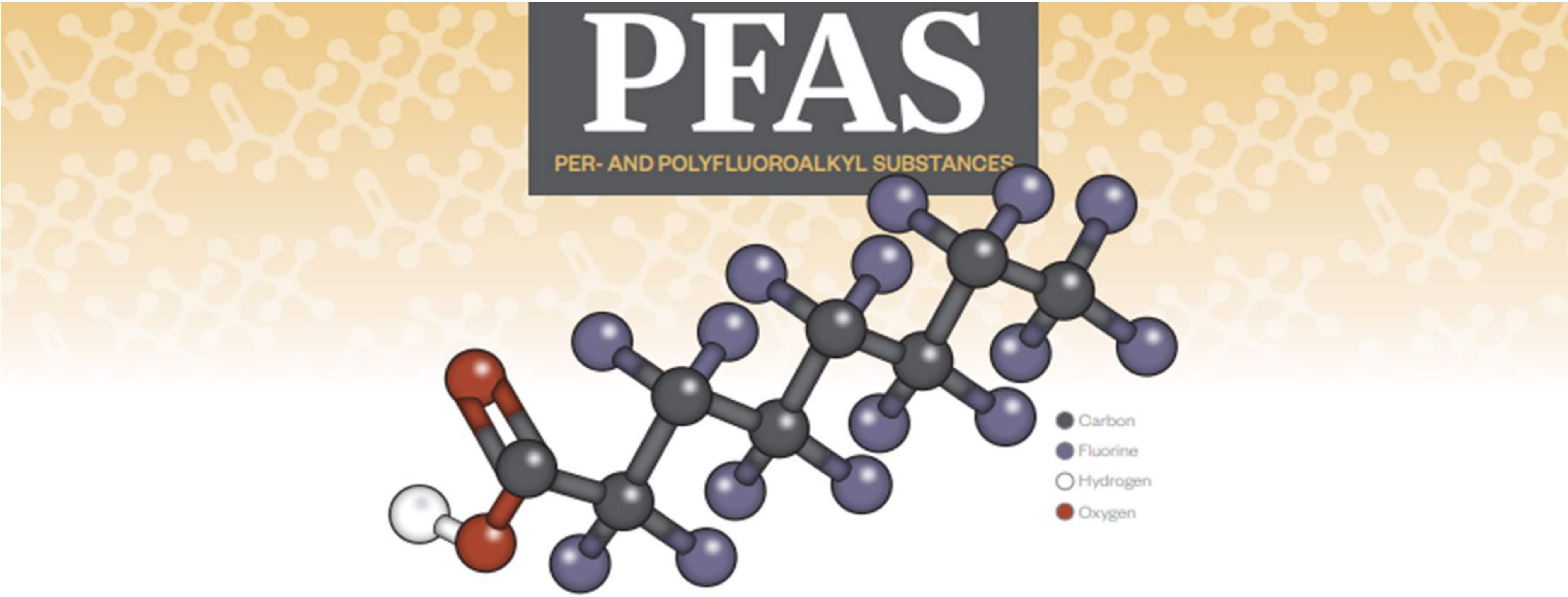
Hazen

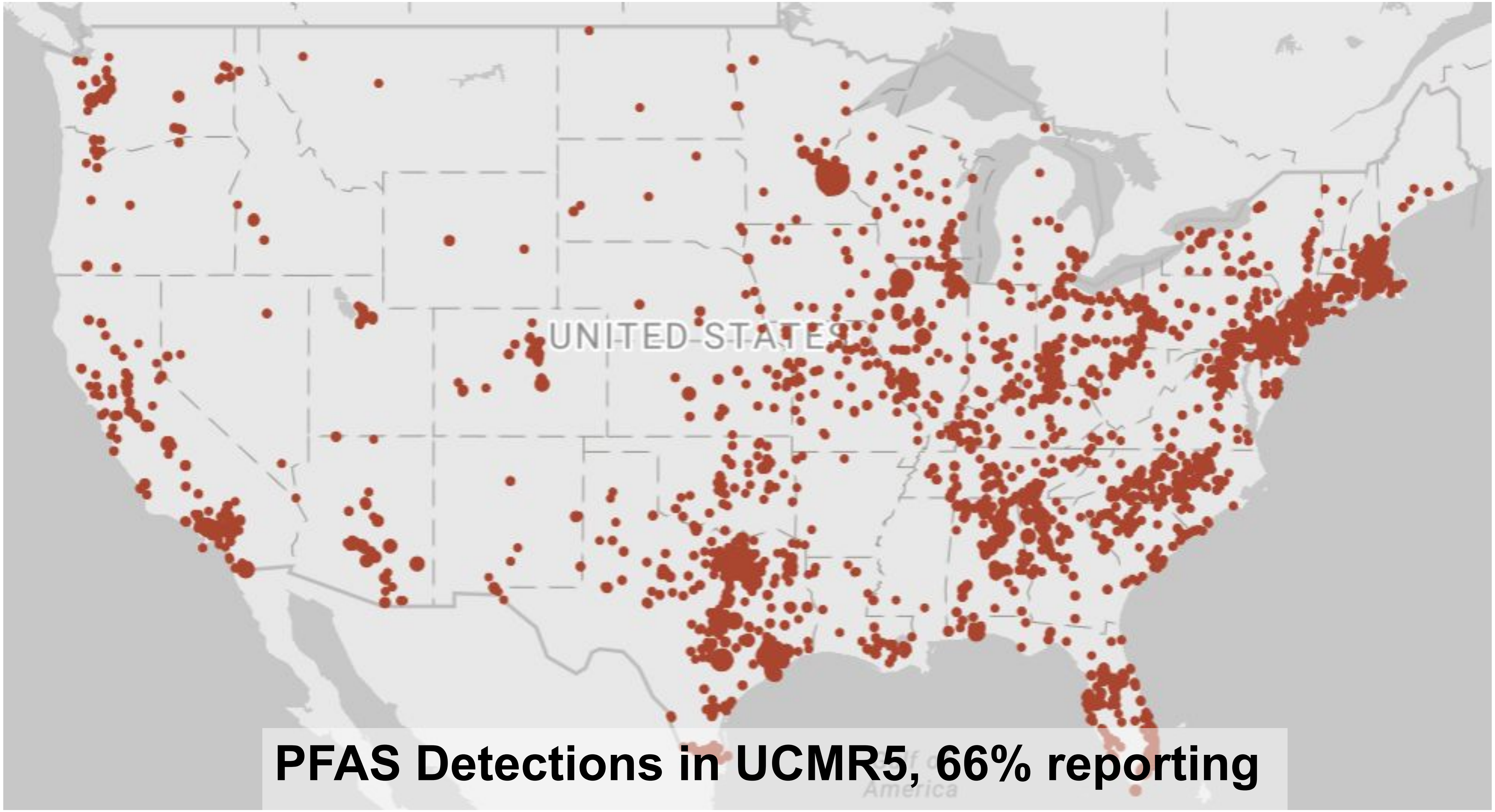


Insight into the next chapter of PFAS management: residuals treatment and disposal

May 9, 2025

Conner Murray, PhD, PE

Hazen



PFAS Detections in UCMR5, 66% reporting

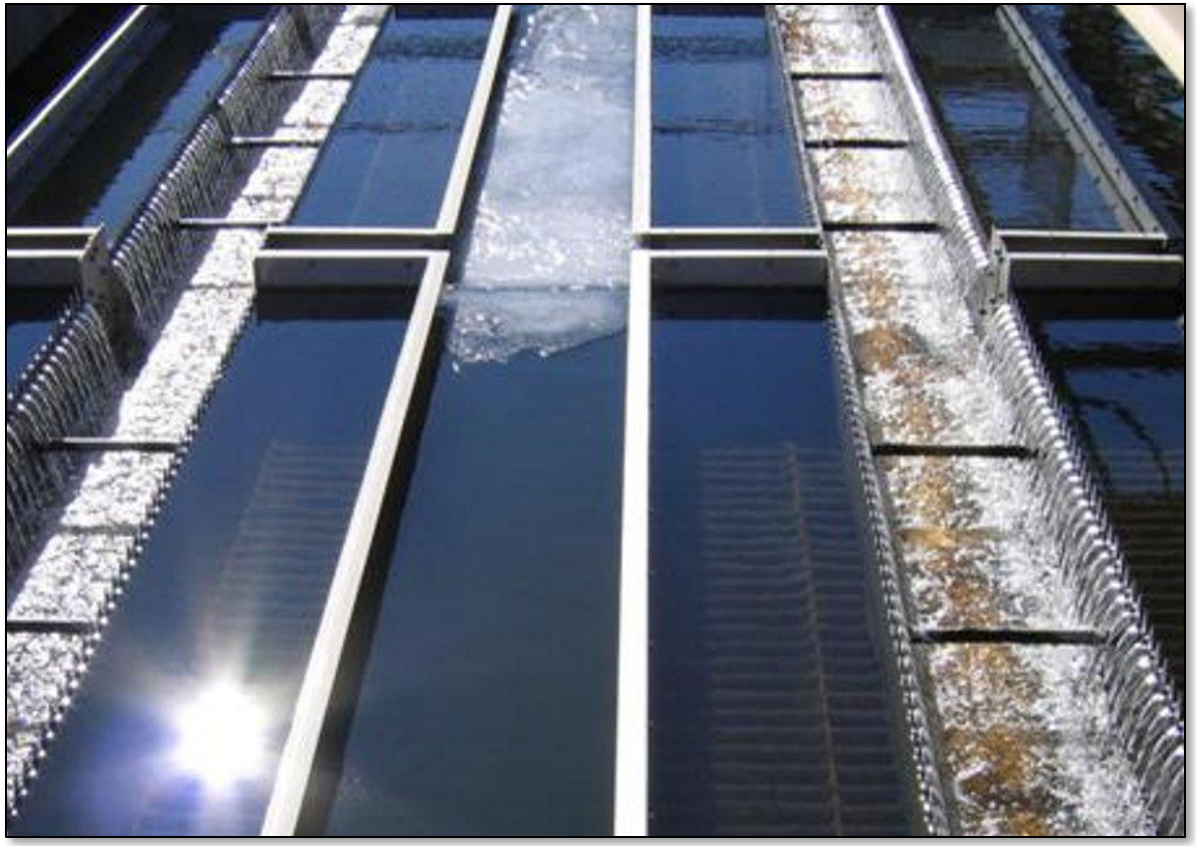
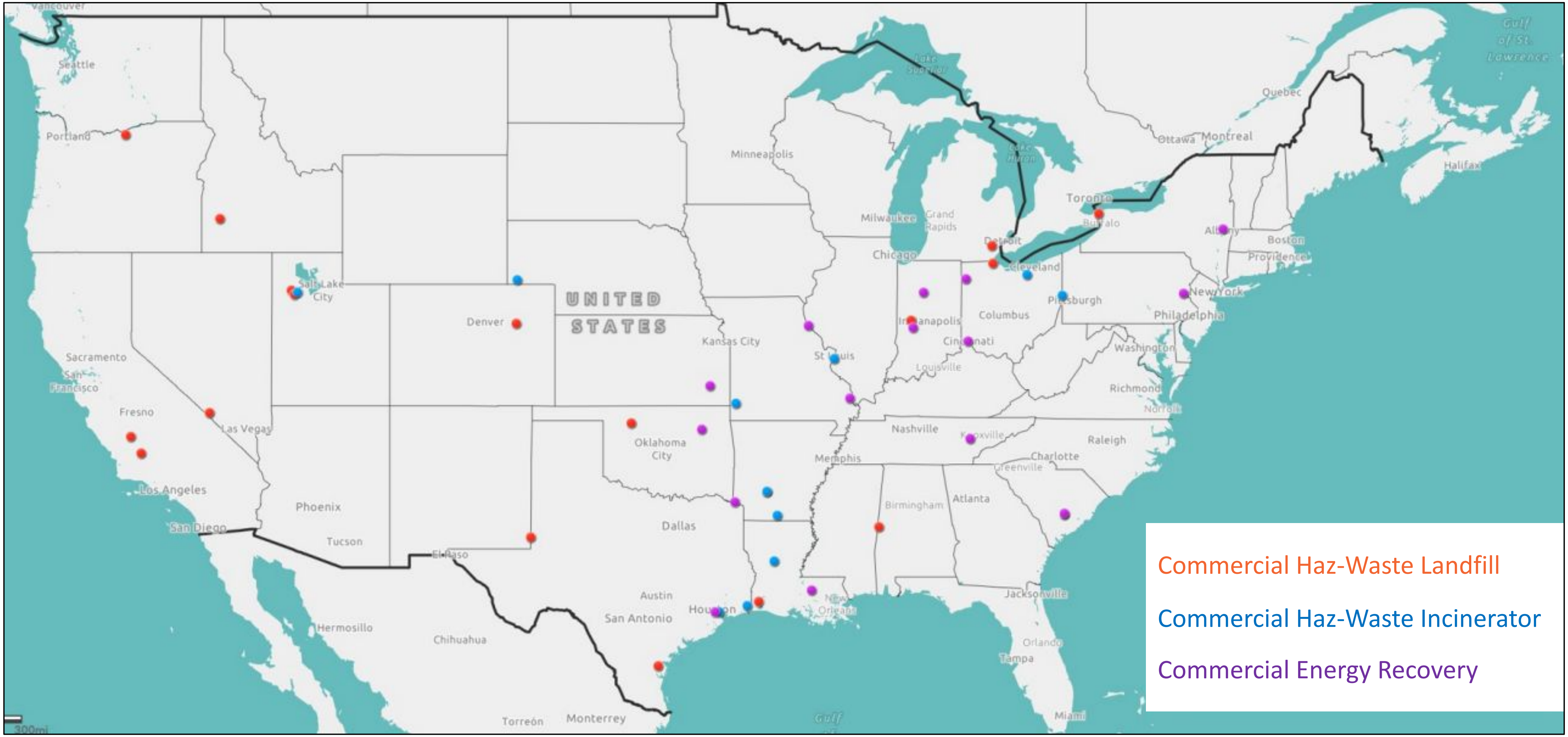


Plate Settlers – Sedimentation Solids

Spent GAC Adsorbents

Hazen

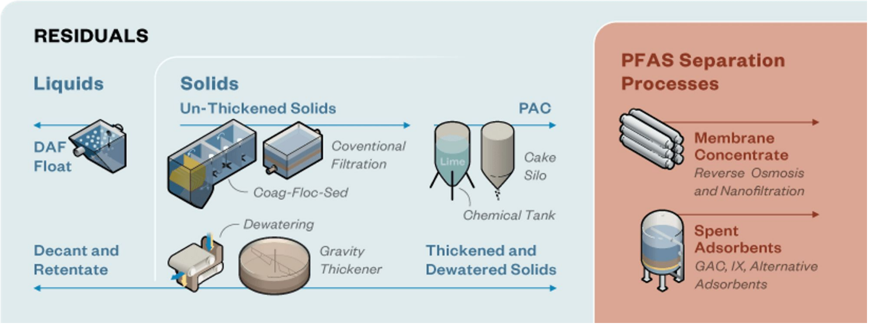


Domestic Hazardous Waste Disposal Alternatives

EPA - 2019 National Capacity Assessment Report

Hazardous Substance, Constituents, Waste???

PFAS laden residuals are the subject of potential new regulations



CERCLA Designation

- 2022 - EPA proposed designating PFOA and PFOS as hazardous substances under CERCLA
- 2023 – EPA considers GenX and other PFAS as Hazardous Substances.
- Hazardous Substances reportable quantity of greater than or equal to 1 pound per 24 hours
- DWTPs are not yet exempt from being named potentially responsible parties for hazardous pollution.

RCRA Designation

- January 31 – EPA Proposes to list 9 PFAS as hazardous constituents under RCRA
  - PFOA, PFOA, PFBS, GenX, PFNA, PFHxS, PFDA, PFHxA, and PFBA
- To be listed, the chemical must have toxic, carcinogenic, mutagenic, or teratogenic effects on humans or other life forms
- Listing provides the groundwork for EPA to list these substances as hazardous waste under RCRA.

Research Background

Received: 9 August 2023 | Revised: 18 January 2024 | Accepted: 5 February 2024

DOI: 10.1002/aws2.1367

ORIGINAL RESEARCH

AWWA WATER SCIENCE

Characterizing PFAS concentrations in drinking water treatment residuals

Conner C. Murray[1] | **Alexander S. Gorzalski**[1] | **Erik J. Rosenfeldt**[1] | **Christine Owen**[1] | **Chris Moody**[2]

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Funding information
WITAF 078

Deputy Editor: Lauren Weinrich
Associate Editor: Issam N. Najm

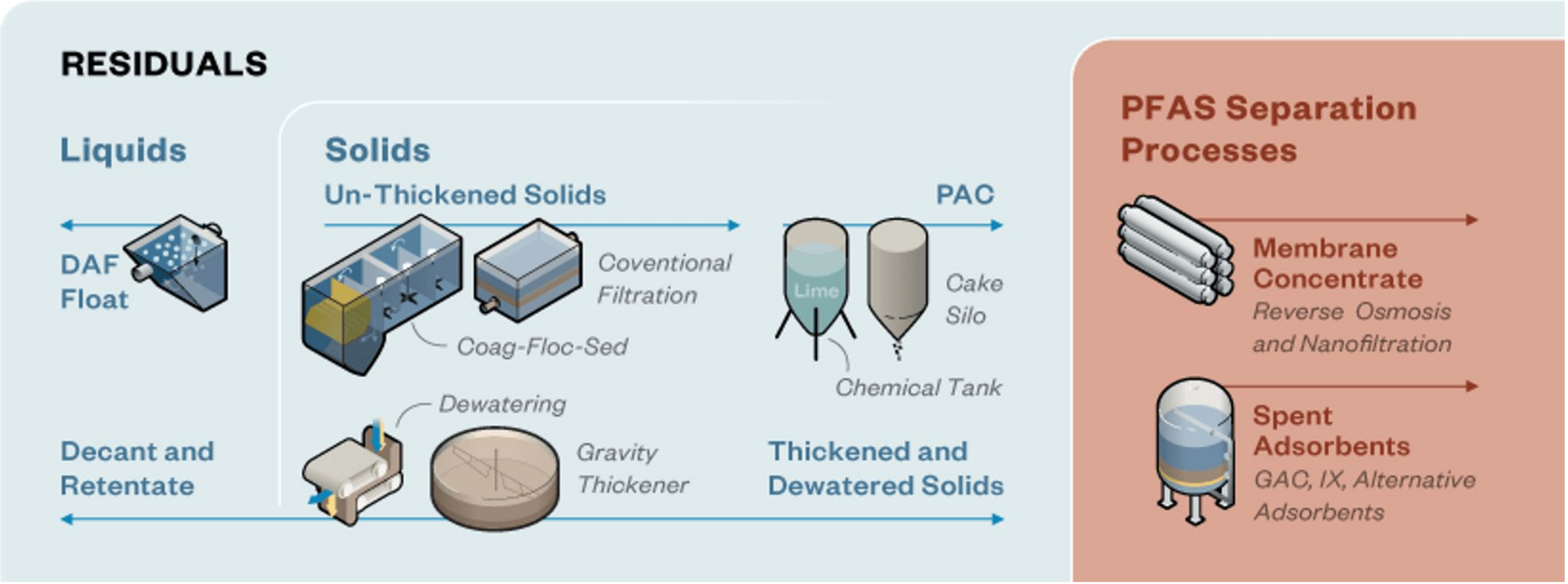
Abstract

While drinking water treatment plants (DWTPs) are not considered a source of per- and polyfluoroalkyl substances (PFAS), PFAS concentrate in treatment residuals relative to their source water concentrations. Regulatory actions considered for PFAS-impacted residuals could affect the cost and viability of conventional residual management practices. This study estimated the annual quantity of residuals generated in the United States and presents a framework for understanding how PFAS may concentrate in these residual streams. Findings of this work indicate that PFAS may substantially impact DWTP residuals management, especially coagulation and softening solids, at concentration factors greater than 100 and spent adsorbents at PFAS concentration factors greater than 10,000. If potential regulatory actions were to apply to coagulation and softening residuals, those regulations must consider impacts on disposal of more than 420,000,000 wet tons of at-risk DWTP residuals which are generated annually.

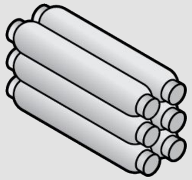
KEYWORDS

adsorbents, concentration factor, hazardous, PFAS, residuals, water treatment

PFAS Concentrated in Drinking Water Residuals

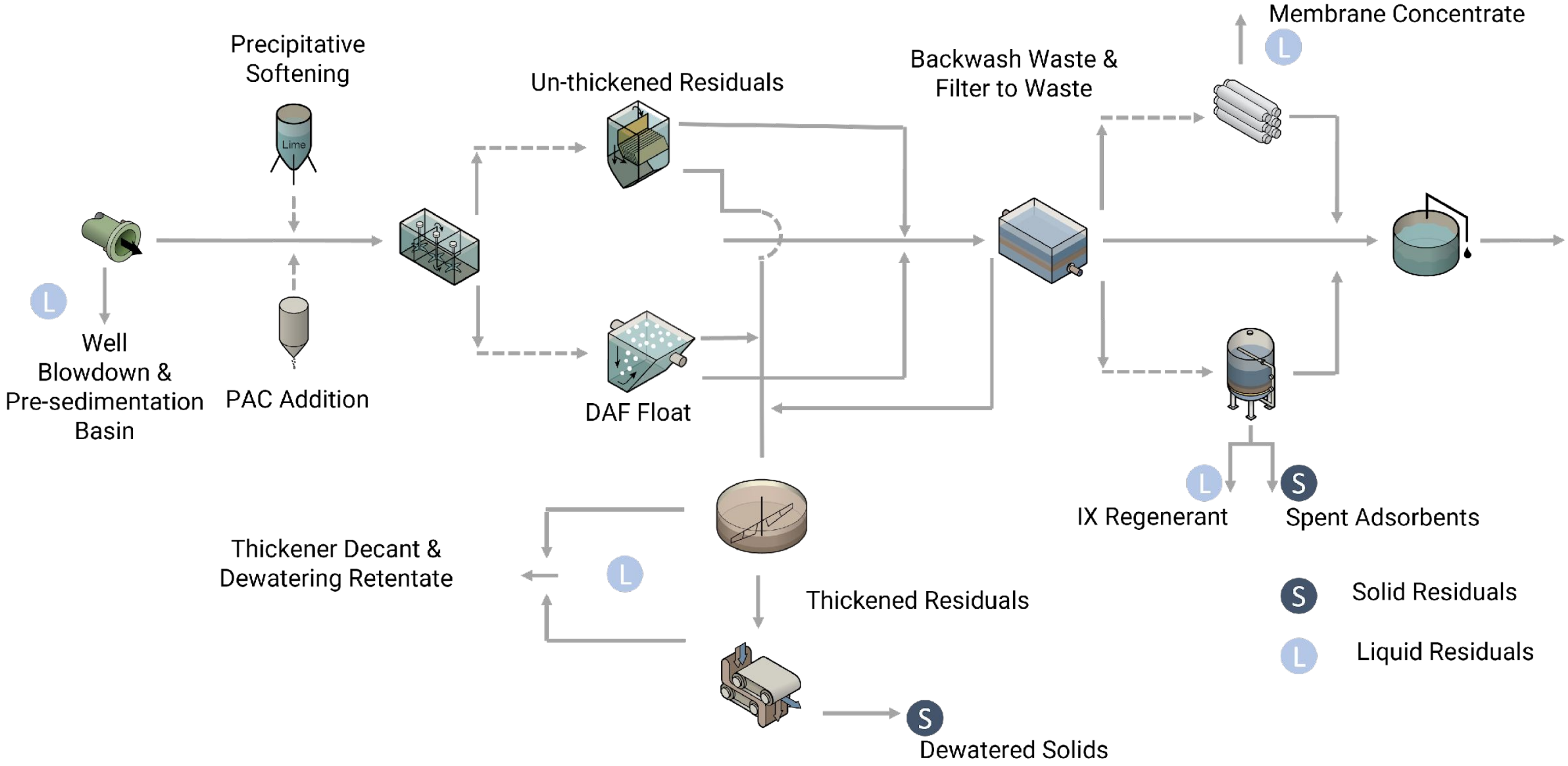


PFAS Separation Residuals

		Pros	Cons
	Reverse Osmosis	Removal of Legacy & Next Generation PFAS	Cost and Concentrate Disposal
	Adsorption / Ion-Exchange	Ease of Implementation, Cost Effectiveness	Treatment Effectiveness Varies with WQ and PFAS
	Powdered Adsorbents / Coagulant Aids	Ease of Implementation	Potential High Dosing, Effectiveness Varies with WQ and PFAS

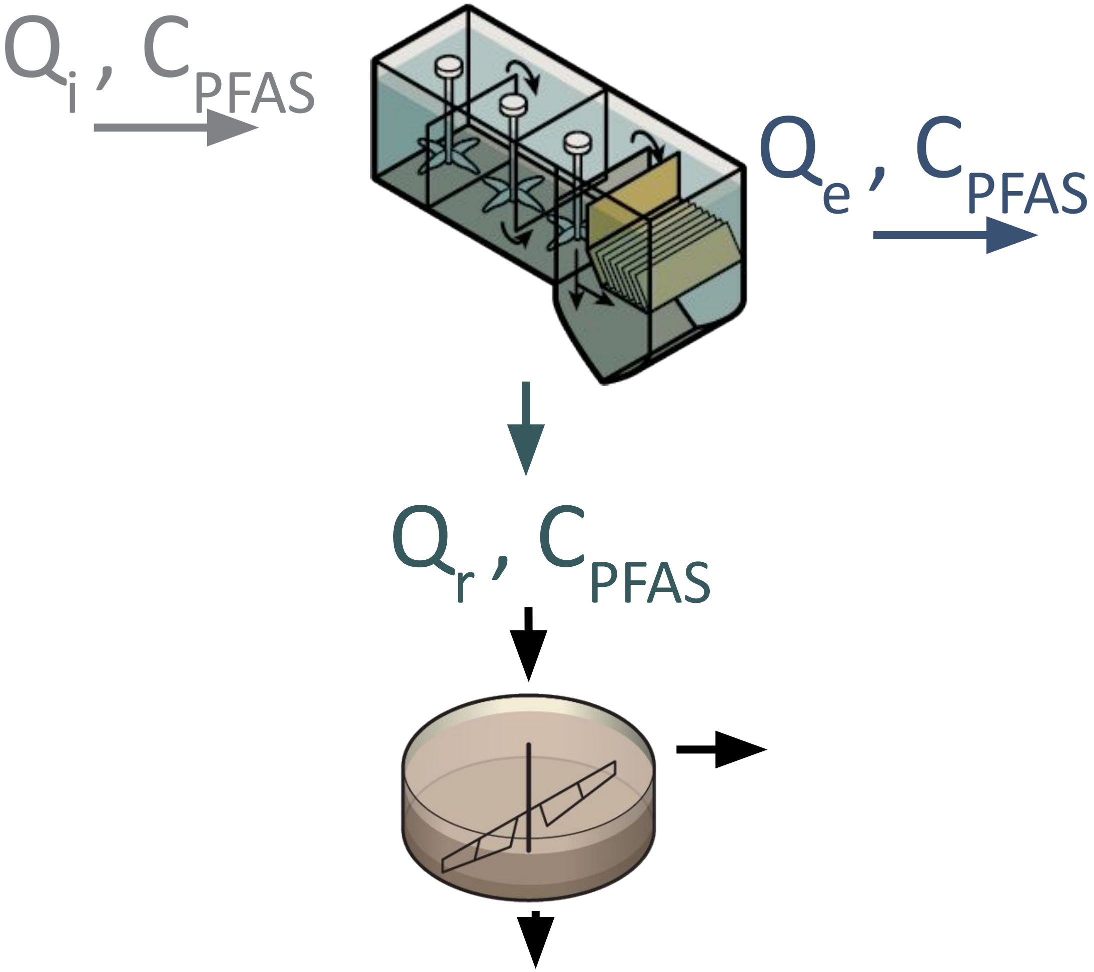
PFAS separation processes effective for accumulating PFAS but residuals management is an outstanding challenge!

Drinking Water Residual Streams



PFAS Concentrations in Drinking Water Residuals

Need for simplified approach for predicting PFAS partitioning in residual streams!



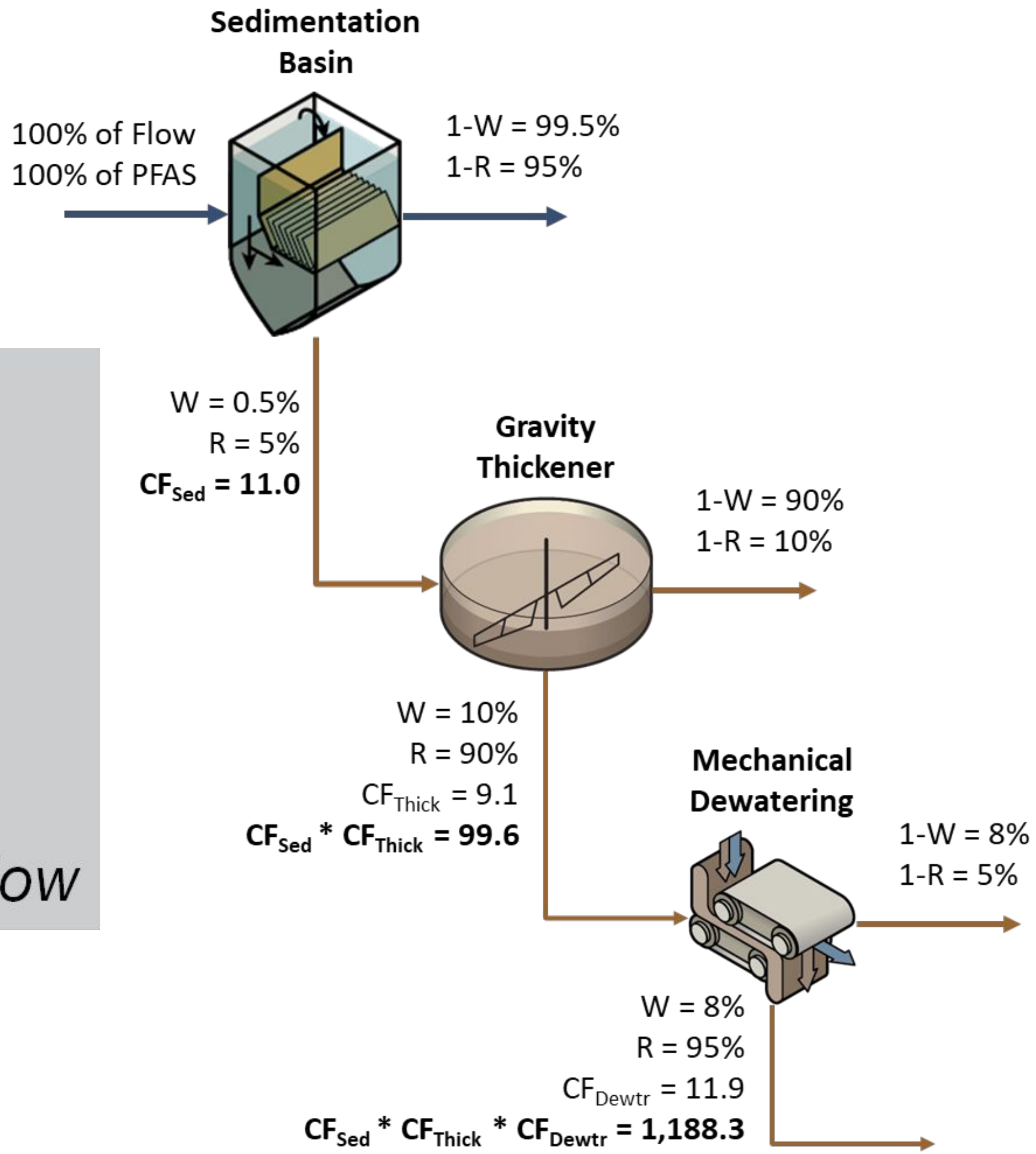
Concentration Factor Approach for PFAS Impacted Residuals

Concentration Factor

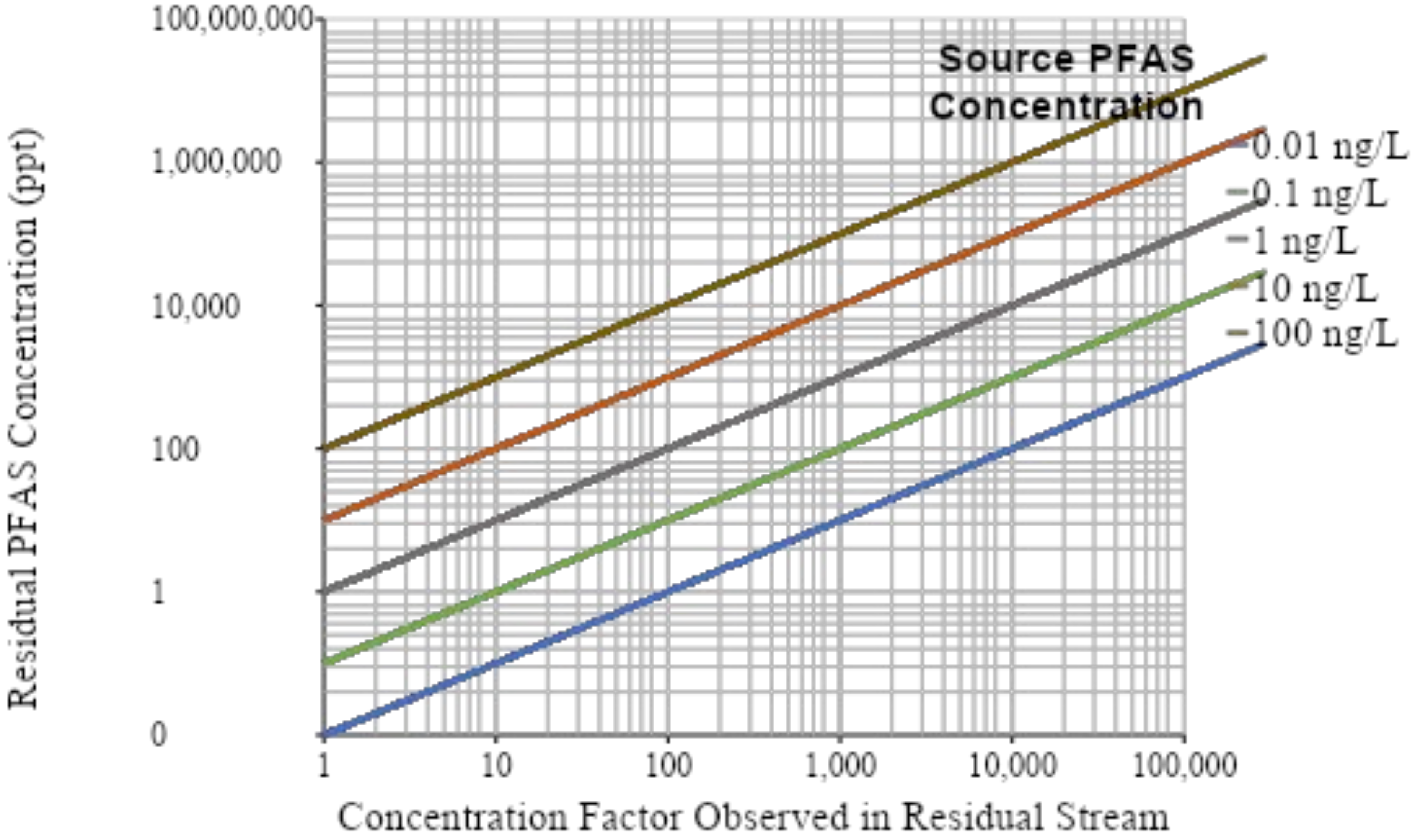
$$1 + R\left(\frac{1}{w} - 1\right)$$

R= PFAS removal %

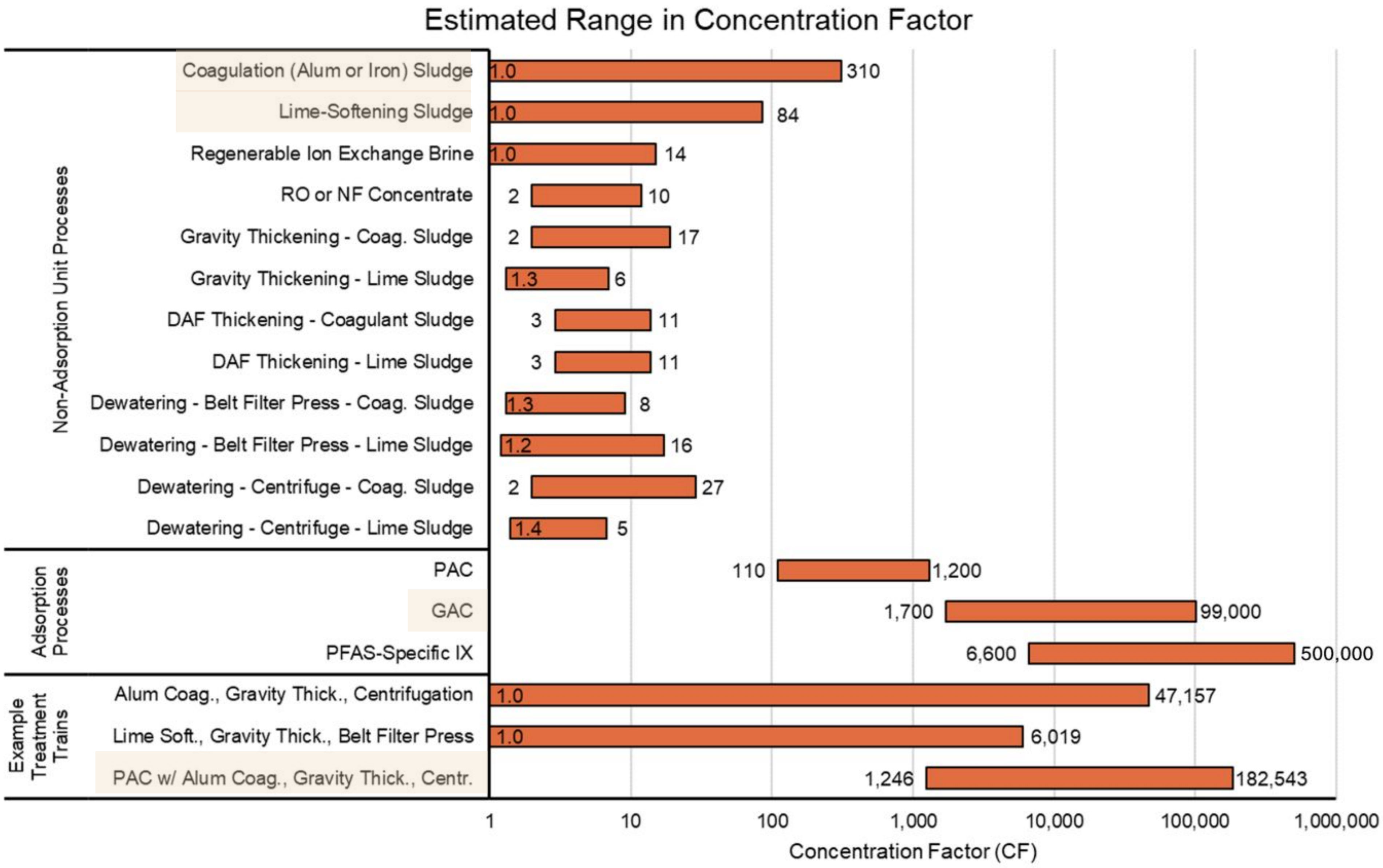
W= Portion of residuals flow as function of total flow



Translation of PFAS Concentration Factor to Concentrations

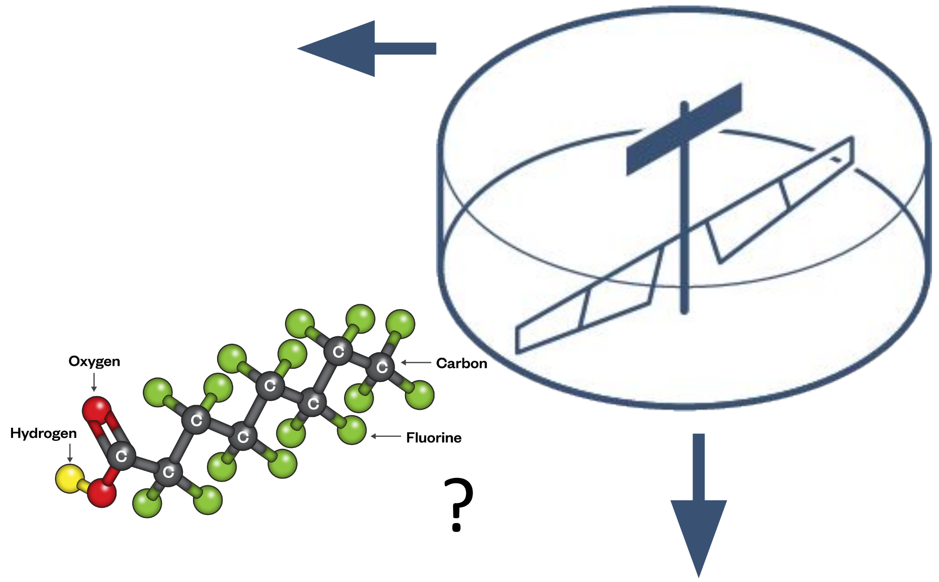


Drinking Water Residuals PFAS Concentration Factors



Uncertainties with Concentration Factor Approach

- PFAS partitioning behavior is not well characterized in solids handling processes (thickening and dewatering)
- Differences in PFAS partitioning behavior based on structural variety
- Regulatory uncertainty for exempt streams



Where do these residuals end up?

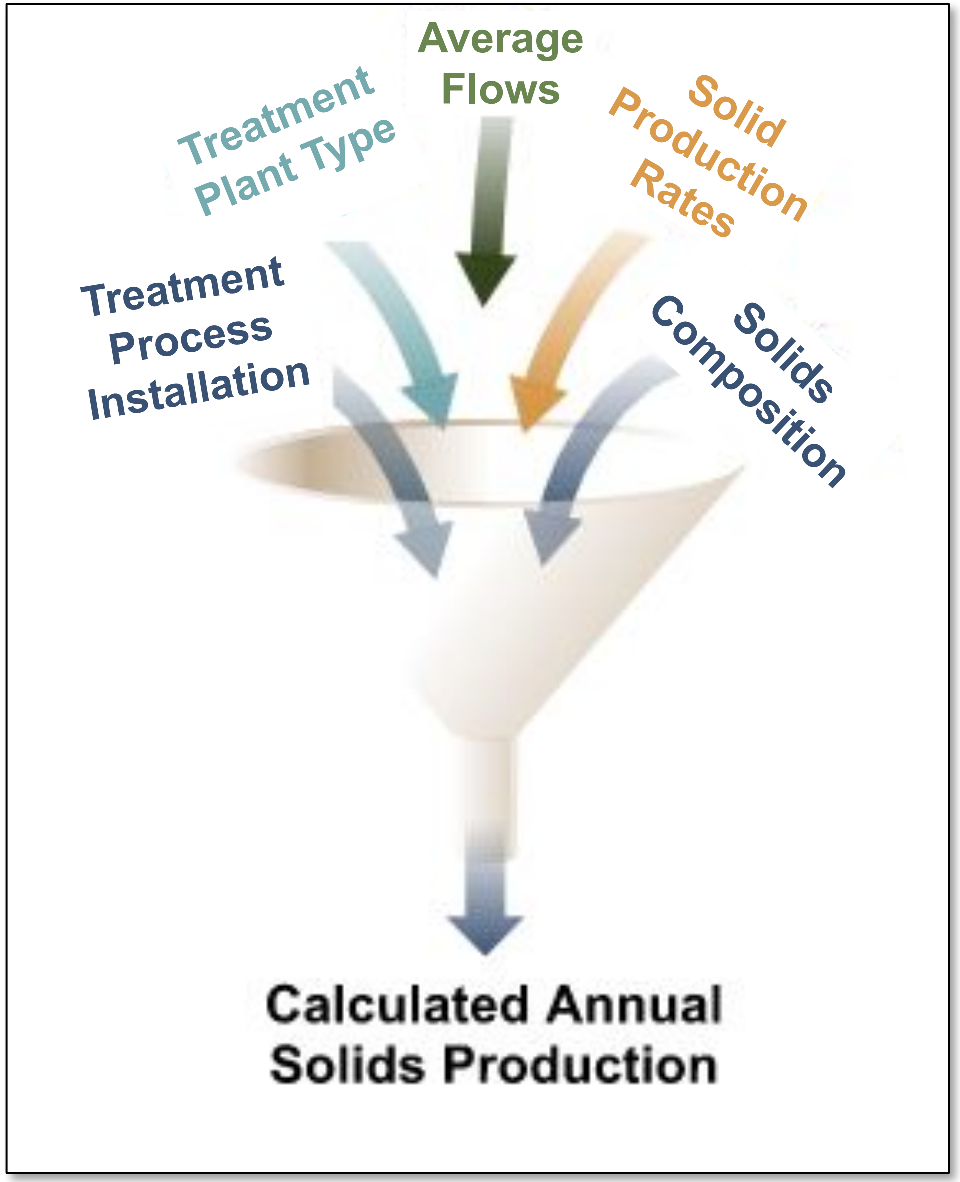
Liquid Residuals Management Alternatives	Solid Residual Management Alternatives
Direct Discharge (Surface Water, Injection)	Lagoons
Discharge to POTW	Landfill
Recycling	Discharge
Evaporation Ponds / Lagoons	Land Application
	Incineration
	Other Thermal Treatment

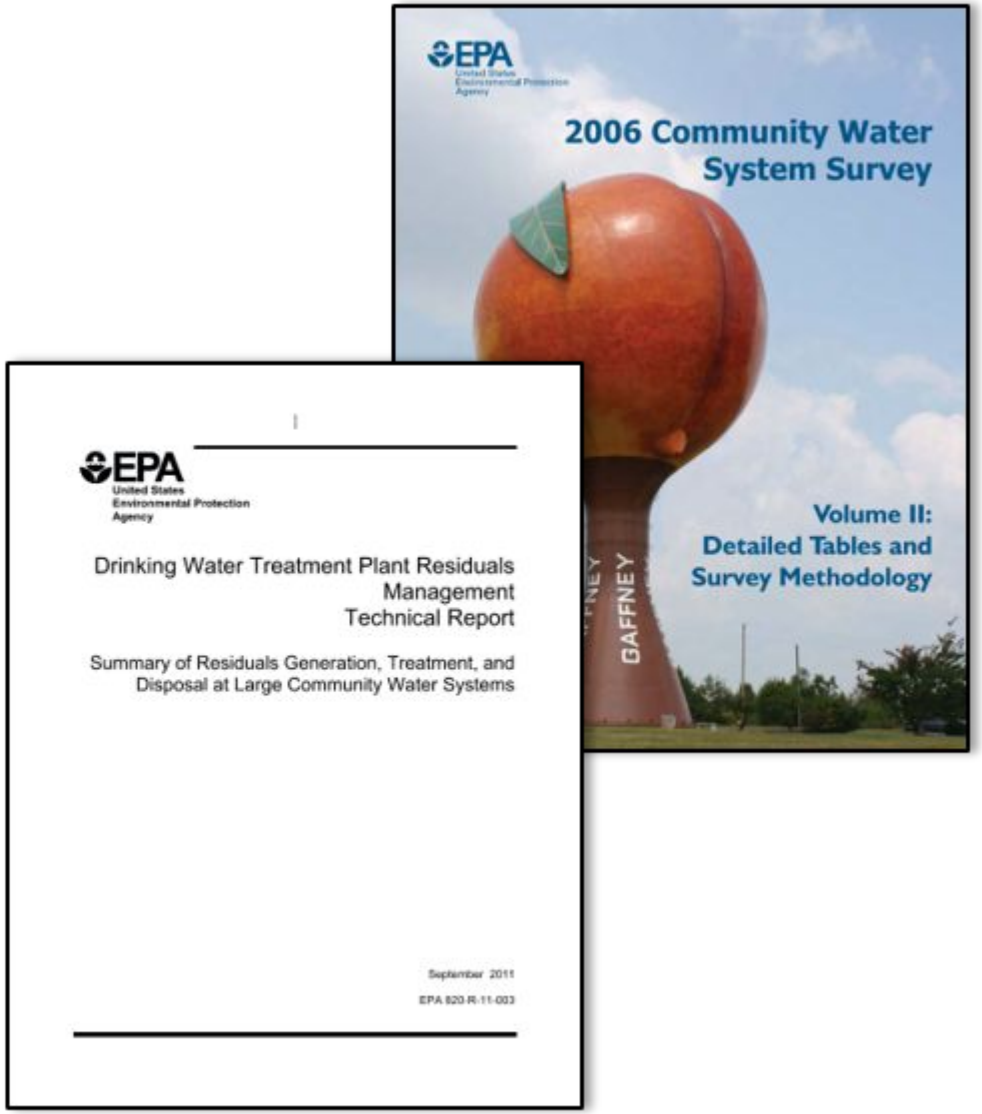
Factors Influencing Residuals Management Selection:

1. Regulatory Drivers
2. Cost
3. Regional Availability
4. Associated Treatment Processes

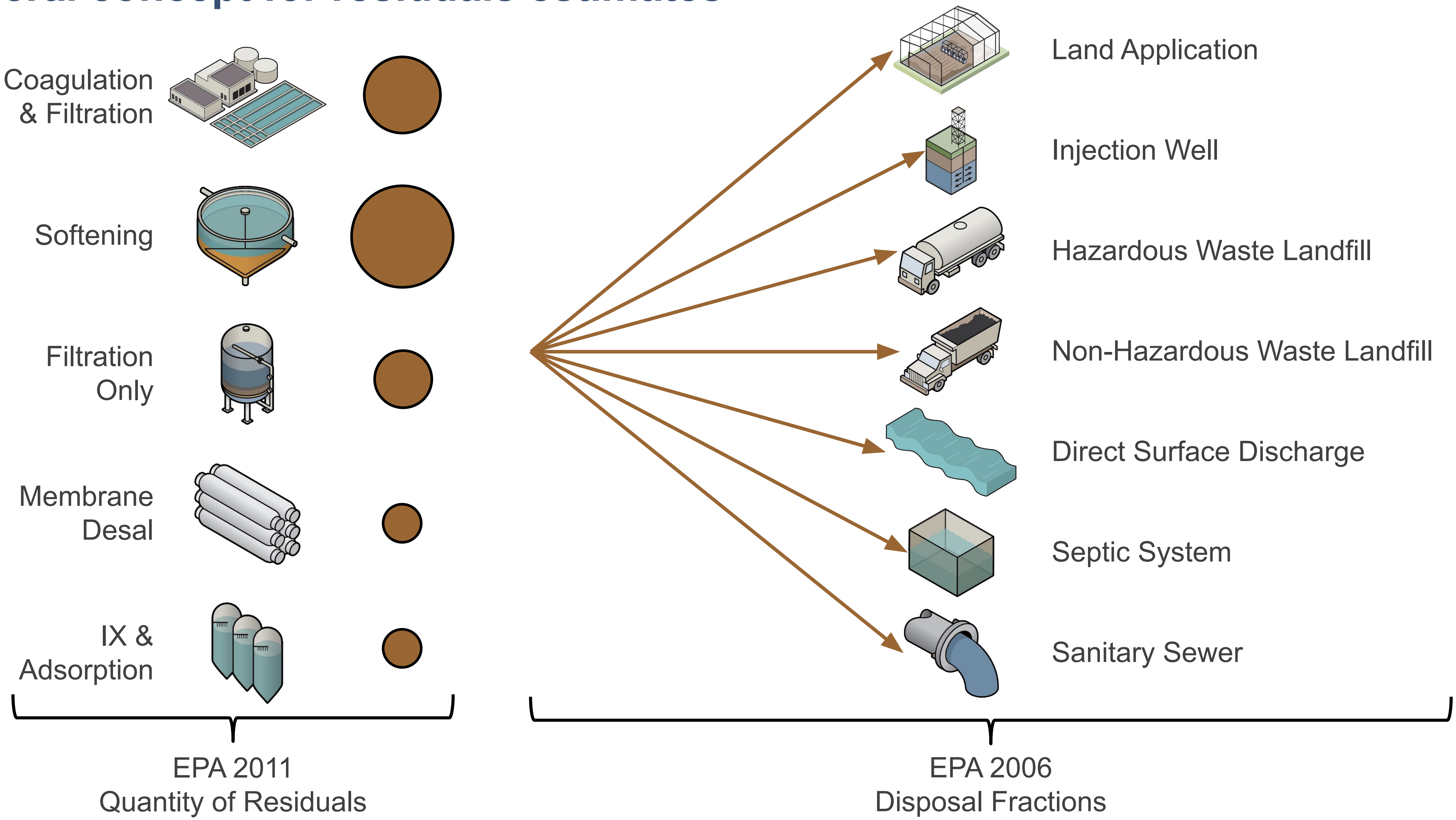
Estimating National Residuals Production

How many residuals can we expect?

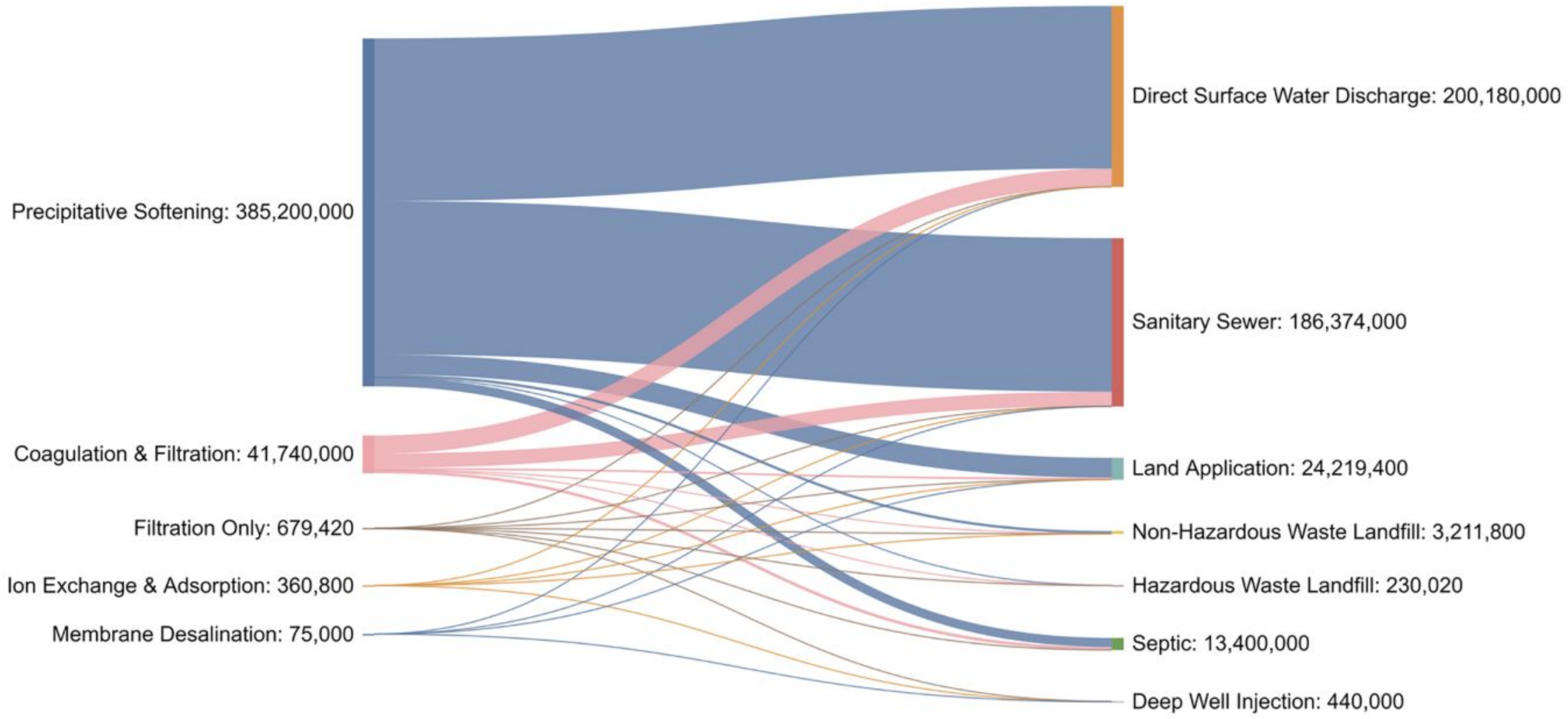




General concept for residuals estimates



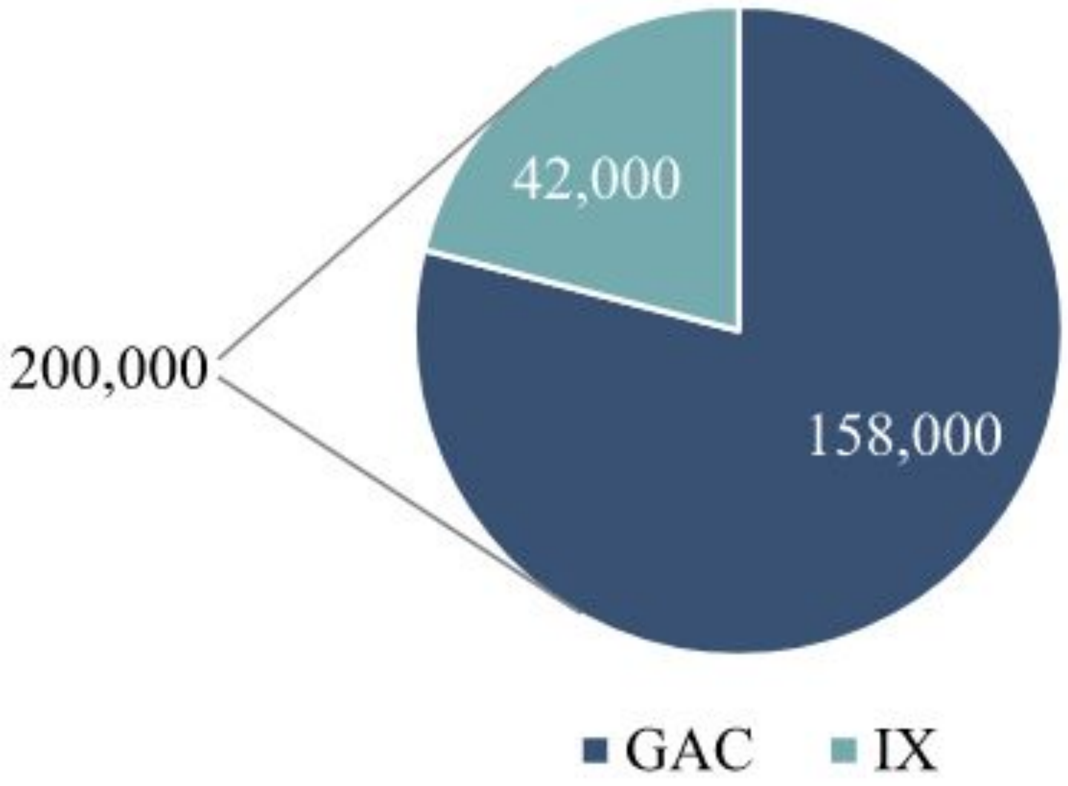
National residuals production rates (annual wet tons)



Generation of spent adsorbents for pfas separation

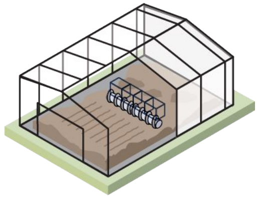
~4,400 impacted utilities by proposed MCL
~9% of total community water systems

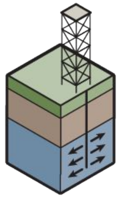
	GAC	IX
% of Systems Using	51	36
Bed Life Projections	40,000 BVs	175,000 BVs

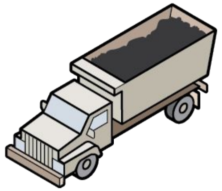


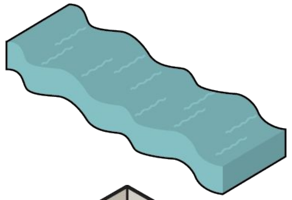
Wet Tons per Year

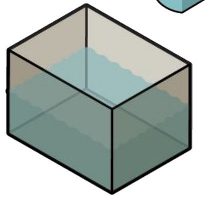
Where do all the residuals end up?


Land Application

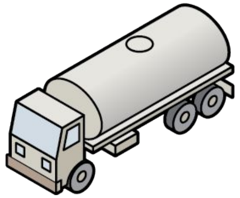

Injection Well


Landfills


Direct Surface Discharge


Septic System


Sanitary Sewer


Hazardous Waste Landfill


Hazardous Incineration / Reactivation

Very limited domestic hazardous waste capacity

Only 41 domestic hazardous waste disposal sites in the United States, 1 subtitle C facility in Idaho – US Ecology Idaho Landfill

87 million tons of available domestic hazardous waste landfill (Subtitle C) capacity for next 25 years

Idaho disposed of **10,000** tons of subtitle C waste in 2024 - Idaho Hazardous Waste

DW Residuals	Generation Rate
Conventional Solids	428 million tons annually
PFAS Spent Adsorbents	0.2 million tons annually

Potential Residuals Handling Challenges

Regulatory Uncertainty

- At what concentration will (if at all) PFAS be designated as hazardous in drinking water residuals?

Applicability

- What residuals handling technologies are suitable for hazardous materials and which are likely to be phased out?

Partitioning at Relevant Concentrations

- Is there demonstrated partitioning at representative concentrations (< 10 ng/L).

Types of Compounds

- How does PFAS partitioning change based on PFAS speciation (long, short, and/or perfluoroether compounds)?

Operational Demand

- How much labor is required for changeout/process control?
- Different labor needs for hazardous materials.

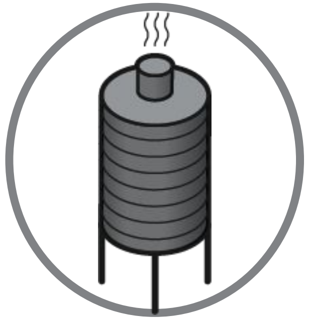
Cost/Energy Requirements

- What is the current supply and cost of hazardous waste handling facilities?
- Is there a large energy / carbon footprint requirement?

Cost of hazardous disposal options for DW residuals

Landfilling:

- Municipal Solid Waste $50-1,000 per ton
- Hazardous Waste $2,500+ per ton



Incineration:

- MSW Incinerator $200-$300 per ton
- HW Incinerator $5,000+ per ton

Destruction:

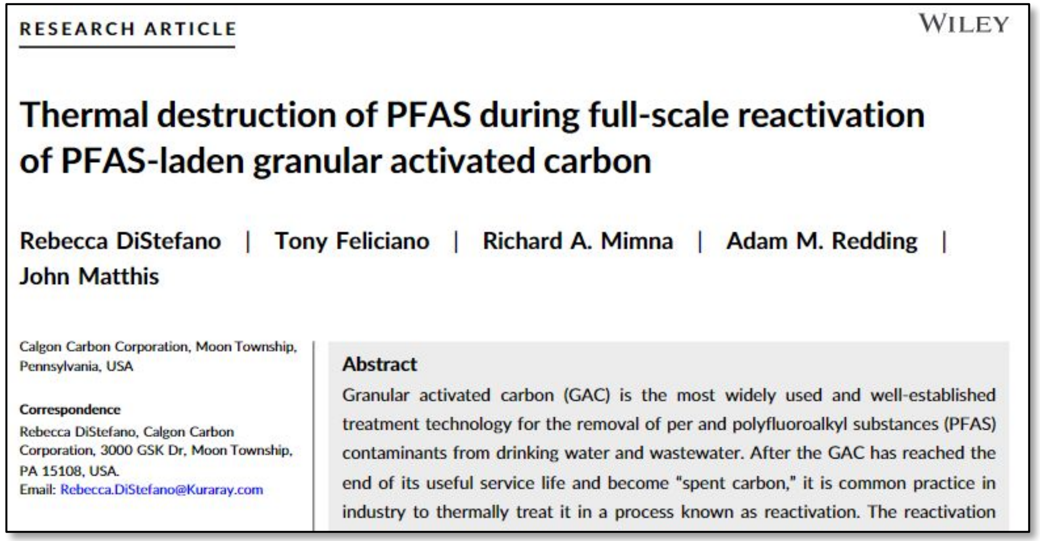
- Costs not well developed

GAC Regeneration vs GAC Reactivation

1. GAC Regeneration
   a) Low Temperature < 400 °F
   b) Designed to restore pore structure
   c) Does not destroy PFAS

2. GAC Reactivation
   a) High Temperature > 1700 °F
   b) Results in ~ 20% carbon loss
   c) Does destroy PFAS

Within these categories additional distinction between “pooled” processing and “custom municipal” processing



RESEARCH ARTICLE

WILEY

Thermal destruction of PFAS during full-scale reactivation of PFAS-laden granular activated carbon

Rebecca DiStefano | Tony Feliciano | Richard A. Mimna | Adam M. Redding | John Matthis

Calgon Carbon Corporation, Moon Township, Pennsylvania, USA

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Abstract

Granular activated carbon (GAC) is the most widely used and well-established treatment technology for the removal of per and polyfluoroalkyl substances (PFAS) contaminants from drinking water and wastewater. After the GAC has reached the end of its useful service life and become "spent carbon," it is common practice in industry to thermally treat it in a process known as reactivation. The reactivation

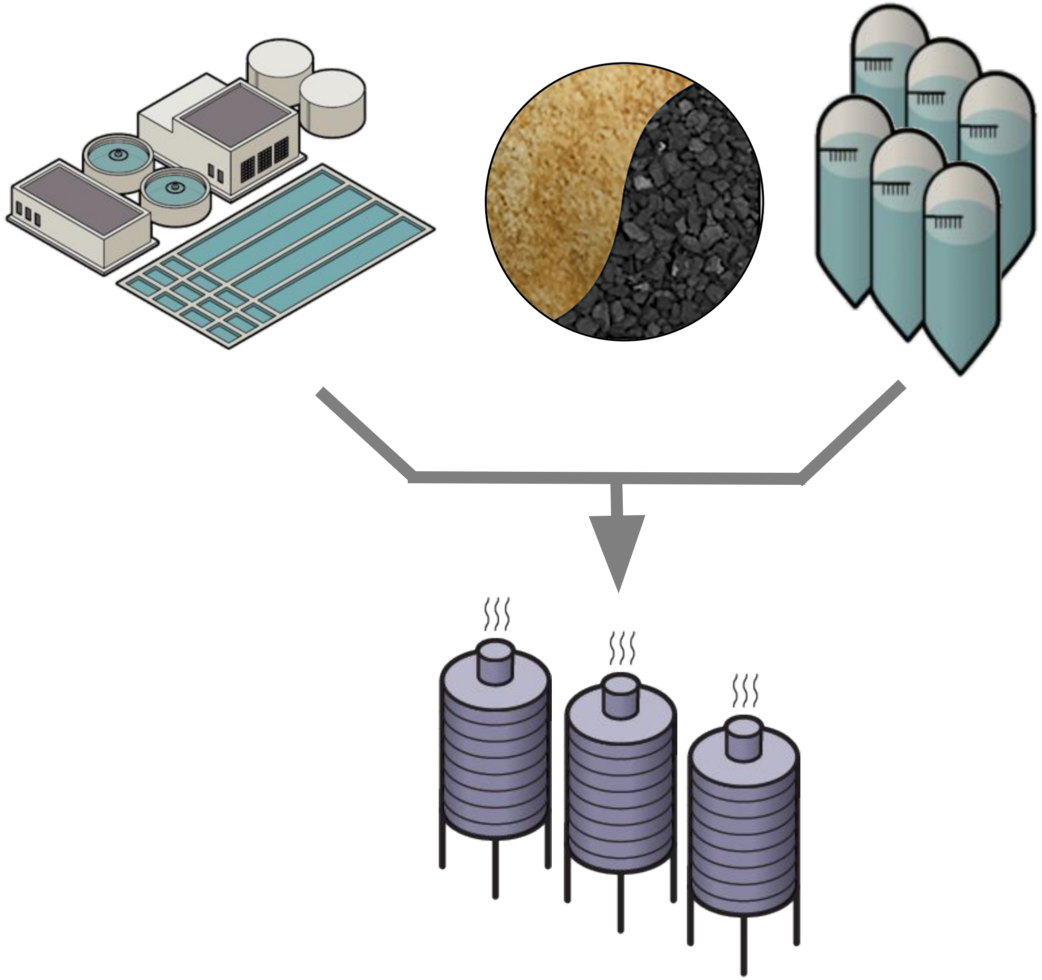
Calgon Research Article on GAC Disposal

Potential Solutions for PFAS Impacted Residuals

1. A variety of destruction approaches being developed for PFAS impaired solid residuals

2. Minimize solids production volumes with dewatering approaches and selective adsorbents

3. Regional collaboration for residuals handling (incineration/reactivation)



Reservoir Residuals Sampling

2025 Case Study

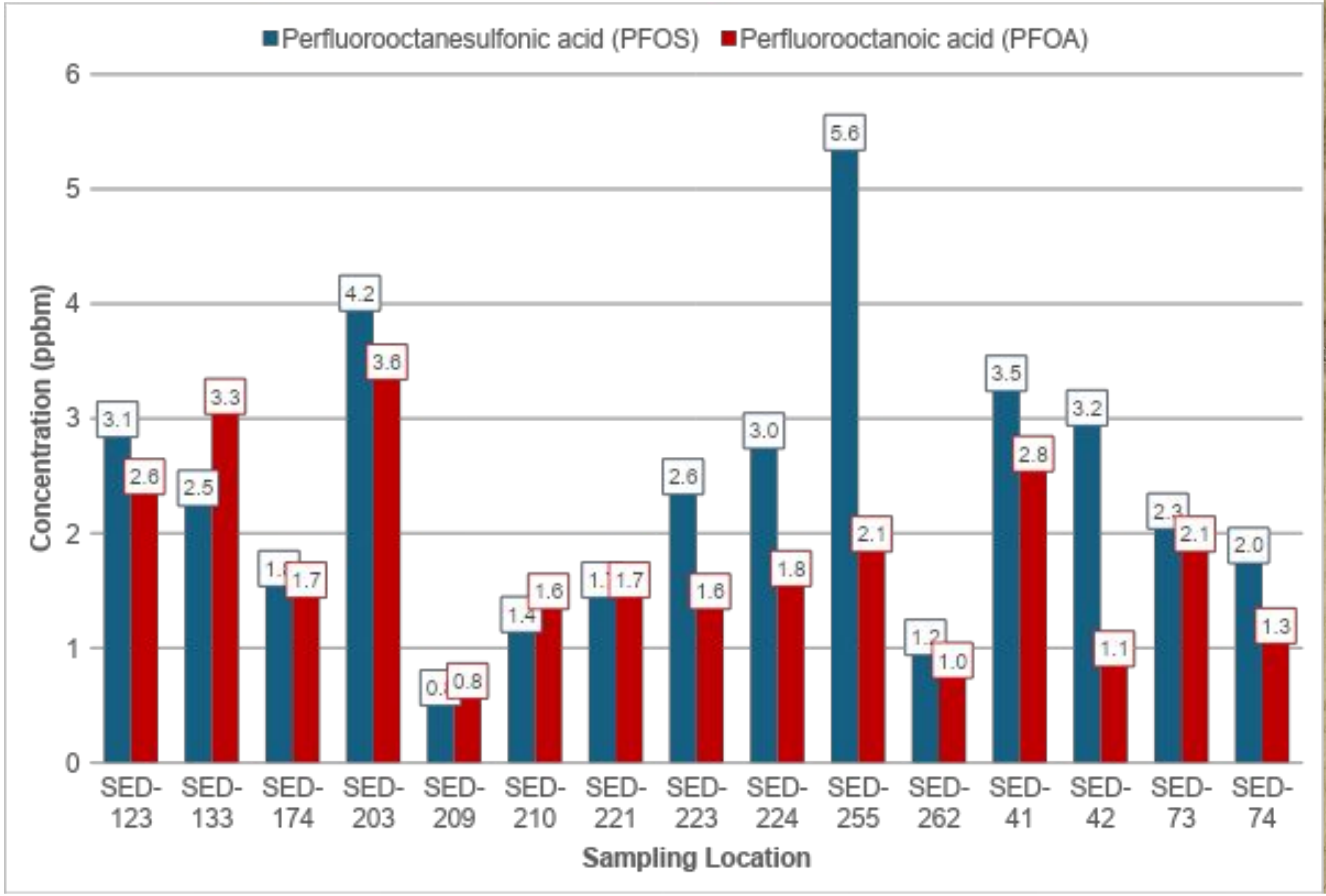
PFAS – Reservoir Sediment Samples

Analyte	Detected in How Many Samples?	Mean Concentration (ppbm)	Standard Deviation (ppbm)
Perfluorooctanoic acid (PFOA) [1,2,3]	15 / 15	1.9	0.8
Perfluorooctanesulfonic acid (PFOS) [1,2,3]	15 / 15	2.6	1.3
Perfluorononanoic acid (PFNA) [2,3]	11 / 15	0.40	0.13
Perfluorohexanesulfonic acid (PFHxS) [2,3]	13 / 15	0.41	0.21
Perfluorobutanesulfonic acid (PFBS) [2,3]	10 / 15	0.41	0.12
Hexafluoropropylene Oxide Dimer Acid (HFPO-DA) [2,3]	2 / 15	0.32	NA [4]
Perfluorodecanoic acid (PFDA) [3]	9 / 15	0.31	0.05
Perfluorohexanoic acid (PFHxA) [3]	6 / 15	0.32	0.09
Perfluorobutanoic acid (PFBA) [3]	0 / 15	NA [5]	NA [4]
N-ethylperfluorooctanesulfonamidoacetic acid (NEtFOSAA)	2 / 15	0.26	NA [4]
Perfluoroheptanesulfonic acid (PFHpS)	2 / 15	0.28	NA [4]
Perfluoroheptanoic acid (PFHpA)	5 / 15	0.35	0.07
Perfluoropentanesulfonic acid (PFPeS)	2 / 15	0.25	NA [4]
Perfluoroundecanoic acid (PFUnA)	1 / 15	0.31	NA [4]
Perfluoropentanoic acid (PFPeA)	0 / 15	NA [6]	NA [4]

[1] CERCLA-designated hazardous substance
[2] Species with National Primary Drinking Water Regulation (NPDWR) Maximum Contaminant Limits (MCLs)
[3] RCRA-designated hazardous constituent
[4] Not enough samples (< 5) contained significant levels to reasonably calculate a standard deviation
[5] Not detected in any samples
[6] Below reportable concentration in Reservoir samples but above reportable concentration in TCLP eluent

PFAS

CERCLA-Designated Hazardous Substances by Sampling Location



One final plug…

DC BEAT

Water Systems Could Face Costly PFAS Waste Rules

Chris Moody and Conner Murray

Moody

The US Environmental Protection Agency (EPA) is preparing to advance several actions that could have costly implications for drinking water and wastewater treatment facilities with waste residual streams containing per- and polyfluoroalkyl substances (PFAS). These actions will create long-term cleanup liability and will increase operating costs associated with management and disposal of typical treatment wastes like coagulation sludge, lime softening sludge, biosolids, and PFAS-containing treatment media.

Hazardous Substance Designations

The first of these rules is the designation of perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS) as hazardous substances under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly referred to as the Superfund program. EPA proposed this rule in November 2022 and is expected to finalize the rule this spring. The agency is also considering designating other PFAS in the future. EPA expects that this would benefit communities by helping to facilitate the cleanup of PFAS at designated Superfund sites across the country.

The framework of Superfund, however, creates a retroactive, joint, and shared liability for all entities that may have been involved in the presence of PFAS at a contaminated site. Potentially responsible parties are

RCRA. While Superfund creates a liability for cleanup and indirectly affects waste management activities, RCRA is the agency's direct authority for establishing waste management requirements. The listing of PFAS as hazardous constituents is a first step toward listing wastes containing PFAS as hazardous wastes, which triggers more controlled waste management requirements (e.g., documentation and reporting, transportation, disposal practices).

Under RCRA, EPA can list hazardous wastes either through a characteristic or a categorical approach. Using a characteristic approach, EPA will establish a regulatory threshold for a hazardous constituent, which is compared with the result of a toxicity characteristic leaching procedure (TCLP) test. During a TCLP test, waste material is subjected to simulated landfill leachate, and the concentration of the hazardous constituent in the leachate is compared with the regulatory threshold level. Waste material that releases more than the threshold level is considered hazardous. In contrast, a categorical listing of hazardous waste involves the agency identifying and specifying categories of waste streams that contain hazardous constituents. The characteristic listing approach is a very broad approach to identifying hazardous wastes, while the categorical approach targets specific waste streams generated by certain types of facilities.

Questions?

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Phone: (336) 675-9676

Bullpen

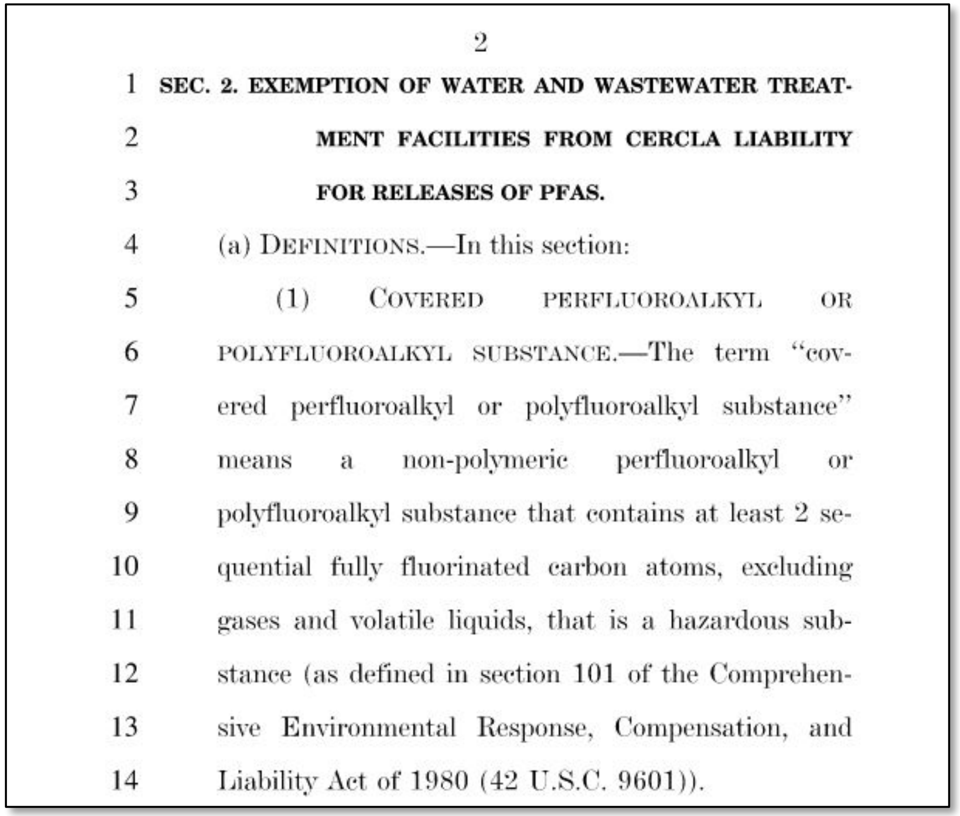
Water Systems PFAS Liability Protection Act

Introduced on May 3, 2023 by Senator Cynthia Lummis (WY)

1. Seeks to exempt drinking water, wastewater, and storm water agencies from legal liability associated with PFAS under CERCLA

2. Strong support from "Water Coalition Against PFAS"

3. Also introduced bills to protect airports, fire suppression systems, agricultural plots, and solid waste facilities



2

SEC. 2. EXEMPTION OF WATER AND WASTEWATER TREATMENT FACILITIES FROM CERCLA LIABILITY FOR RELEASES OF PFAS.

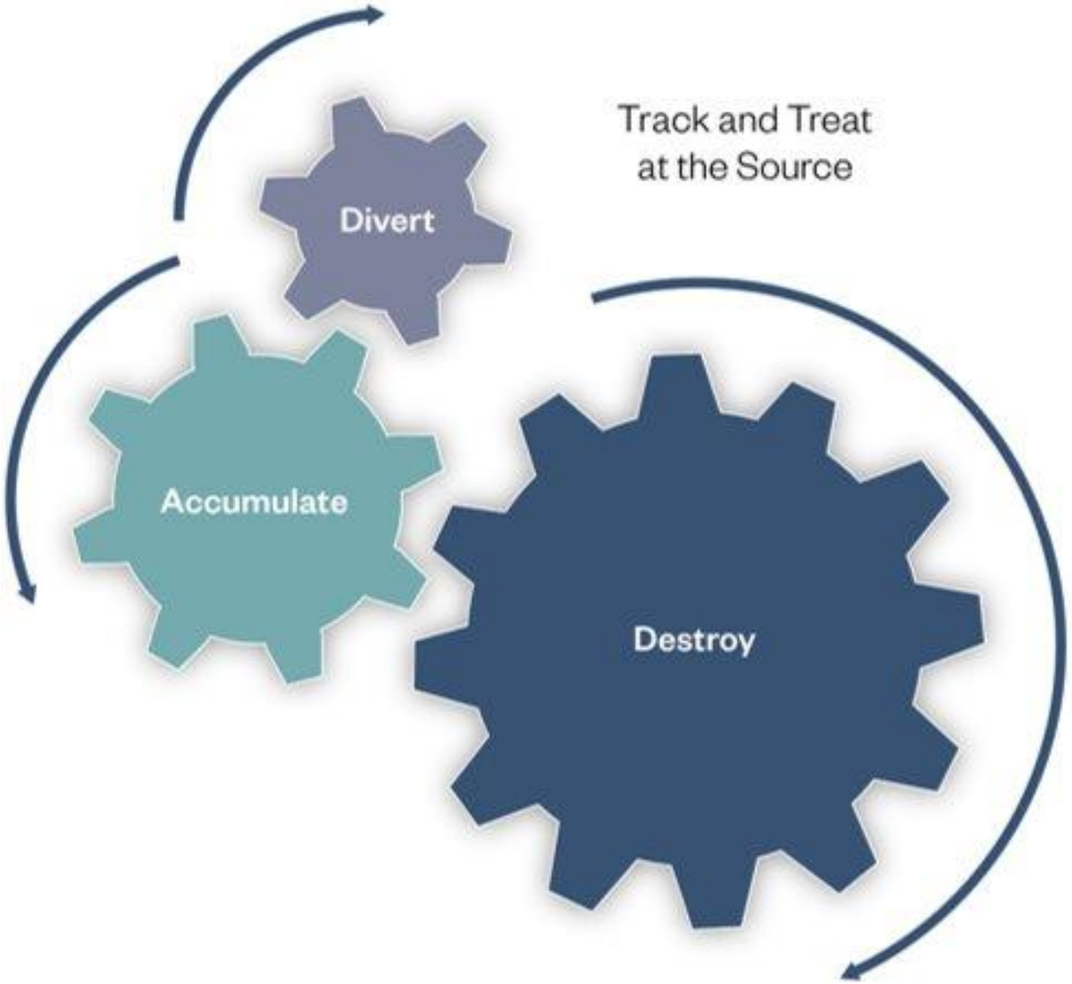
(a) DEFINITIONS.—In this section:

(1) COVERED PERFLUOROALKYL OR POLYFLUOROALKYL SUBSTANCE.—The term "covered perfluoroalkyl or polyfluoroalkyl substance" means a non-polymeric perfluoroalkyl or polyfluoroalkyl substance that contains at least 2 sequential fully fluorinated carbon atoms, excluding gases and volatile liquids, that is a hazardous substance (as defined in section 101 of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (42 U.S.C. 9601)).

PFAS Destruction

PFAS Separation ≠ PFAS Destruction

Many of our well established PFAS treatment processes are simply PFAS separation processes.



- PFAS destruction in drinking water applications will likely start with the highest concentration streams.
- Destruction for spent adsorbents, membrane concentrates, and other residuals are dominantly focused on low flow applications.
- Still working to verify the long-term applicability of some of these technologies.

The Promise of PFAS Destruction

Destruction Technologies

Highly Contaminated Matrices

	Concentrated PFAS Waste Streams				
Destruction Technologies	**Foam Fractionation Foamate**	**Spent Adsorbents**	**Settled Powdered Adsorbent/Coagulant Aid Residuals**	**Membrane Concentrate**	**Biosolids**
Supercritical Water Oxidation	✔	✔	✔	☐	✔
Gasification/ Pyrolysis	☐	✔	✔	☐	✔
Electrochemical Oxidation	✔	☐	☐	✔	☐
Photochemical Degradation	✔	☐	☐	✔	☐
Nonthermal Plasma	✔	☐	☐	✔	☐
Hydrothermal Liquefaction	✔	✔	✔	✔	✔

PFAS Residuals Management Case Study

Residuals Handling in PFAS Treatment

GAC Installation in Southeast

Price of GAC disposal increased by 16x between start of construction and first changeout event.

Price expected to increase further due to uncertainty in liability, fate and transport

Additional supply of hazardous disposal facilities may ultimately reduce cost but for now disposal market remains chaotic.

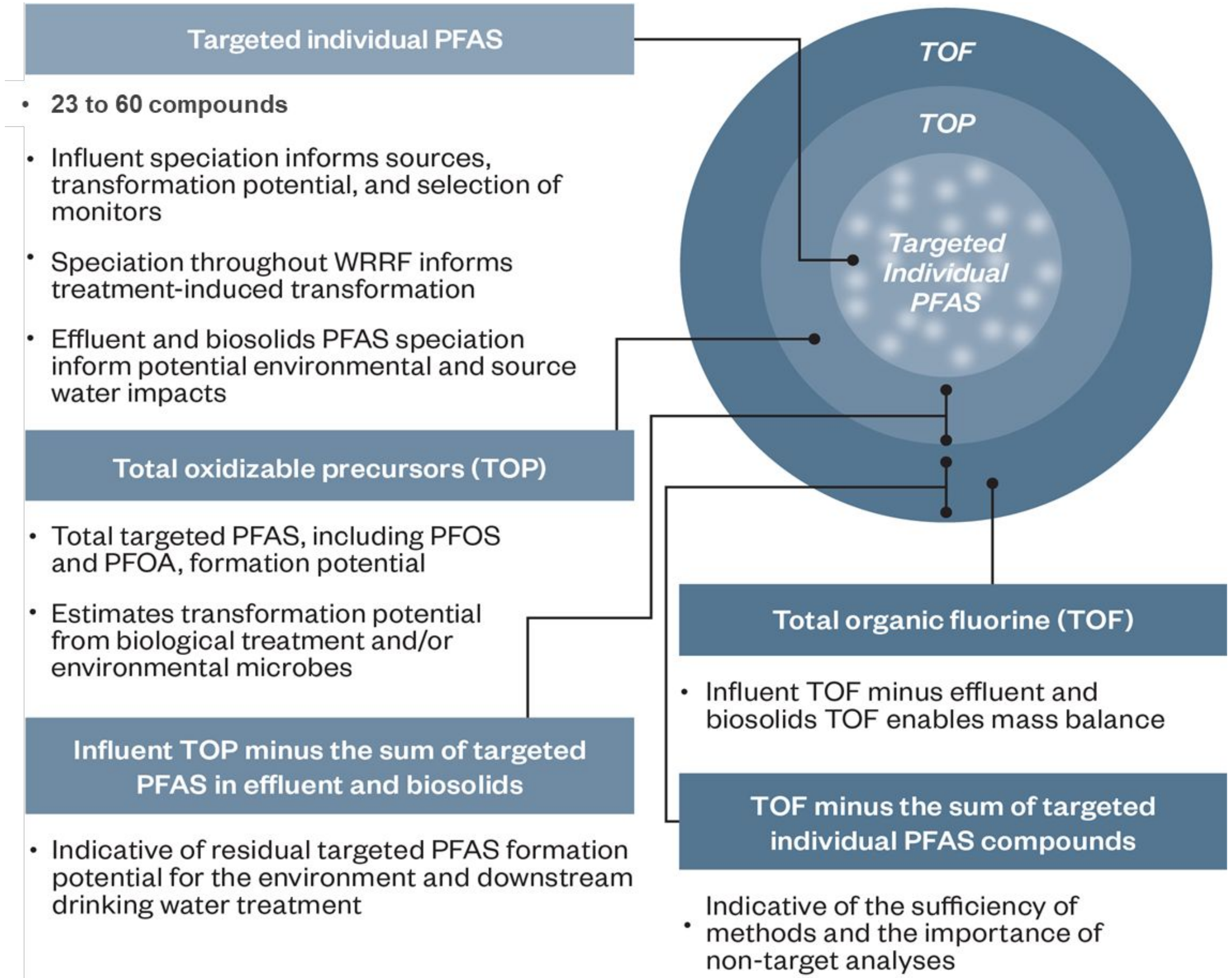
Future studies

1. Investigate PFAS partitioning behavior in thickening and dewatering

2. Evaluate the sensitivity of residuals management cost and hazardous waste designation for PFAS

3. Incorporate costs for PFAS destruction technologies into cost calculations

Analytical Challenges for PFAS in Residual Streams



Thorough PFAS analysis required to “close” mass balance on PFAS concentrations in residual streams.

- **Sampling of both aqueous and solid matrices required**
- **Potential for PFAS transformation impacting PFAS mass balance**
- **Analytical difficulty with matrix interferences with many residuals streams**

PFAS Fingerprint in Residuals

Conclusions

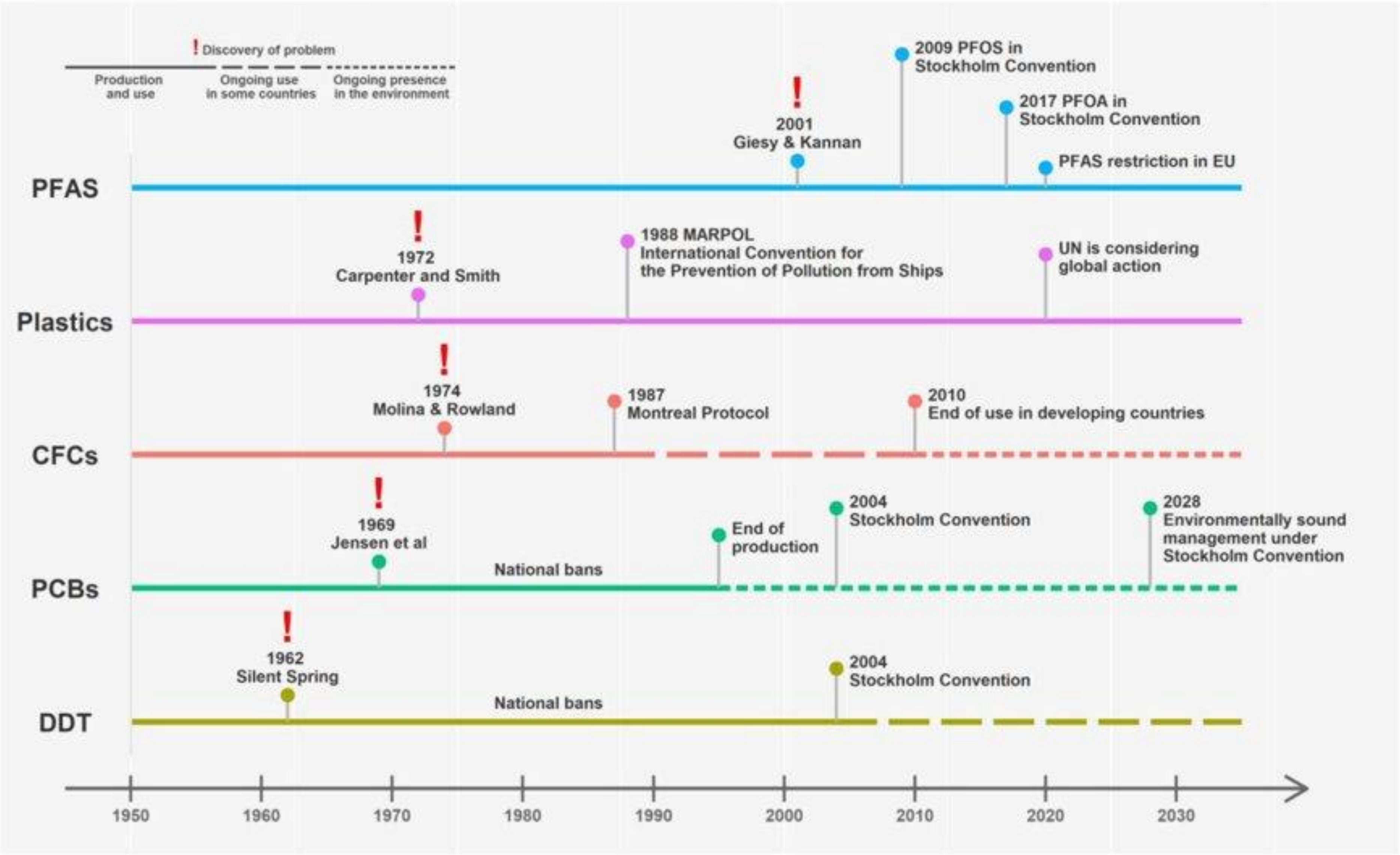
1. Large financial implications associated with hazardous waste designation for DW residuals

2. PFAS spent adsorbents are expected to contain highest PFAS residual concentration

3. Uncertainty surrounding PFAS partitioning in solids handling processes

Looking ahead

PFAS are the center of universe… for now!



Scheringer et al. 2022