PFAS Treatment Applications: Technology Options and Fundamentals

NEBC 2023 Business & the Environment

Presented by

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Presentation Topics

- PFAS in Our Water Cycle
  - Application points
  - Concentrations and flow rates
- Treatment Approaches
  - Bulk removal, drinking water, and destruction
- Technologies
  - Foam fractionation
  - Destructive
  - Membranes
  - Packed bed media

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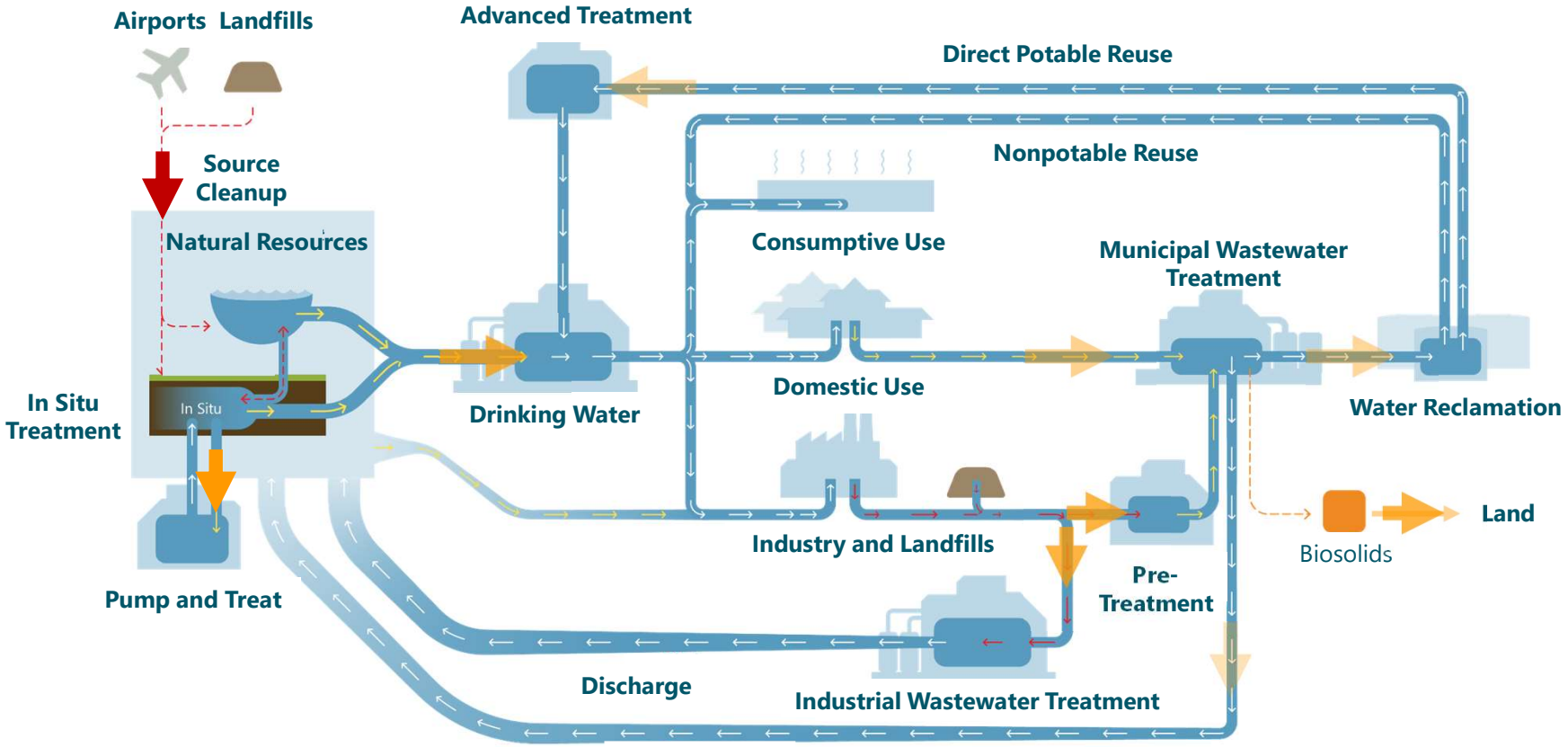
PFAS in Our Water Cycle



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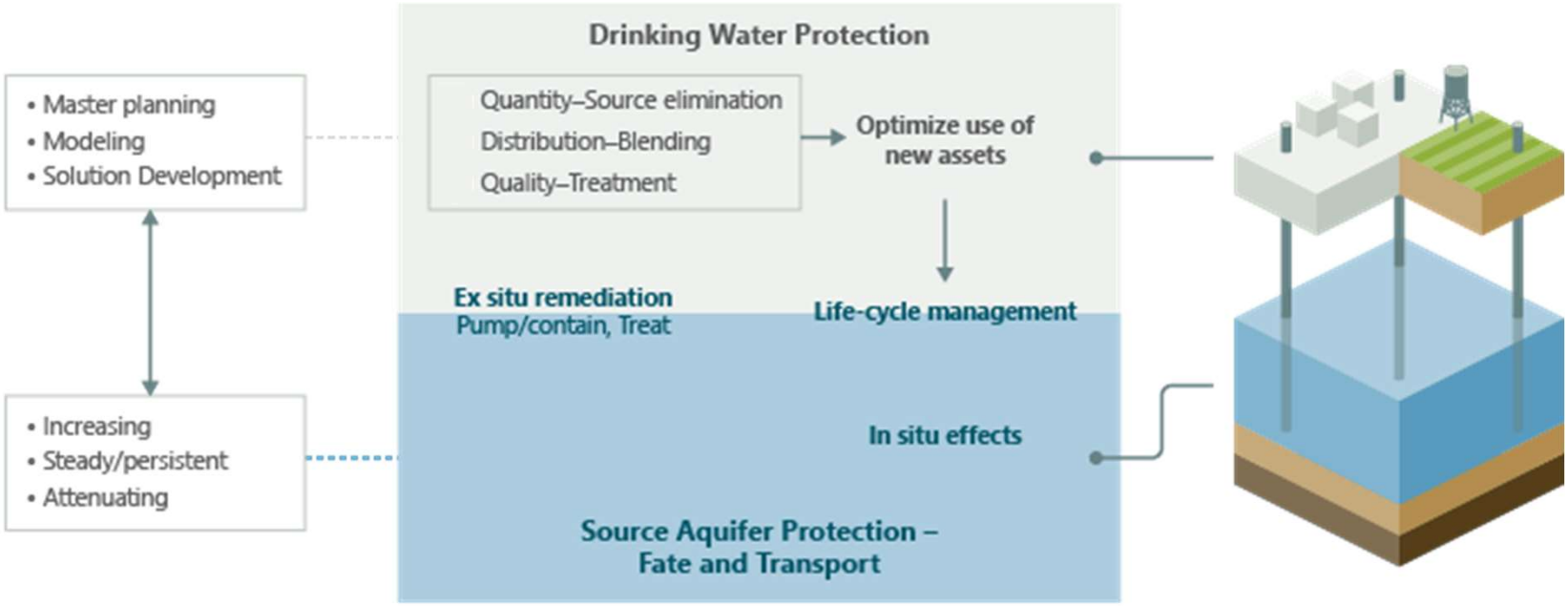
Public and Private (NEBC) Perspective: Drinking Water and Remediation



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PFAS Treatment Technologies

- With the exception of highly concentrated nominally low flow streams, treatment is via *separation*:
  - Physical, membrane separation: nanofiltration, reverse osmosis
  - Partitioning to the air-water interface on bubbles in foam fractionation
  - Partitioning to the solid phase onto adsorptive media in packed bed or subsurface soil applications
- Destructive in-stream treatment
  - Not practical for moderate to high flow rates due to high energy demand
- High energy residuals destruction

Application Scenarios – Orders of Magnitude

Application	Concentration (ng/L or ppt)	Flow Rates (gpm)	Variability	Service Life
Domestic water cycle	<10 to 100s	1000s (several MGD)	Diurnal, seasonal flows; possibly attenuating	Permanent
Groundwater (remediation)	10s to 100s	10s to 100s or in situ (ft/day)	Constant or attenuating	Decades
Industrial wastewater	100s	10s to 100s	Constant or work shifts	Business cycle
Landfill leachate	1,000s to 100,000s	1s to 10s	Weather	Essentially permanent
"Spills," hot spots	1,000s to 100,000s	1s to 10s (trickles) or soils	Diminishing/attenuating	Short, reactive
Regeneration	*1 – 10 mg/kg*	N/A	Periodic – off site (in place advancing)	Permanent/ centralized
Residuals	Biosolids, spent media	N/A	Steady – landfill (?) or destructive	Permanent/ centralized

Removal of 50 ppt at 1 MGD flow rate in 40,000 lb granular activated carbon bed operating for several months to 2 years removes less than ½ pound of PFAS.````

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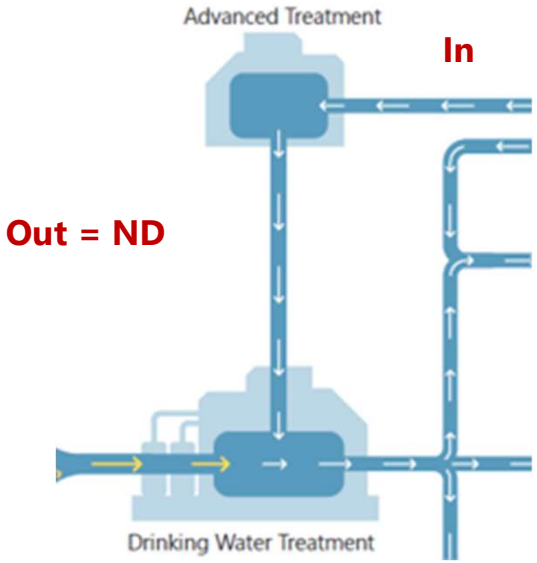
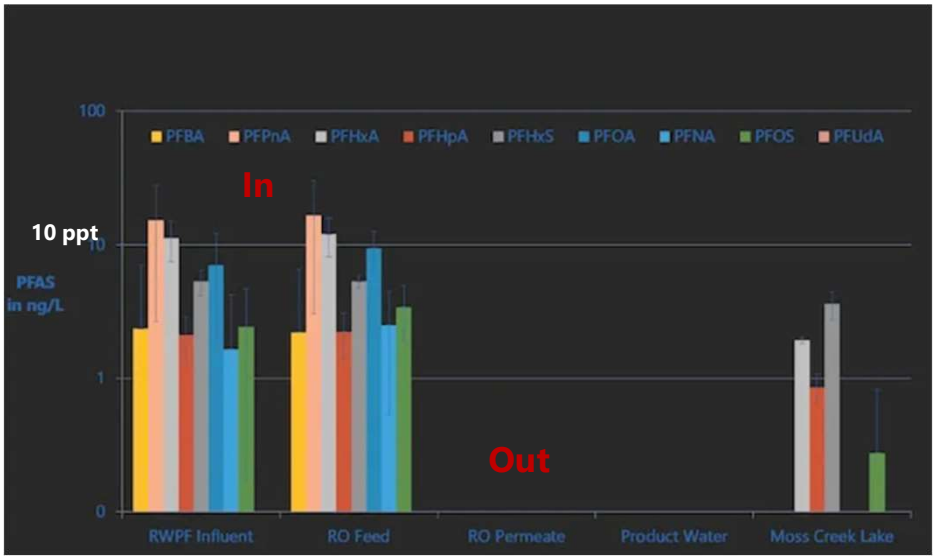
Reverse Osmosis and Nanofiltration

- Very effective—reverse osmosis (RO) more so than nanofiltration (NF)
  - Can achieve non-detect concentrations for most PFAS compounds of concern
  - Leakage can occur at high PFAS concentrations
- But essentially always eliminated during alternatives screening
  - High cost
  - Reject or concentrate management
- Collateral effectiveness in advanced water treatment (AWT)
  - e.g., direct potable reuse (DPR), where reverse osmosis is required for other contaminants

Advanced Water Treatment Case

- Big Spring, Texas: first direct potable reuse application in the US





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Advanced Water Treatment Case (cont.)

"However, for potable reuse projects, the crisis is less acute: in many cases, concentrations in conventional recycled water will already be lower than regulatory limits for drinking, and where they are not, ***AWT processes already in place in typical potable reuse projects [can] address them adequately****.*

Furthermore, it is more than happenstance that potable reuse projects are well-positioned to address the presence of PFAS. The potable reuse industry as a whole has been proactive in ***addressing a large range of constituents of emerging concern through*** *extensive monitoring and* ***advanced treatment systems*** *designed to address not only regulated parameters but many others as well."*

[1] Eva Steinle-Darling, 2021. "PFAS in Potable Reuse: Crisis or Non-Issue?" *Wastewater Digest*, May 25, 2021.

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Hot Spots, Regeneration Waste and Destruction

- Instream
  - Foam fractionation
  - Various energy intensive technologies based on sound waves, cavitation, high pressures, high temperatures, and/or chemical additives. Applications for in-place media.
- Soils, biosolids, other residuals
  - Incineration – control fugitive emissions
  - Pyrolysis – produces biochar, retains some biosolids benefits
  - Gasification
  - Super critical water oxidation (SCWO)-
    - PFAS mineralization
    - Can destroy GAC media

Adsorption and “Ion Exchange”

- Ion exchange involves the exchange at a designated *site*
  - The exchange capacity is based on the number of sites
  - Essentially a one-to-one relationship regardless of concentration
- Adsorption is the partitioning of a compound onto a solid surface due to the compound’s hydrophobicity and other properties
  - Capacity is not based on sites and *is* related to the compound’s concentration in water.
  - The capacity-to-concentration relationship is defined by an isotherm
- Media
  - Calgon, DuPont Dowex, Purolite, ECT2 in packed beds
  - Regenesis PlumeStop® for CAC

Ion Exchange Resins - IER

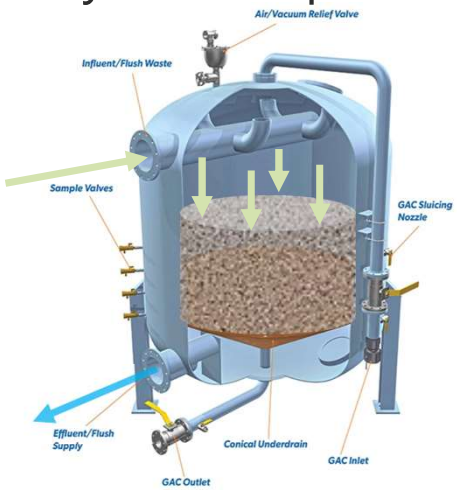
- Strong base anion exchange resins, 'off-the-shelf', have been found effective for PFAS.
- Applying an advertised capacity of 0.6 eq/L:
  - 1 liter of IER could treat 1.3 billion gallons of 50 ppt water
- PFAS removal using IER is understood to be a combination of adsorption and exchange.
- Capacity is not the advertised exchanged capacity.
  - 1 liter of IER can treat on the order of 50,000 gallons
- Regeneration (reverse exchange) of PFAS is not effective for off-the-shelf resins.

Adsorptive Media

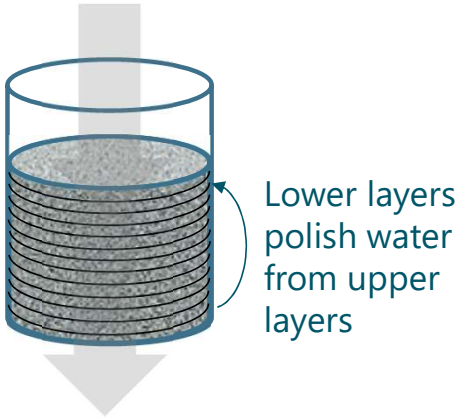
- Resins
  - Off-the-shelf
  - PFAS specific, innovative
  - Regenerable (in place) PFAS specific
- Activated carbon
  - Granular – GAC, packed bed and trenches, PRBs
  - Powdered – PAC, in suspension, not effective
  - Colloidal (liquid) – CAC, injection into groundwater
- Adsorption relative to other compounds
  - 5 mg/L (DOC, chlorinated hydrocarbons, etc.) = 100s of pounds removed per year.
  - Recall, PFAS at 50 ng/L, results in < ½ pounds removed per year.

Packed Bed Media

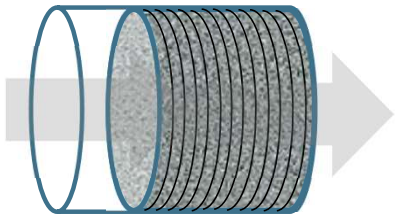
- Flow evenly distributed to avoid short circuiting
- Water advancing downward through 'layers' of media
- The layer concept also applies to PRBs or CAC injection.



Media bed loaded and flow distributed



Visualized bed with flow through discrete layers in series



PRB or CAC coated soils

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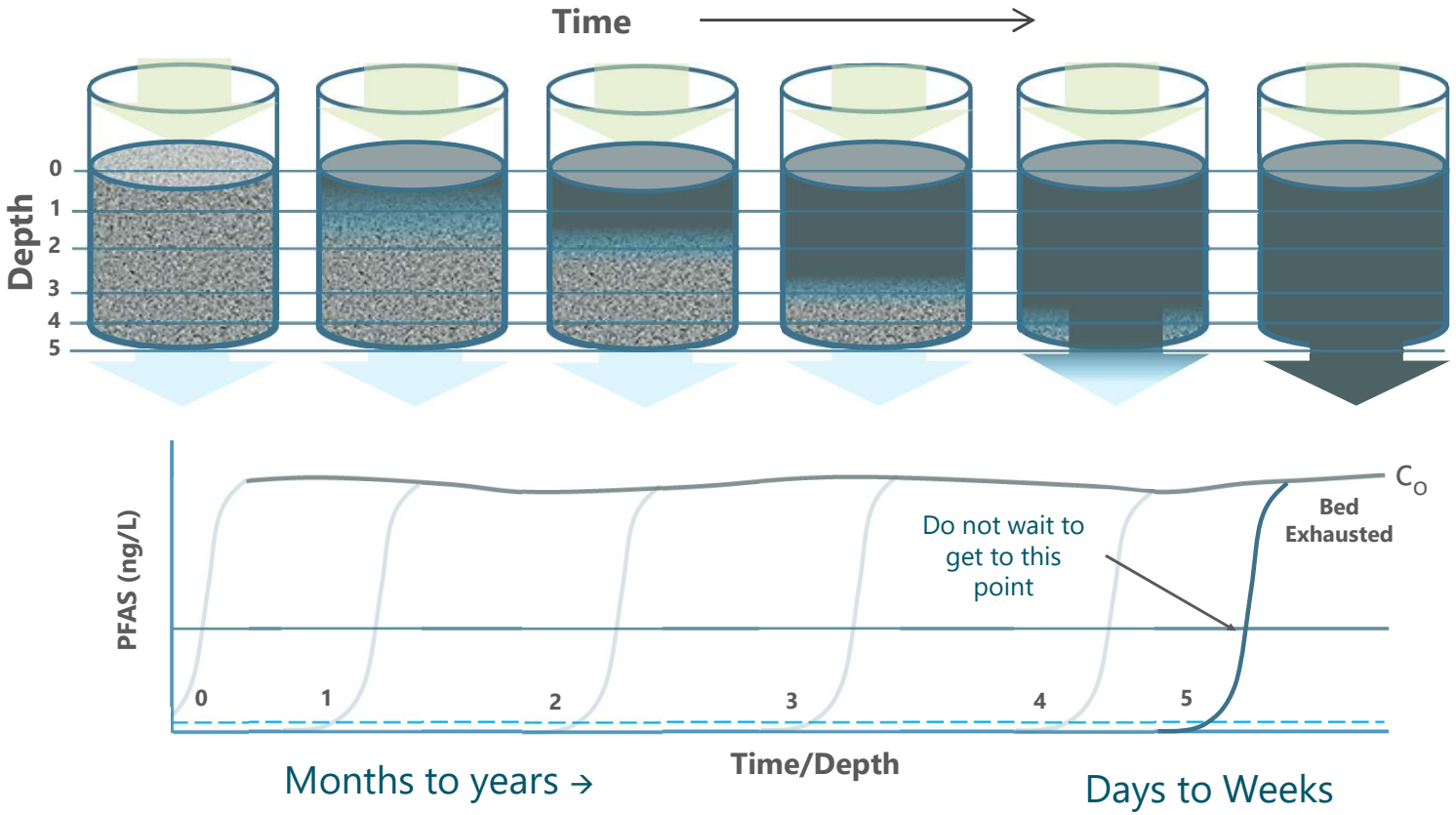
Breakthrough – Loading Media to Full Capacity



Packed Bed Media (cont.)

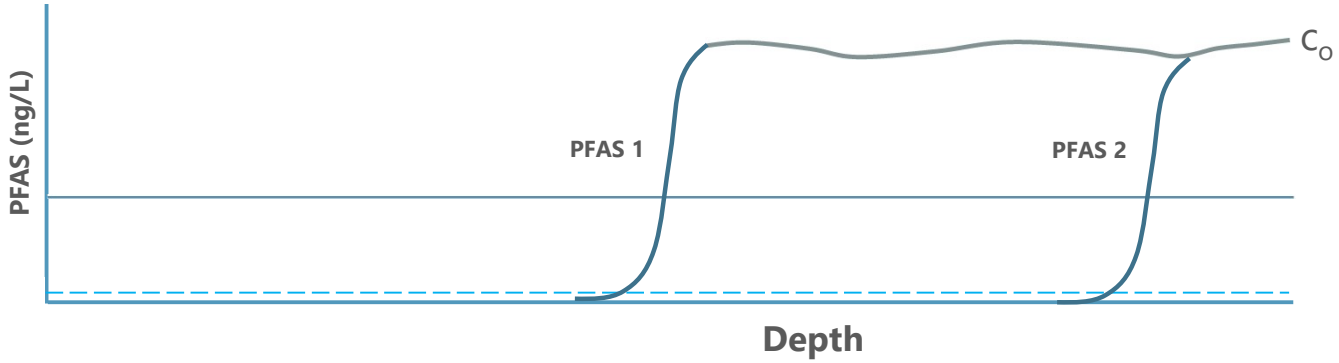
- Adsorbent media, whether GAC or IER, can achieve non-detect performance
- Not completely dependent on PFAS feed level
- Activated carbon:
  - Lower adsorption capacity in ng/kg.
  - Slower reaction rate: 10 minutes of exposure time
  - Lower cost
- Ion exchange resins (IER):
  - Higher adsorption capacity in ng/kg.
  - Faster reaction rate: 2 to 3 minutes of exposure time
  - Higher cost

Multi Compound Breakthrough

Massachusetts

Sum of PFAS-6 < 20 ppt

- PFOA
- PFOS
- PFHPa
- PFHPx
- PFNA
- PFDA



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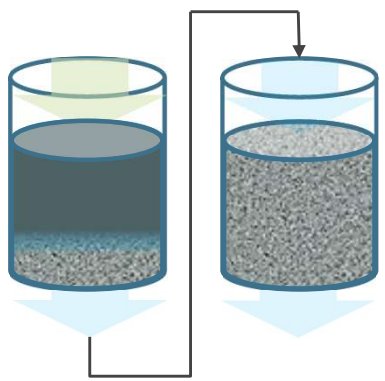
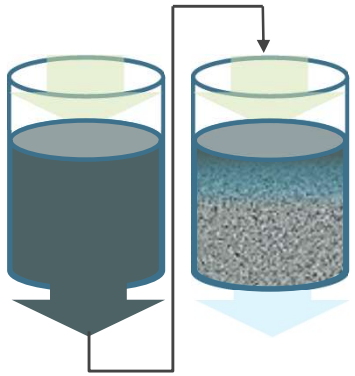
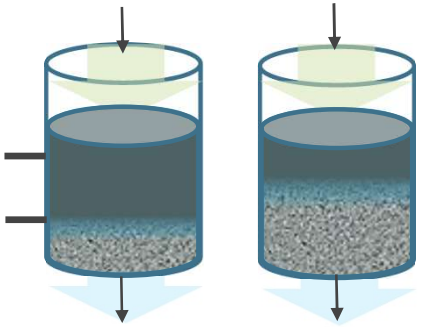
Managing Breakthrough with Two Beds



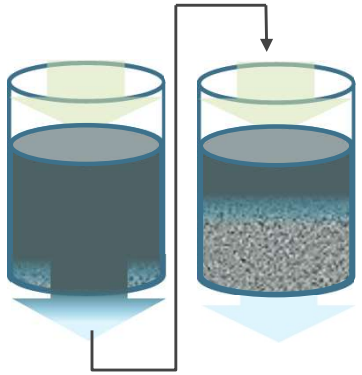
Series



Sampling Ports



Parallel-Series



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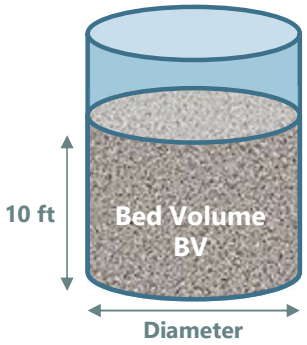
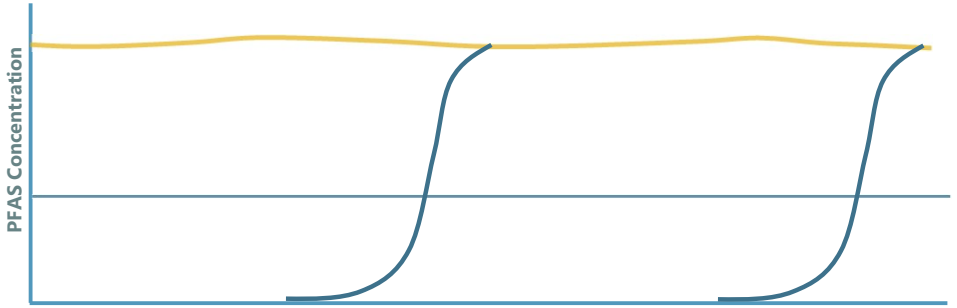
Media Rate, Capacity, and Cost

Parameter	Description	Units	Used for Establishing	Low (GAC)	High (IER)
Hydraulic rate	Resistance of media to water flow	Bed velocity in feet per minute	Vessel diameter (VD)	0.8–1.2 fps (VD)	1.6 fps (0.75x VD)
Reaction rate	Allow time for adsorption	Empty bed contact time in minutes	Bed depth Vessel height	10–15 minutes (10–15 feet)	2–3 minutes (3–5 feet)
Adsorption capacity	Mass of PFAS on mass of adsorbent	Nanograms/gram	Frequency of media replacement	20,000–40,000 treatable bed volumes	5x to 10x higher
Removal efficiency	Achievable effluent concentration	Nanograms/liter	Not applicable	Non-detect	Non-detect
Media cost	—	$/cubic foot	Not applicable	$50–$75 (reuse)	$300–$600

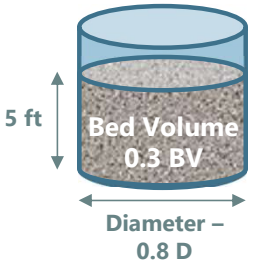
Media Rate and Capacity – Sense of Scale

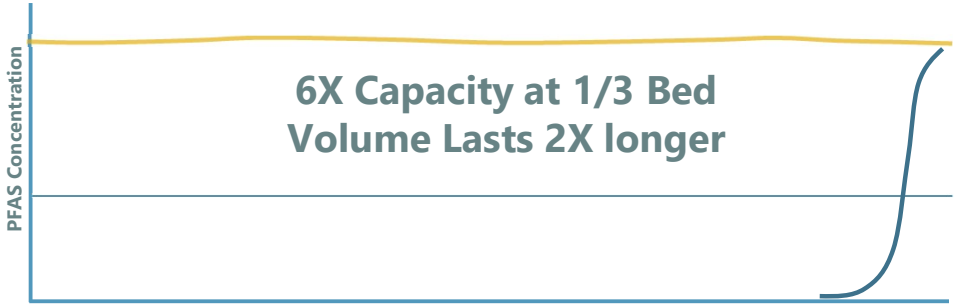
Low Rate, Low Capacity – Activated Carbon





High Rate, High Capacity – Resins, Hybrids





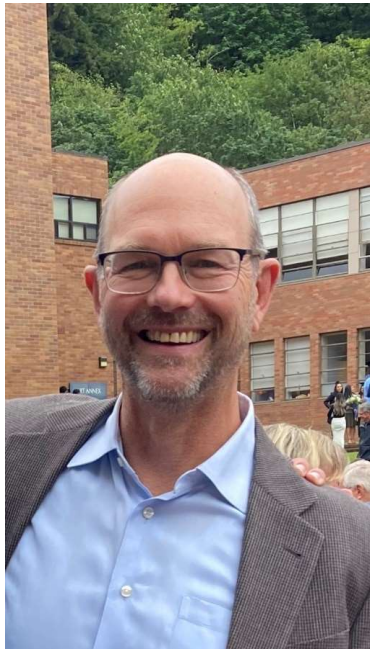
Complete Study Process – GAC vs IER

- Jar testing to develop isotherms.
  - Not critical, but requires little time overall
- Rapid small scale column tests (RSSCT), bench scale.
  - Run to breakthrough or only to demonstrate efficacy of PFAS removal. Roughly 1 to 4 months required.
- Pilot testing
  - Important to support life cycle cost analysis
  - Depending upon scale and PFAS limits, can be integrated in existing treatment system with a temporary skid to improve water quality in the interim.
- Note: Competing contaminants or other water quality constraints may eliminate IER feasibility

Life Cycle Cost Analysis

- Capital
  - Treatment system, pipelines, buildings, power
- Annual
  - Media capacity defined as treatable bed volumes
  - Media cost: $/cubic foot
  - Media changeout and disposal
- Industry trends
  - GAC has been used for vast majority of drinking water applications
  - Mainly due to lower media cost despite lower capacity and larger equipment requirements
  - IER more prone to fouling that may require pretreatment

THANK YOU



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