

PFAS Treatment Technologies: Options, Trade-offs, and Decision Factors

03/19/2026 EMERGING CONTAMINANTS - SMALL AND DISADVANTAGED COMMUNITIES (EC-SDC)

Agenda


EC-SDC Overview
What is PFAS & Why it Matters
Regulatory Landscape
Approved Treatment Technologies
Trade-Offs & Decision Factors
Key Takeaways + Q&A

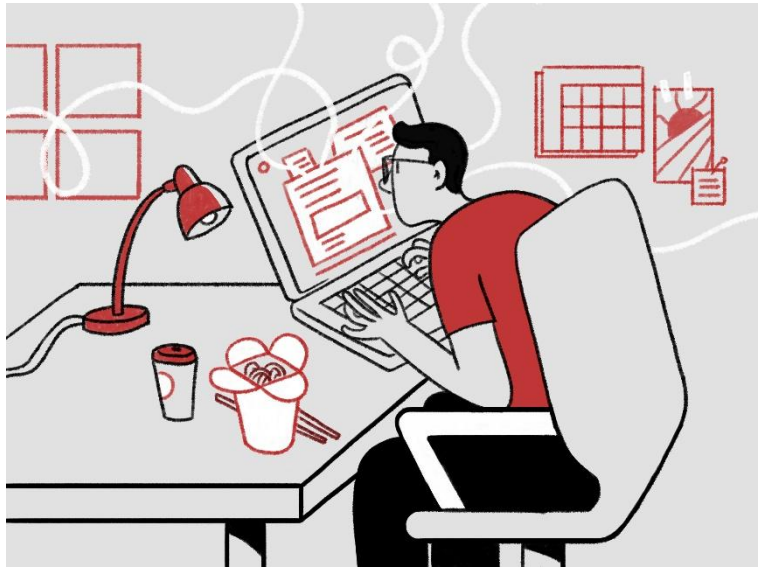
EC-SDC Technical Assistance

- Needs Assessment
- Scope of Work / Budget (EPA review)
- Grant Award
- Reporting & Reimbursements
- Regulatory checklist completion



Technical Assistance - Contacts

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- Eric Lehan, PE elehan@umass.edu



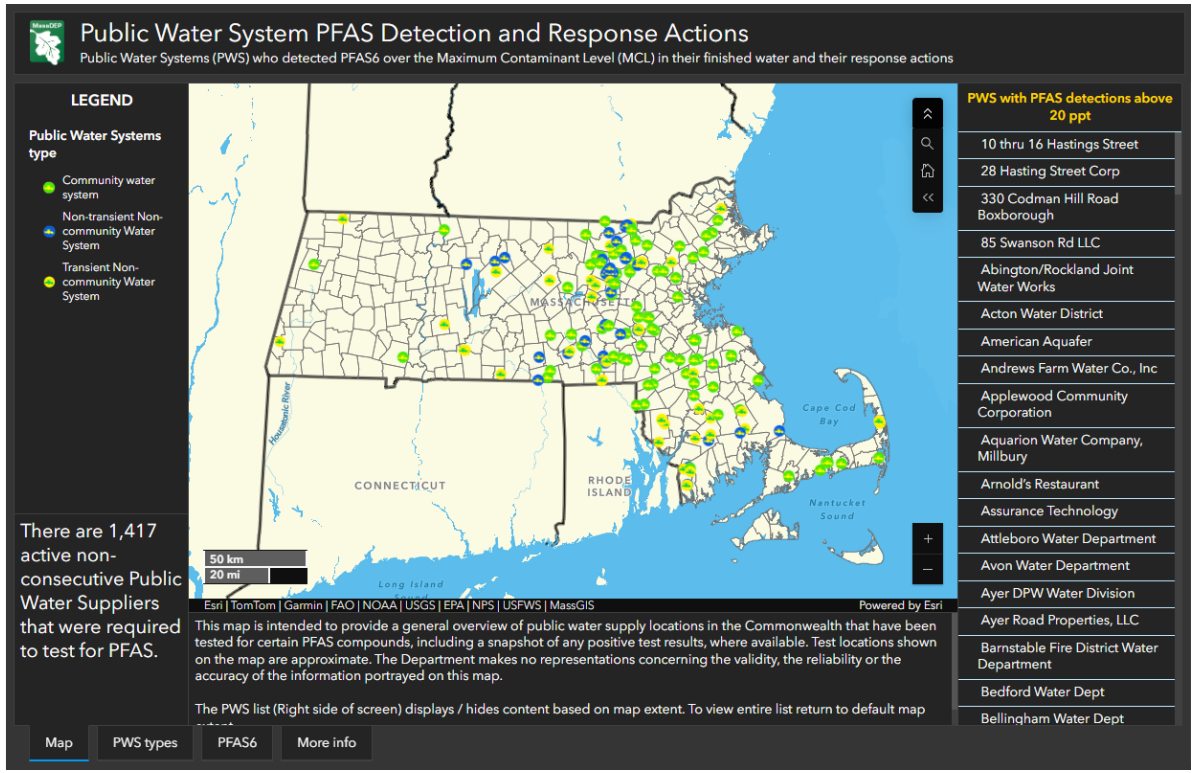
Why This Training Matters

- The State of Massachusetts is actively promoting consistent access to clean drinking water
- Many public water systems across the state have detected elevated PFAS levels
- Compliance deadlines are on the horizon

PRESS RELEASE

Healey-Driscoll Administration Awards $14.7 Million to Address PFAS and Other Emerging Contaminants

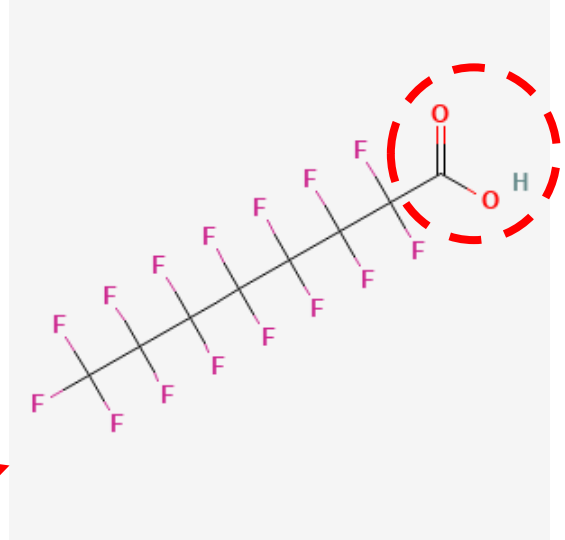
https://www.mass.gov/news/healey-driscoll-administration-awards-147-million-to-address-pfas-and-other-emerging-contaminants

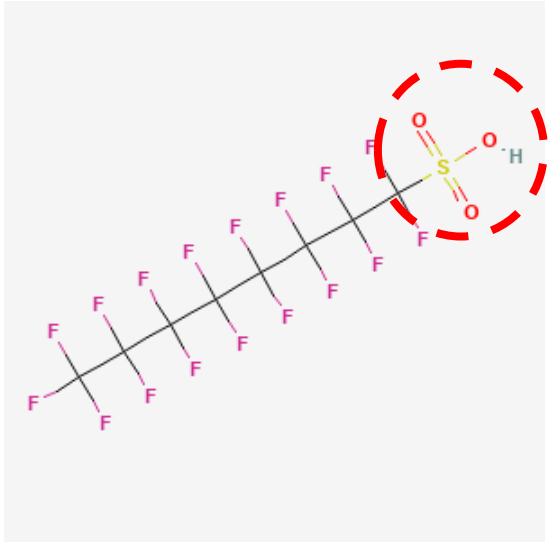


https://www.mass.gov/info-details/per-and-polyfluoroalkyl-substances-pfas-in-drinking-water

What is PFAS?

- Class of over 14,000+ fluorinated synthetic organic compounds (EPA CompTox)
- Poly- and Perfluoroalkyl substances (PFAS)
  - Perfluoroalkyl acids (PFAAs)
    - Perfluoro**carboxylic** Acids (PFCAs)
      - PFOA = 8 carbons chain (C8) + carboxylate group
      - C4-C12 measured
    - Perfluoro**sulfonic** Acids (PFSAs)
      - PFOS = 8 carbons chain (C8) + sulfonate group
      - C4-C10 measured
- Classified as an **emerging contaminant** by EPA, MassDEP





Why is PFAS a problem?

- Widely used in many consumer products
- Very stable: carbon-fluorine bond is very strong
  - Remains stable in environment
- Human toxicity
  - Possible carcinogen, possible adverse reproductive effects, possible immunotoxin



https://kingcounty.gov/en/dept/dnrp/waste-services/hazardous-waste-program/news-events/news/2024-12-12-pfas-explained

Current Regulatory Landscape

Massachusetts PFAS6

Compounds	MCL
PFOA	-
PFOS	-
PFHxS	-
PFNA	-
PFHpA	-
PFDA	-
PFAS6 Sum	∑20ppt

Applicable to community (COM) and non-transient non-community (NTNC) systems

EPA

Compounds	MCL
PFOA	4 ppt (ng/L)
PFOS	4 ppt
PFHxS	10 ppt
PFNA	10 ppt
HFPO-DA	10 ppt
Hazard Index (2 or more PFHxS, PFNA, HFPO-DA, PFBS)	1 (unitless)

5/14/2025 – EPA announced it intends to rescind

$$\text{Hazard Index (1 unitless)} = \left(\frac{[\text{HFPO} - \text{DA}_{\text{ppt}}]}{[10\ \text{ppt}]}\right) + \left(\frac{[\text{PFBS}_{\text{ppt}}]}{[2000\ \text{ppt}]}\right) + \left(\frac{[\text{PFNA}_{\text{ppt}}]}{[10\ \text{ppt}]}\right) + \left(\frac{[\text{PFHxS}_{\text{ppt}}]}{[10\ \text{ppt}]}\right)$$

Current Federal Regulatory Landscape

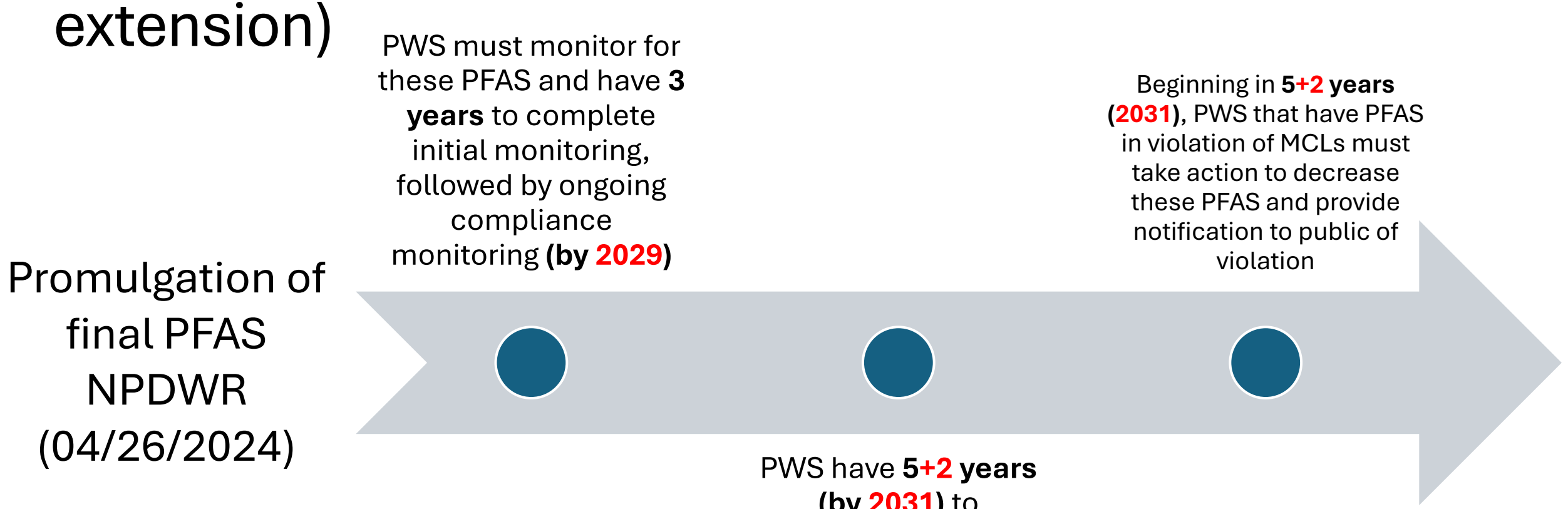
Promulgation of final PFAS NPDWR (04/26/2024)

PWS must monitor for these PFAS and have **3 years** to complete initial monitoring, followed by ongoing compliance monitoring **(by 2027)**

PWS have **5 years (by 2029)** to implement solutions that decrease these PFAS if in exceedance of MCLs

Beginning in **5 years (2029)**, PWS that have PFAS in violation of MCLs must take action to decrease these PFAS and provide notification to public of violation

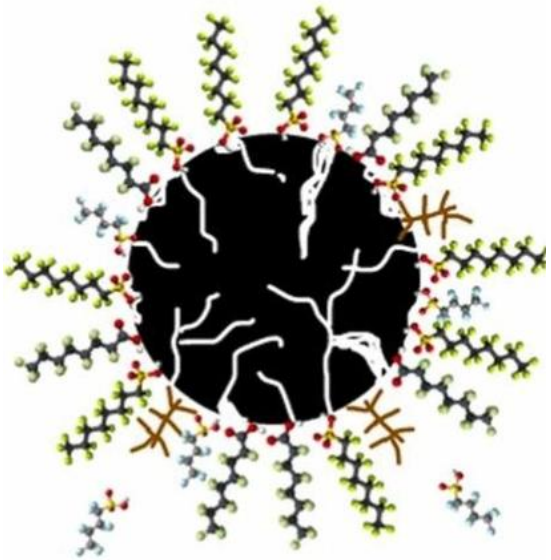
Current Federal Regulatory Landscape (with PFAS extension)



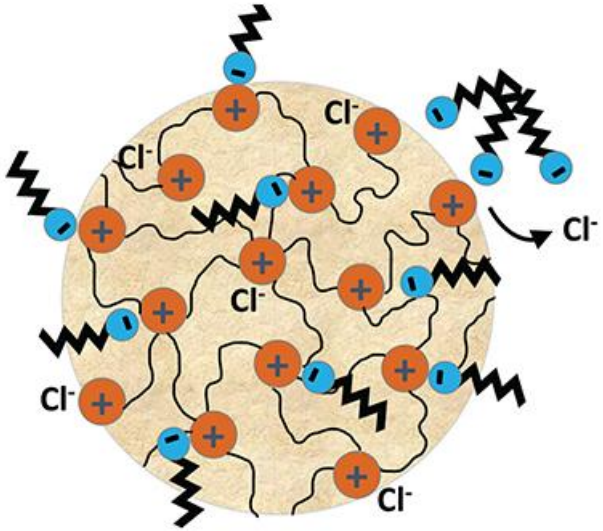
Proposed extension, to be finalized Spring 2026

What are some approved treatment solutions?

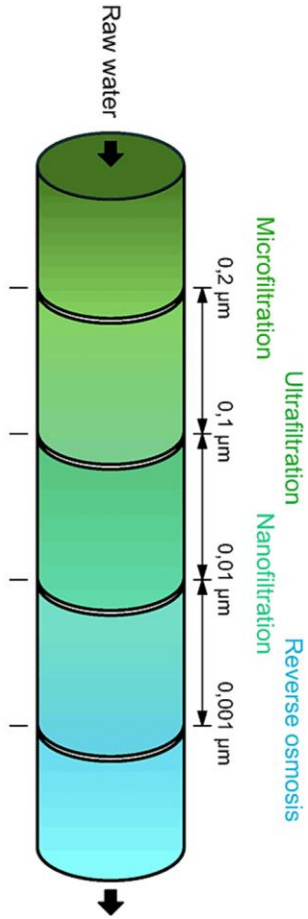
Granular Activated Carbon (GAC)



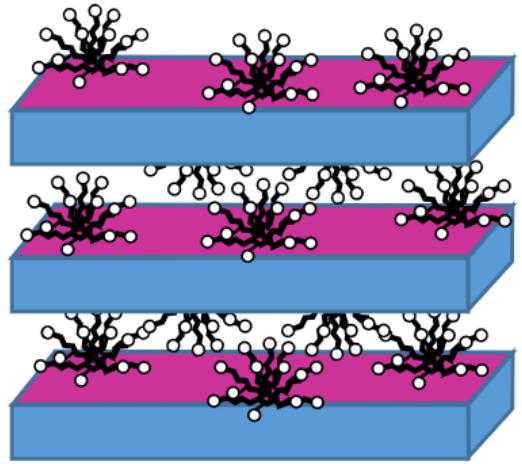
Ion Exchange (IX)



Reverse Osmosis (RO) / Nanofiltration (NF)



Other sorbents

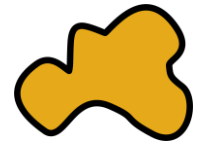


Activated Carbon 101

PFAS



Natural Organic Matter (NOM)



- Adsorption process
  - AC functions as solid adsorbent for aqueous contaminants
  - Primarily physical adsorption
- Very high surface area
  - 500 – 1500 m^2 / g
- Non-specific
  - Co-contaminants compete for sites on activated carbon
    - Natural organic matter (NOM)

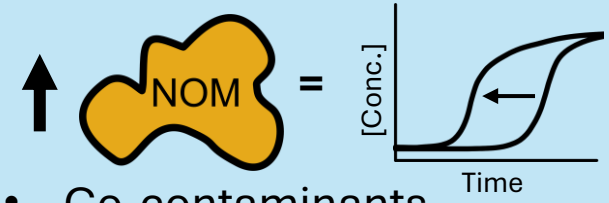


(Gomri et al., 2024)

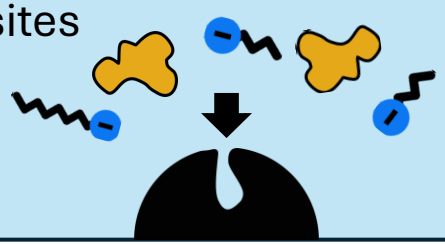
GAC – Performance and Design Considerations

Raw Water Matrix

- NOM can decrease GAC performance
  - Higher TOC/DOC generally leads to faster breakthrough



- Co-contaminants compete for adsorption sites



Breakthrough Behavior

- PFAS compete with each other for adsorbtion sites

- Short-chain PFAS will generally break through first

- Carboxylates often break through before sulfonates

Design Implications

- EBCT around 10-20 minutes

- Bed life best determined by pilot testing or RSSCTs
- Two vessels in series (lead-lag) common

Typical Activated Carbon Configuration

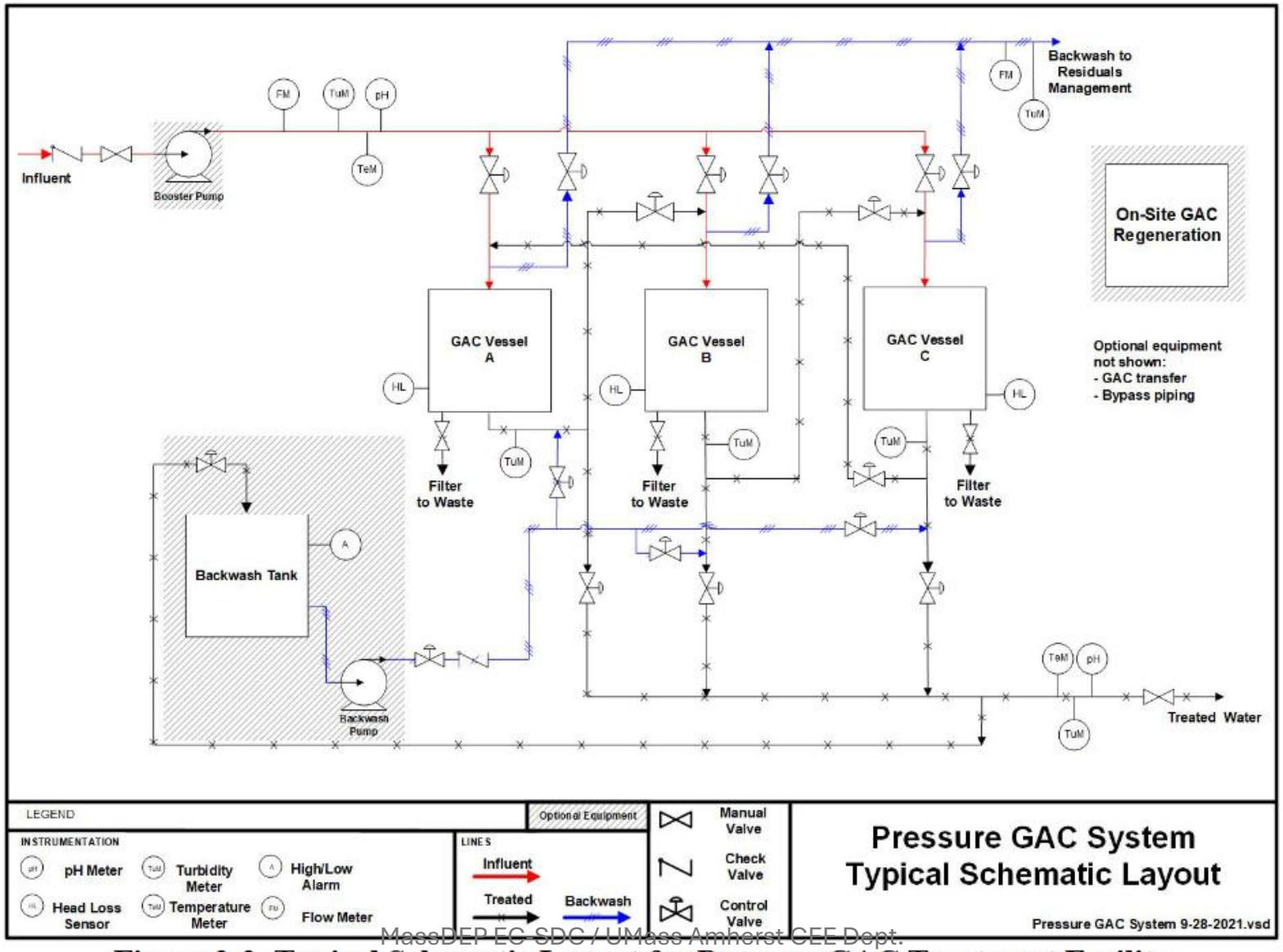


Figure 2-2. Typical Schematic Layout for Pressure GAC Treatment Facility

Examples of GAC Systems

Technologies and Cost for Removing Per- and Polyfluoroalkyl Substances (PFAS) from Drinking Water
March 2024

Location	Flow rate (MGD)	Groundwater or Surface Water	Year of Startup	Sources
Emerald Coast Utilities Authority, Pensacola, Escambia County, Florida	1.44	Groundwater	2017	Robinson 2018; Forrester 2019
Rome Water and Sewer Division, Rome, Georgia	9	Groundwater	Not reported	Forrester 2019; City of Rome 2019
Former Naval Air Station, Brunswick, Maine	Not reported	Not reported	2011	Danko 2018
Kennebunk, Kennebunkport & Wells Water District, Kennebunk, Maine	2.90	Groundwater	2020	Berretta et al. 2021; Business Wire 2018
Mary Dunn Water Supply Wells, Hyannis & Town of Barnstable, Massachusetts	1.44	Groundwater	2015	Gallagher 2017; Forrester 2019
City of Westfield Department of Public Works, Westfield, Massachusetts	Not reported	Groundwater	2018	Westfield 2019
Plainfield Township, Kent County, Michigan	9	Groundwater	2018	Biolchini 2018
Ann Arbor Water Treatment Plant, Ann Arbor, Michigan	50	Surface Water	2018	Stanton 2019; Page 2020



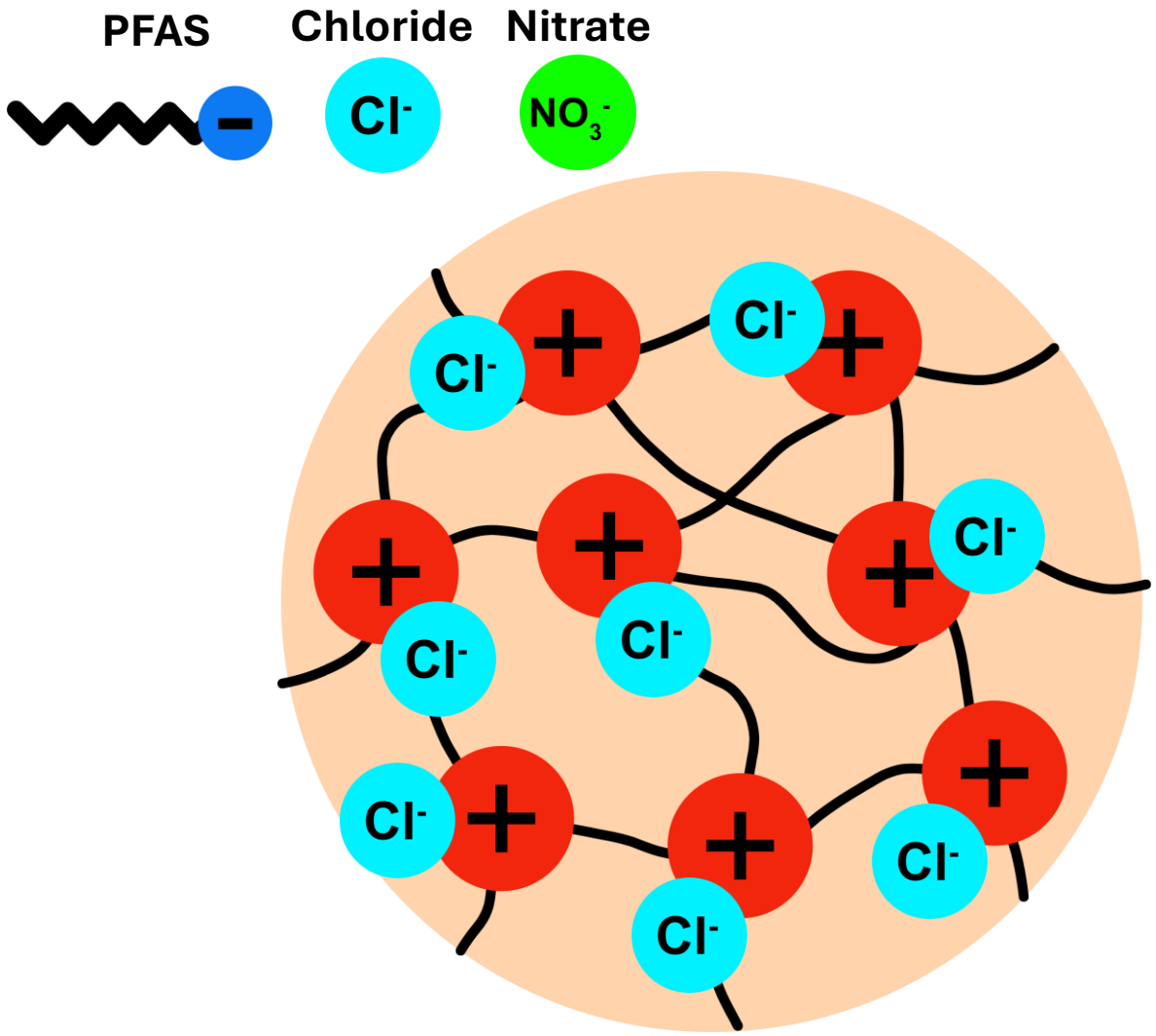
https://www.barnstablepatriot.com/story/news/2015/08/14/water-supply-mary-dunn-wells/33065374007/



https://thewestfieldnews.com/water-treatment-plant-progressing/

Ion Exchange (IX) 101

- Ion exchange process
  - Exchange of ions between aqueous phase and solid phase
  - Principle of electroneutrality
- Semi-selective
  - IX chemistry can be engineered for preferential removal of target contaminants
- Anionic PFAS exchange with chloride on anion exchange resin

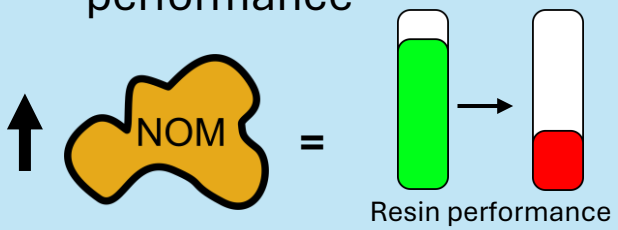


Anion exchange resin

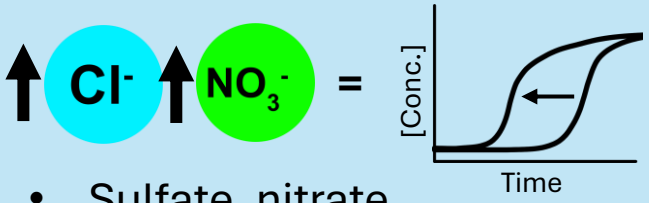
IX – Performance and Design Considerations

Raw Water Matrix

- NOM can decrease IX performance



- Competing anions influence breakthrough



- Sulfate, nitrate, bicarbonate, chloride matter

Breakthrough Behavior

- PFAS compete with each other for exchange sites

- Short-chain PFAS will generally break through first

- Carboxylates often break through before sulfonates

Design Implications

- EBCT around 3-6 minutes

- Bed life best determined by pilot testing or RSSCTs
- Two vessels in series (lead-lag) common

Typical IX Configuration

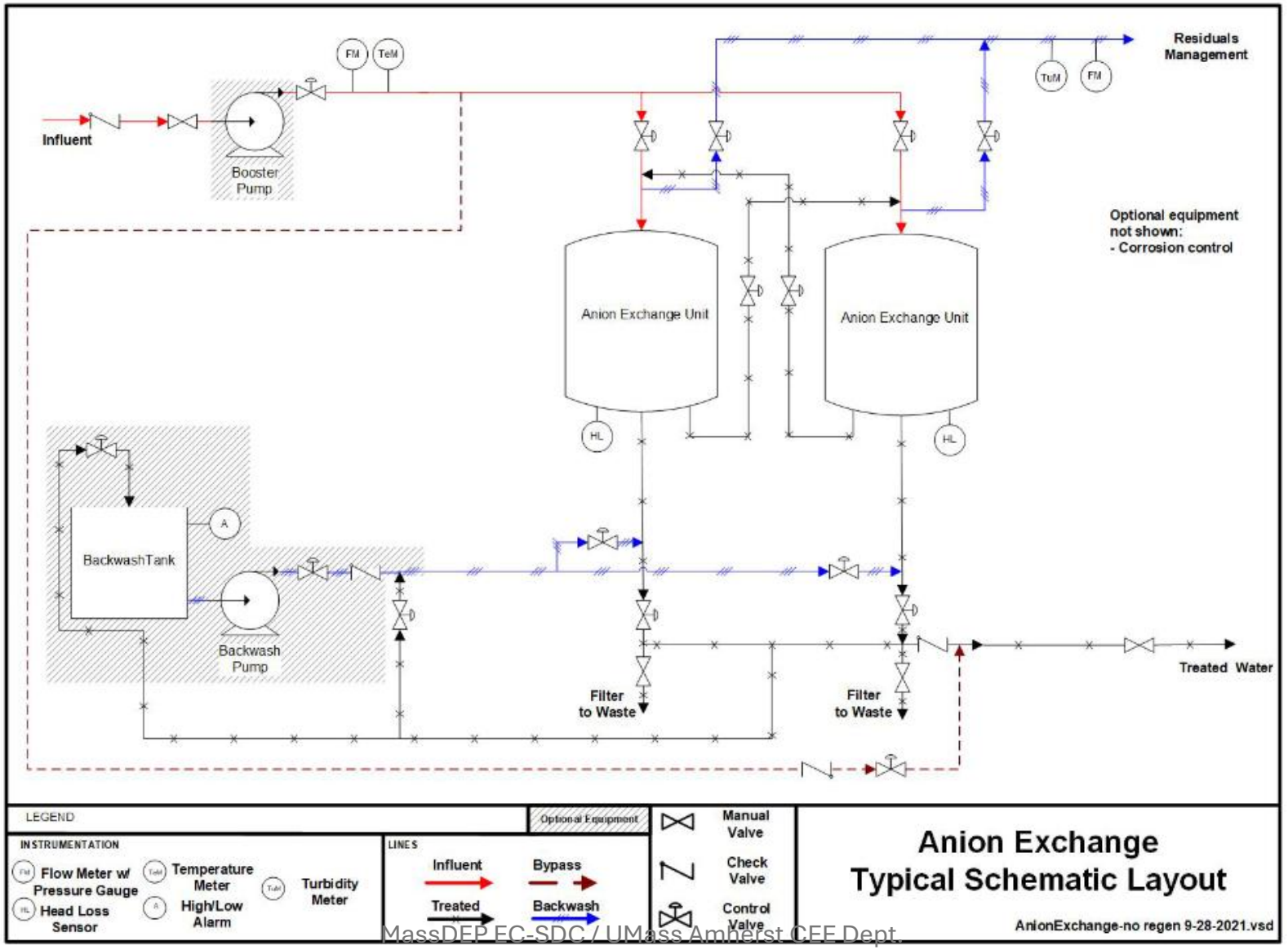
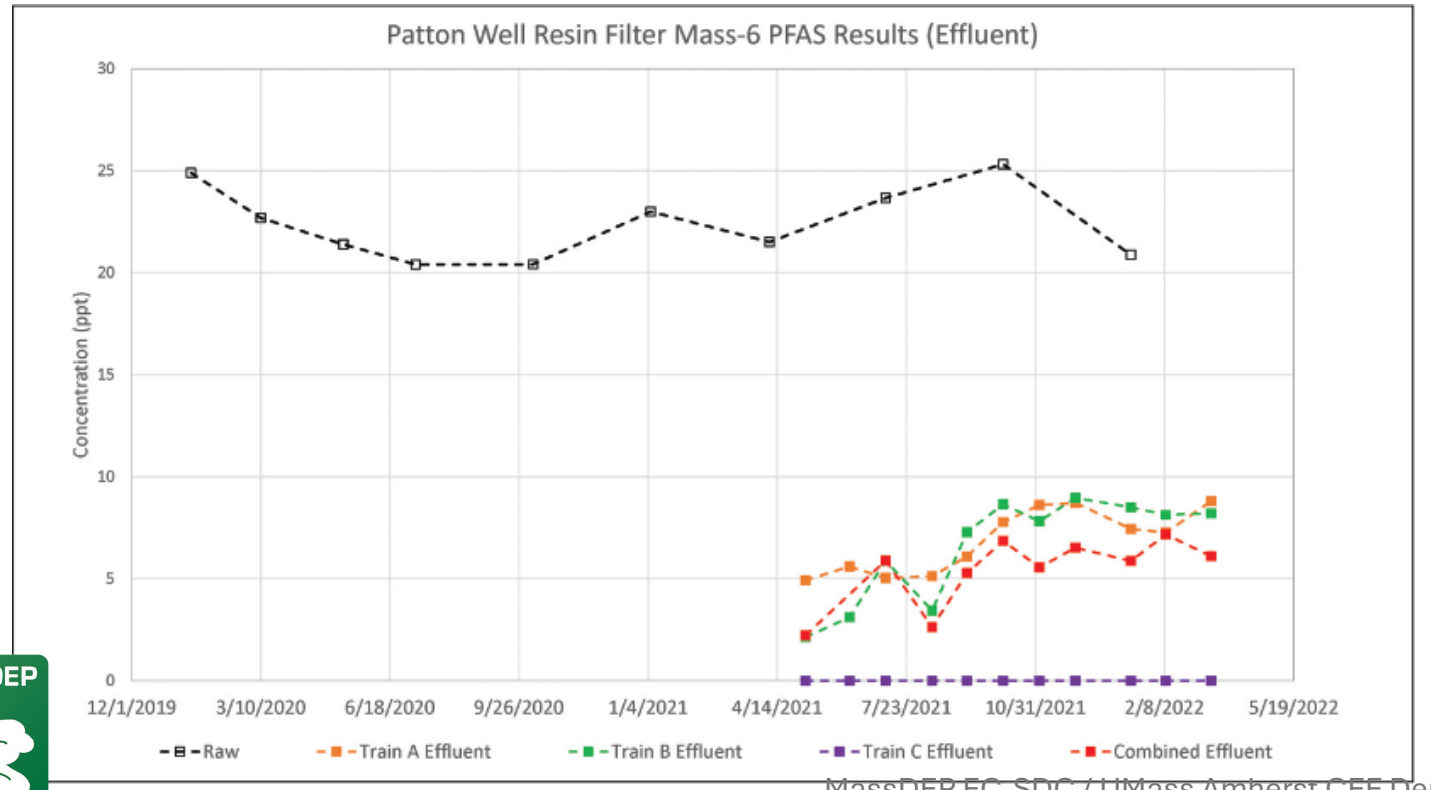


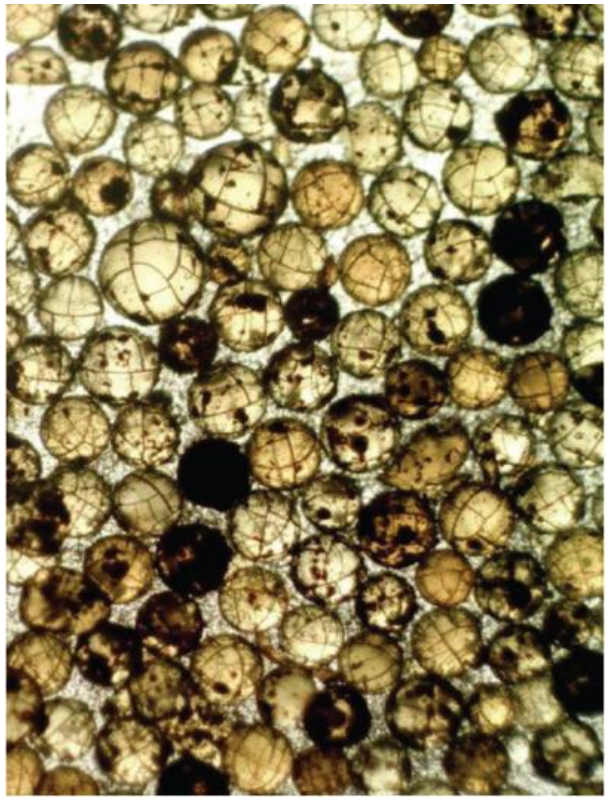
Figure 3-2. Typical Schematic Layout for IX with Resin Disposal

Example of IX System

Location	Flow rate (MGD)	Groundwater or Surface Water	Year of Startup	Sources
Devens, MA-Patton Water Treatment Plant, Devens, Massachusetts	1.44	Groundwater	2020	Francis and Martin 2022



Resin fouled by manganese



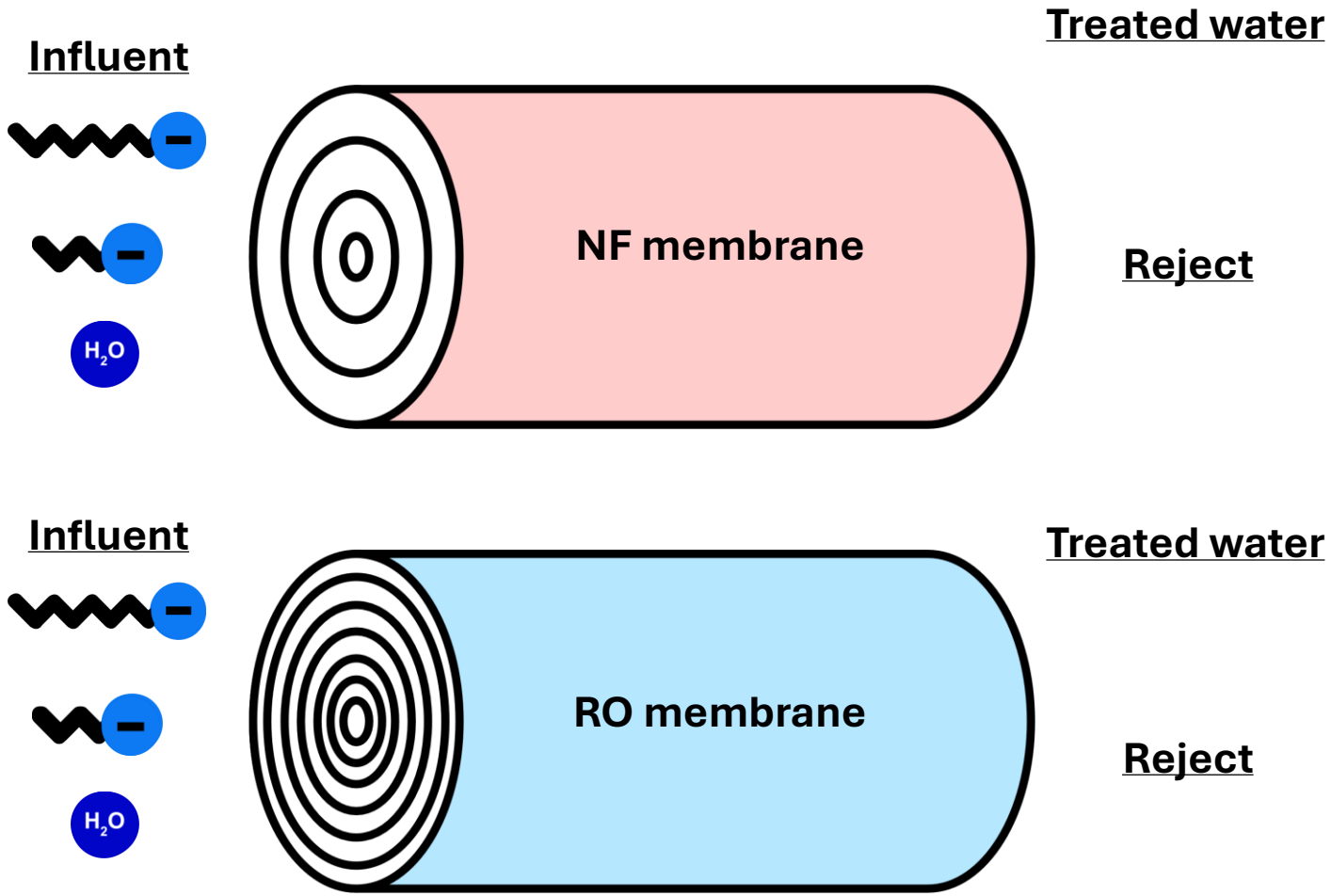
Initially tried Mn sequestering, ended up implementing GreensandPlus™ upstream of IX

https://www.journalofnewwadigital.com/newq/0123_march_20
gedArticle.action?articleId=1865822#articleId1865822

Reverse Osmosis / Nanofiltration 101



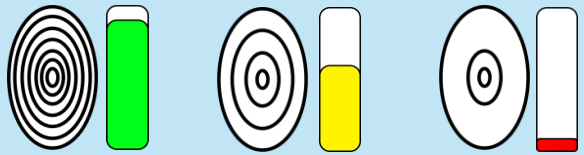
- Separation Process
  - Pressure drives water through semi-permeable membrane, while contaminants are separated from the treated water stream
- Semi selective
  - Solutes can be rejected based on:
    - Size
    - Charge
    - Diffusivity through membrane



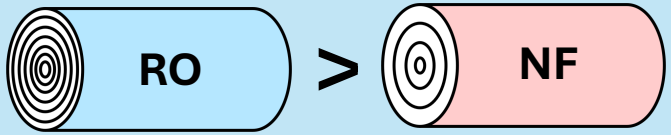
RO/NF – Performance and Design Considerations

Membrane Selectivity

- Tighter membranes generally achieve higher PFAS removal



- RO typically rejects more PFAS than NF



- Smaller PFAS require tighter membranes for effective removal

Performance Behavior

- RO/NF removal generally steady over time
- RO/NF typically do not show breakthrough like GAC or IX

- Performance limited by fouling, scaling, or membrane selection

Design Implications

- Pretreatment important to control fouling and scaling

- Design depends on membrane type, flux, and recovery
- Higher recovery produces less but more concentrated waste

Typical RO/NF Configuration

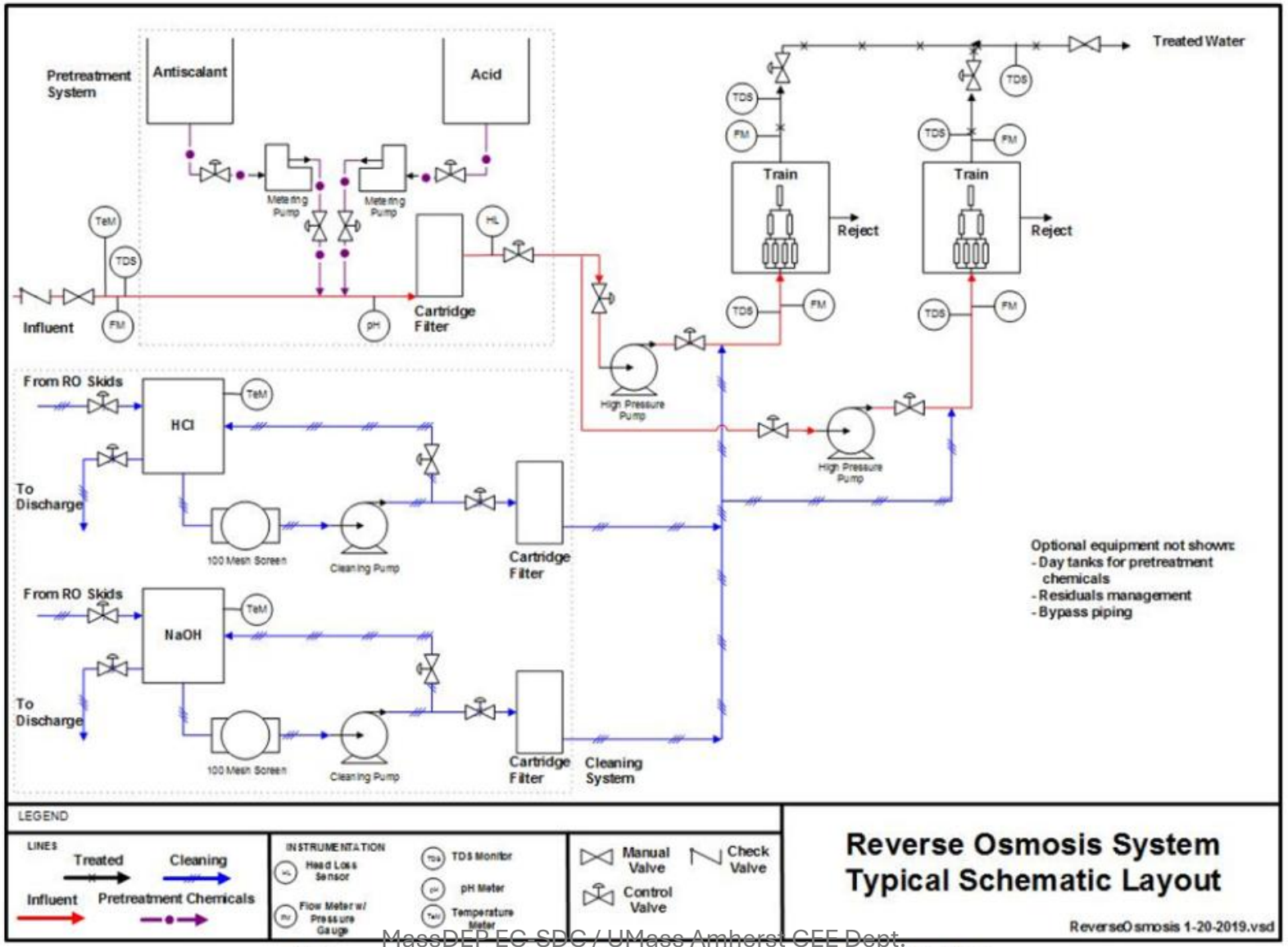


Figure 4-2. Typical Schematic Layout for RO/NF

Residuals management

	GAC	IX	RO/NF
What residuals are produced?	Spent activated carbon • PFAS laden media Backwash • Suspended particles, fines, accumulated organics	Spent resin • PFAS laden resin Initial rinse water • High TDS	Reject brine • Concentrated brine w/ PFAS

How are the residuals typically disposed of	Spent activated carbon
	• Sent offsite for regeneration
	  • Thermal
	  • Solvent-based
	  • Supercritical water ox.
	• Landfill
	Backwash
	• Solids settled out, dewatered and sent to landfill; liquid discharged to sewer
		Spent resin
		• Sent offsite for thermal treatment
		• Landfill
		Rinse water
		• Captured for offsite disposal
		• Discharged to sewer
			Reject brine
			• Sent offsite for thermal treatment
			• Underground injection
			• Landfill

https://www.epa.gov/system/files/documents/2024-04/2024-interim-guidance-on-pfas-destruction-and-disposal.pdf#page=24.77

Comparing Removal Efficiencies

Number of Carbons	Group	PFAS Compound	Maximum Removal Efficiency (%) GAC	IX	NF	RO
10	Carboxylate	PFDA	97	>99	99	>99
9	Carboxylate	PFNA	>99	>99	99	>98
8	Carboxylate	PFOA	>99.8	99.3	99.9	99.9
7	Carboxylate	PFHpA	>99	>99	99	>99
8	Sulfonate	PFOS	99.7	99.7	>99.9	99.9
6	Sulfonate	PFHxS	99.5	>99	>99	>99
6	Ether Carboxylate	HFPO-DA (GenX)	93	99.3	-	>64.2
4	Sulfonate	PFBS	99.5	99.3	99.8	99.8

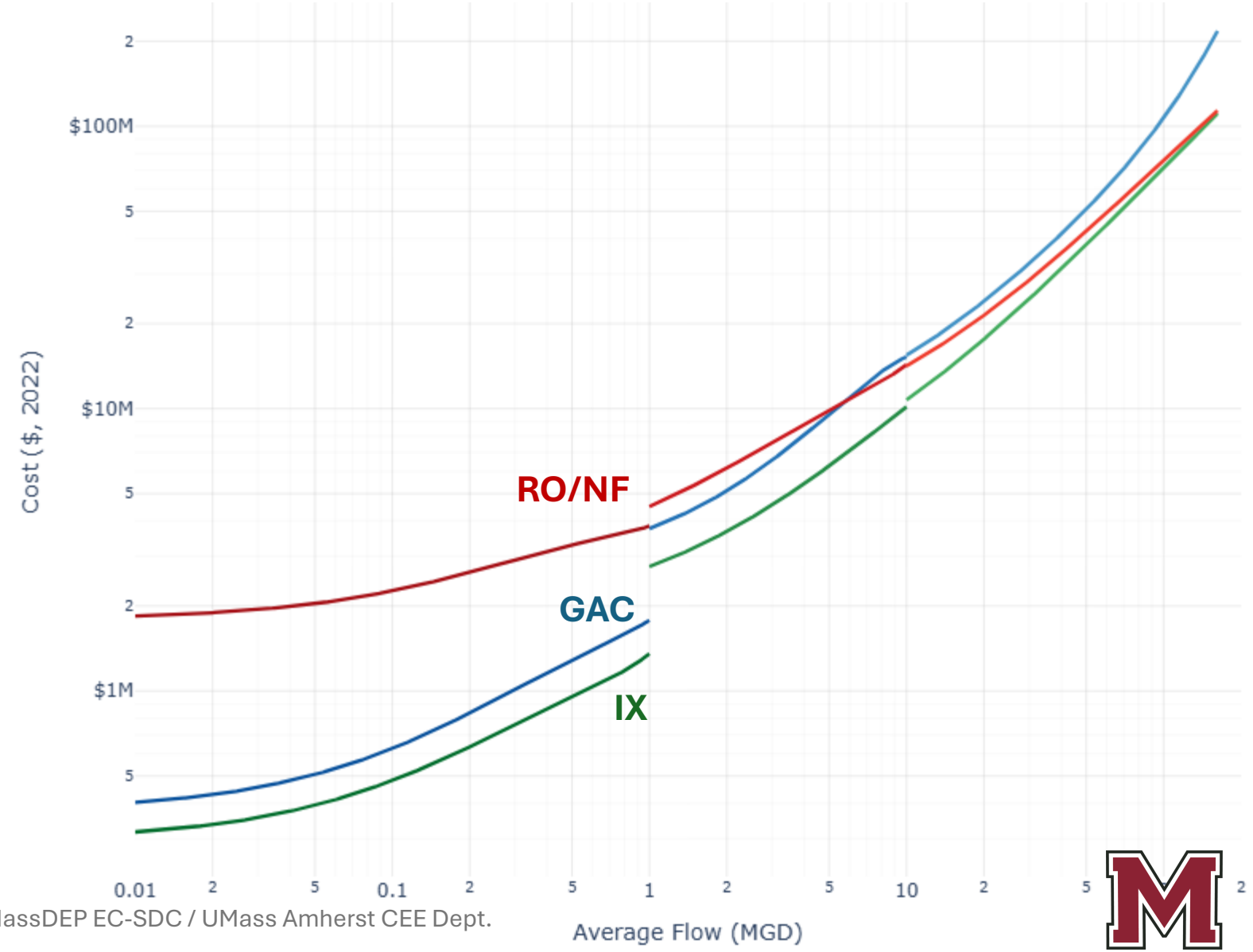
MassDEP PFAS6

- = no data; GAC = granular activated carbon; IX = ion exchange; NF = nanofiltration; RO = reverse osmosis

Comparing Capital Costs

- Assumptions
  - Water: Surface water
  - Cost: High
  - GAC: Pressure system, 60,000BV, non-haz
  - IX: 60,000BV, non-haz
  - RO: N/A

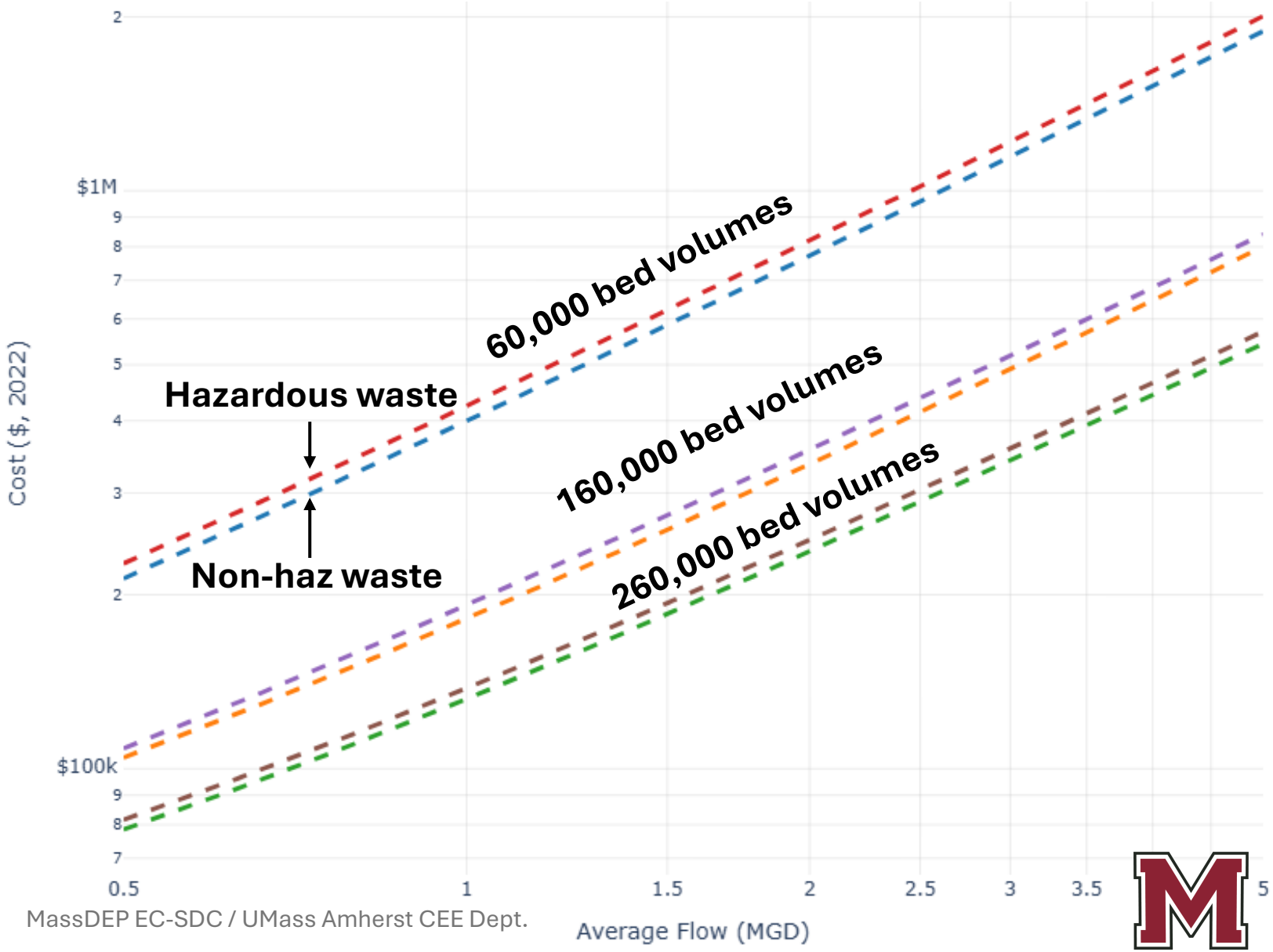
- Technology type, size of system, water source drive capital costs



Comparing Operating Costs

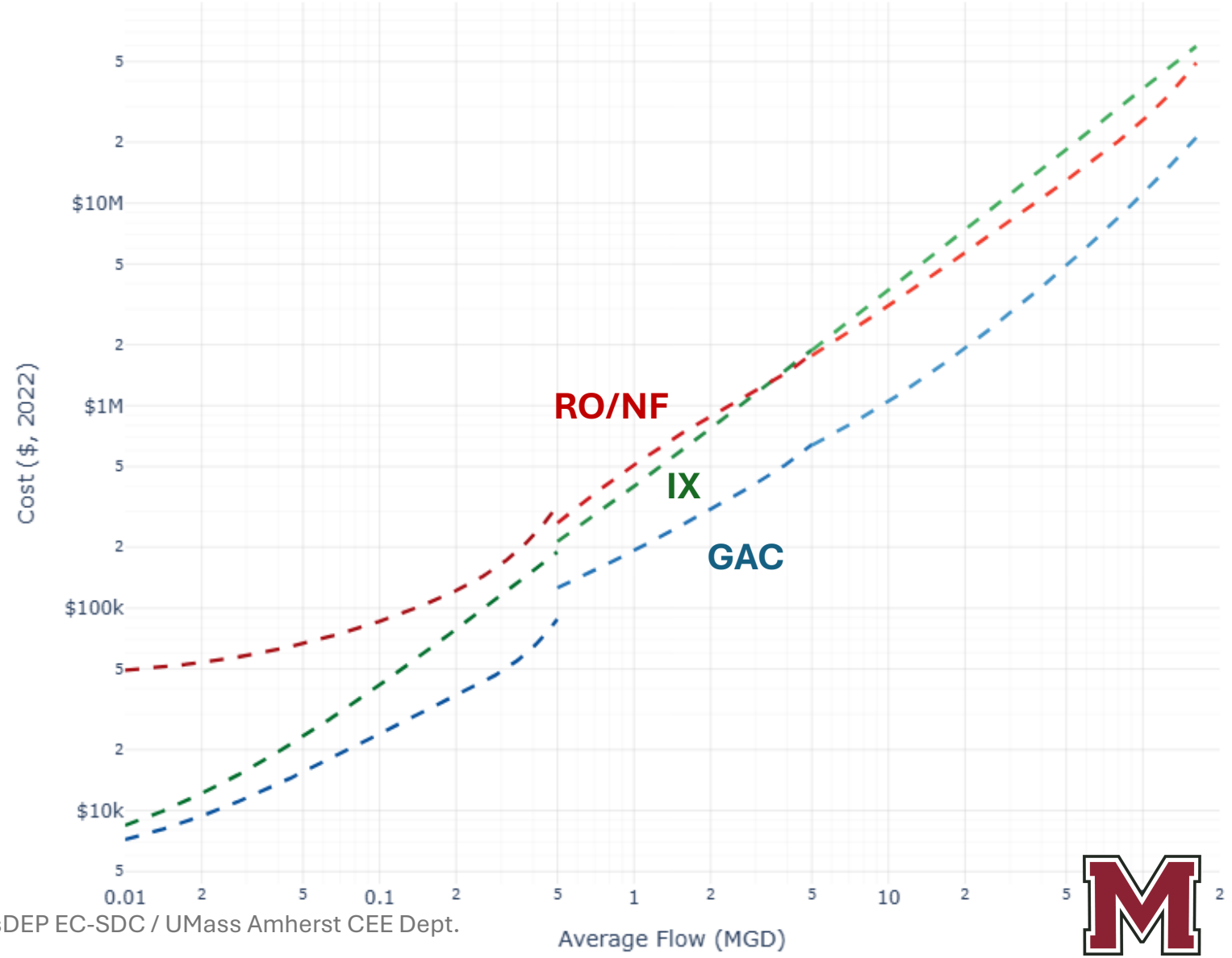
- Assumptions
  - Water: Groundwater
  - Cost: High
  - IX: Variable bed volumes, haz/non-haz waste classification

- Bed volumes, waste classification, system size are some parameters that drive OpEx costs



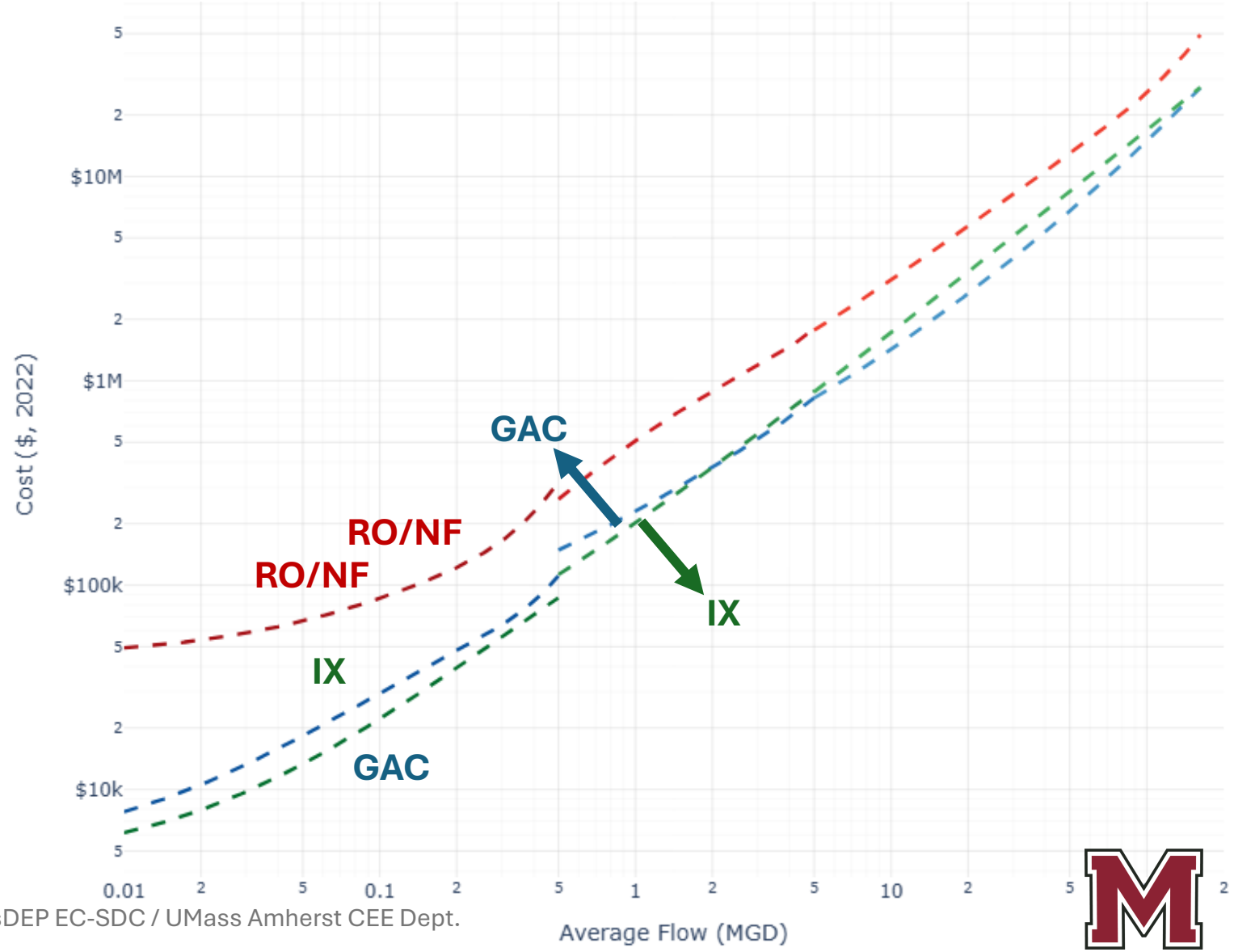
Comparing Operating Costs – same bed volumes

- Assumptions
  - Water: Groundwater
  - Cost: High
  - GAC: Pressure system, **60,000BV**, non-haz
  - IX: **60,000BV**, non-haz
  - RO: N/A
- Bed volumes, waste classification, system size are some parameters that drive OpEx costs



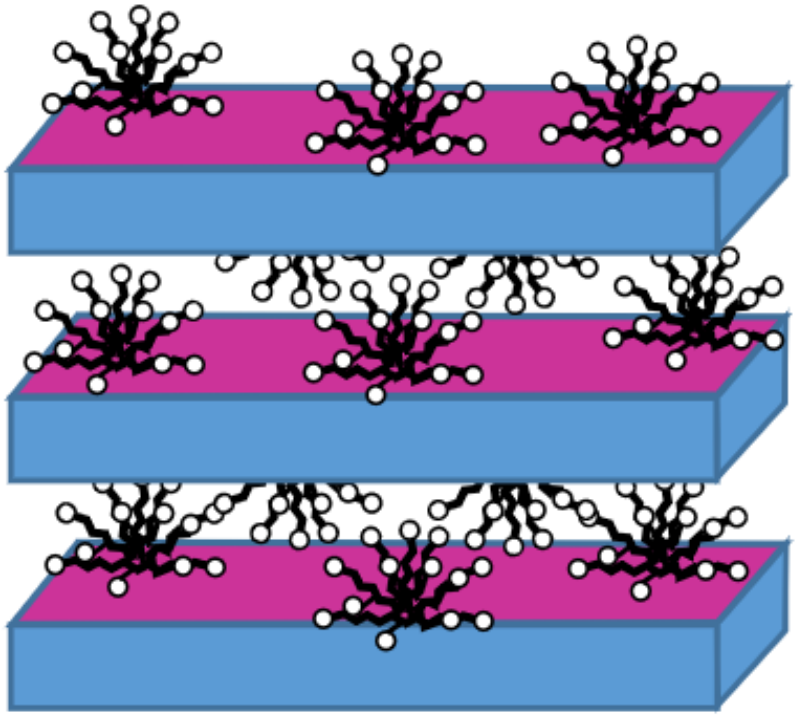
Comparing Operating Costs – different bed volumes

- Assumptions
  - Water: Groundwater
  - Cost: High
  - GAC: Pressure system, **30,000BV**, non-haz
  - IX: **140,000BV**, non-haz
  - RO: N/A
- Bed volumes, waste classification, system size are some parameters that drive OpEx costs



Other PFAS sorbents

- CETCO Fluoro-Sorb 200 & 400
  - Modified bentonite clay media



- CycloPure Inc. DEXSORB
  - Corn based adsorbent



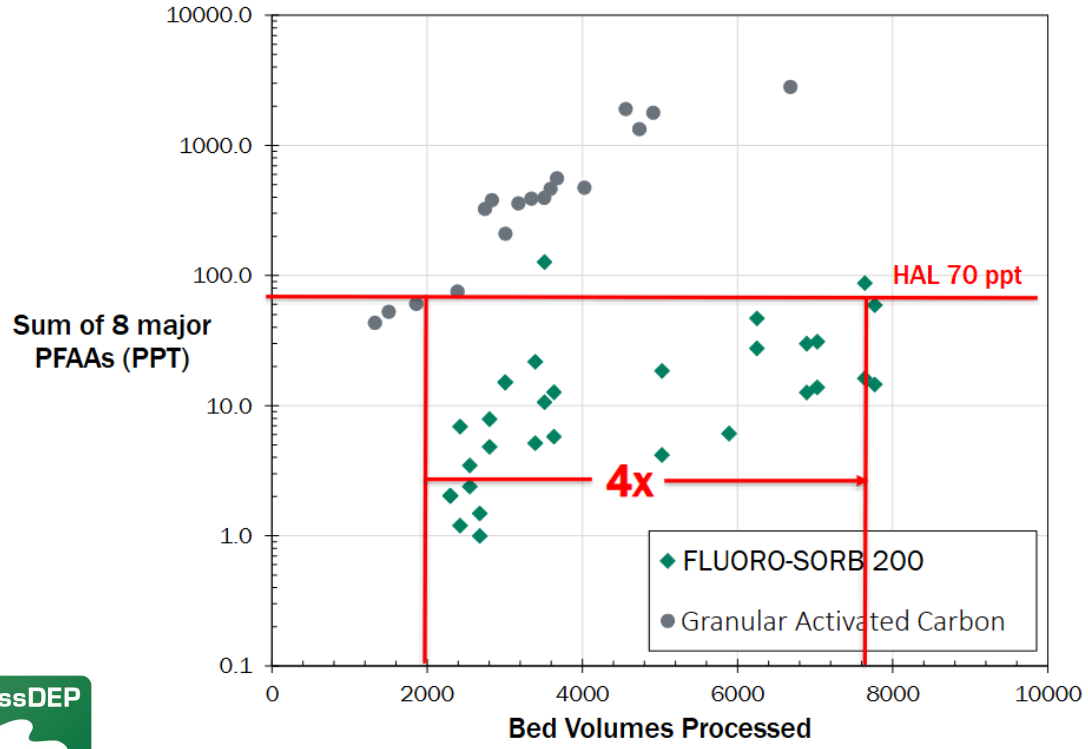
https://www.newmoa.org/wp-content/uploads/2024/08/GearyAdsorptionApril2024.pdf

https://cyclopure.com/dexsorb/

Other PFAS sorbents - Performance

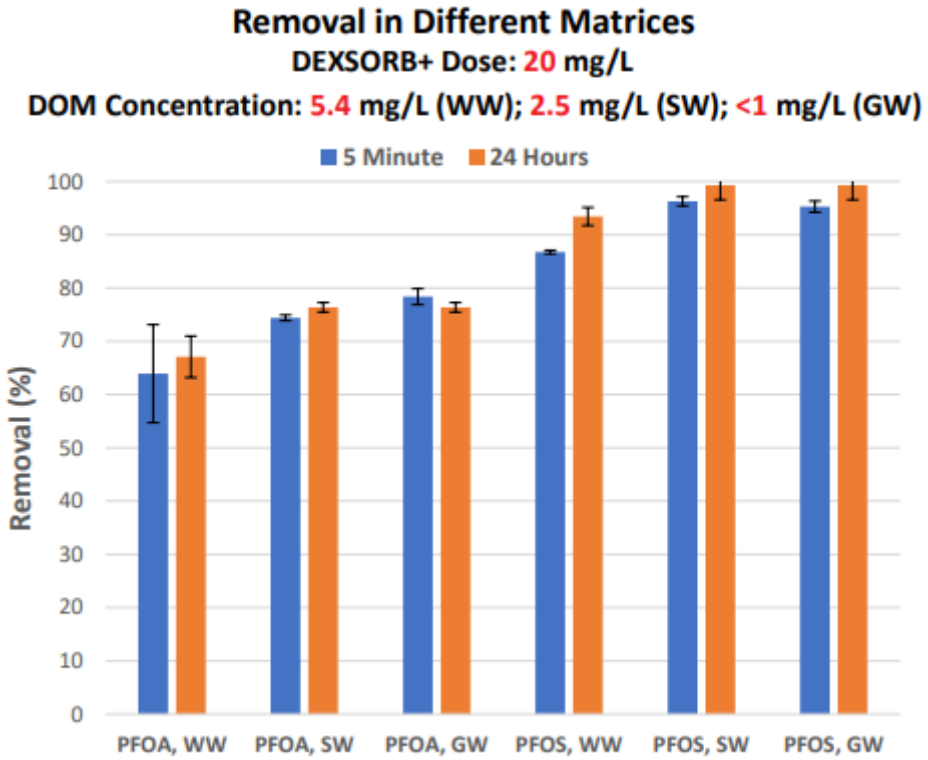
- CETCO Fluoro-Sorb 200 & 400
  - Modified bentonite clay media

PFAA REMOVAL – FLUORO-SORB® 200 ADSORBENT



https://www.newmoa.org/wp-content/uploads/2024/08/GearyAdsorptionApril2024.pdf

- CycloPure Inc. DEXSORB
  - Corn based adsorbent



https://www.ideals.illinois.edu/items/117595

Statewide List of Approved Technologies for PFAS removal

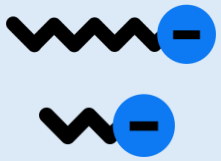
GAC	IX	RO	Other
AqueoUS Vets Inc.	Calgon Carbon Corp.	Osmonics Inc.	CETCO Mineral Tech.
Calgon Carbon Corp.	Dupont Water Solutions	Pall Corp.	Cyclopure Inc.
Carbon Activation Corp.	Evoqua Water Tech.		
Evoqua Water Tech.	Lanxess Corp.		
	Purolite Corp.		
	Resin Tech Inc.		

A PWS may apply to receive site specific approval for any technology in accordance w/ 310 CMR 22.04(1)

Comparison Matrix

	GAC	IX	RO/NF
PFAS Removal			
Water Matrix Sensitivity			
Capital Cost			
O&M Cost			
Residuals Produced			
Residual Management			
Full-Scale Experience			
Co-removal of Other Contaminants			
Pre/Post Treatment Needs			

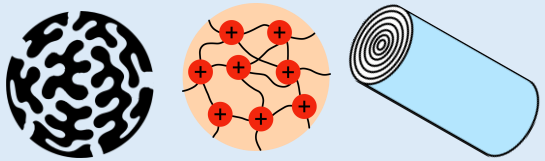
Key Takeaways



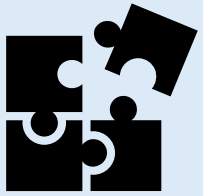
PFAS are persistent and linked to harmful human health effects



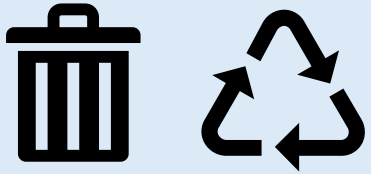
Regulatory compliance deadlines are approaching



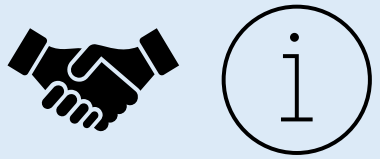
Three main proven treatment technologies are approved for PFAS removal



There is no one-size-fits-all solution; technology selection is site specific



Residuals management is a critical and evolving challenge



The EC-SDC Program is here to help!

Thank you!

Questions?



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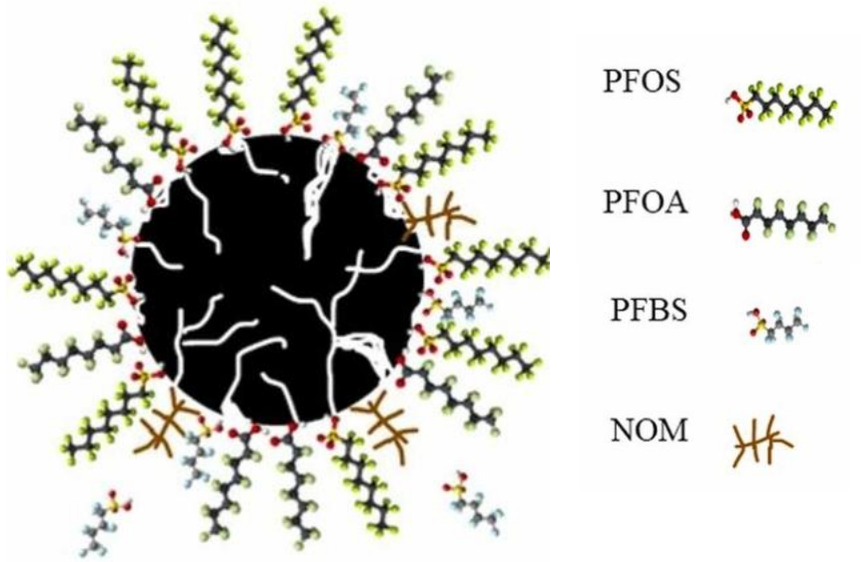
Cited References

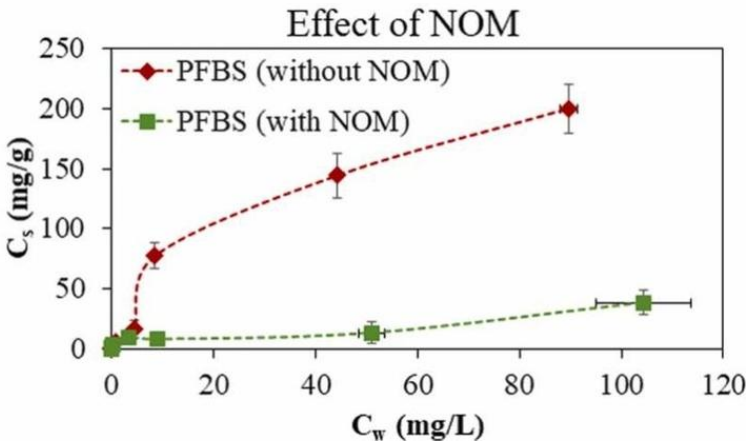
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Appendix

GAC – Raw Water Controls Performance

- Sensitive to natural organic matter (NOM)
  ↑ TOC/DOC = faster breakthrough
- Co-contaminants compete for sites on GAC
  - PFAS compete with each other
- Short-chain (<=C6) PFAS generally break through first
  - Carboxylates generally break through before sulfonates
- Pilot + monitor to determine media usage and breakthrough





(Meservey et al., 2026)

GAC – Design Parameters

- Empty Bed Contact Time (EBCT)
  - Current full scale PFAS EBCTs: 7.6 – 26 minutes; vendors typically recommend a minimum of 20 minutes
- Bed life
  - **Most accurately determined via piloting or RSSCTs**
- Residuals management
  - Media regeneration and backwash management
- Contactors in series or parallel
  - Lead-lag configuration common in pressure systems

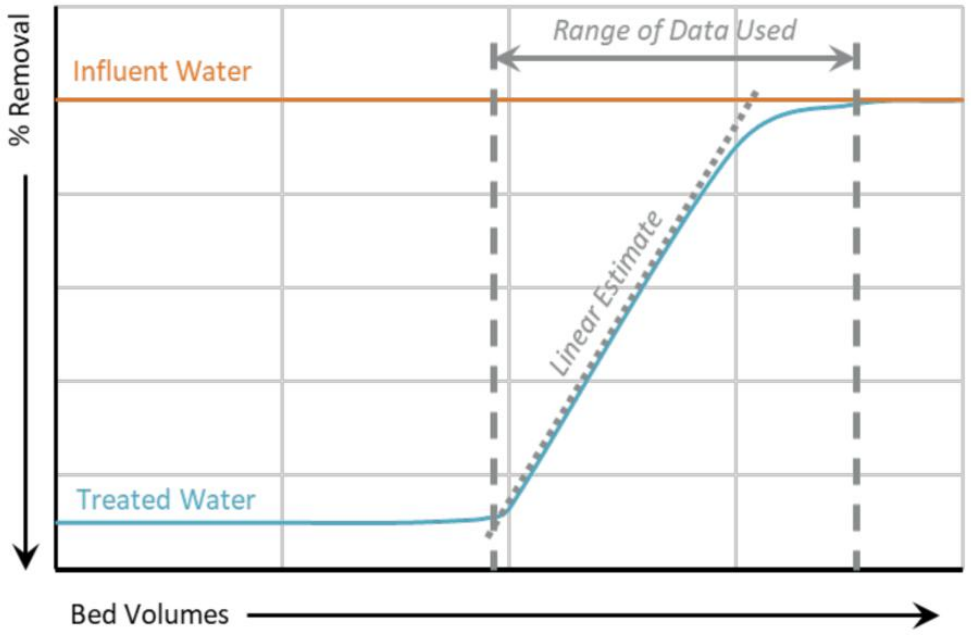
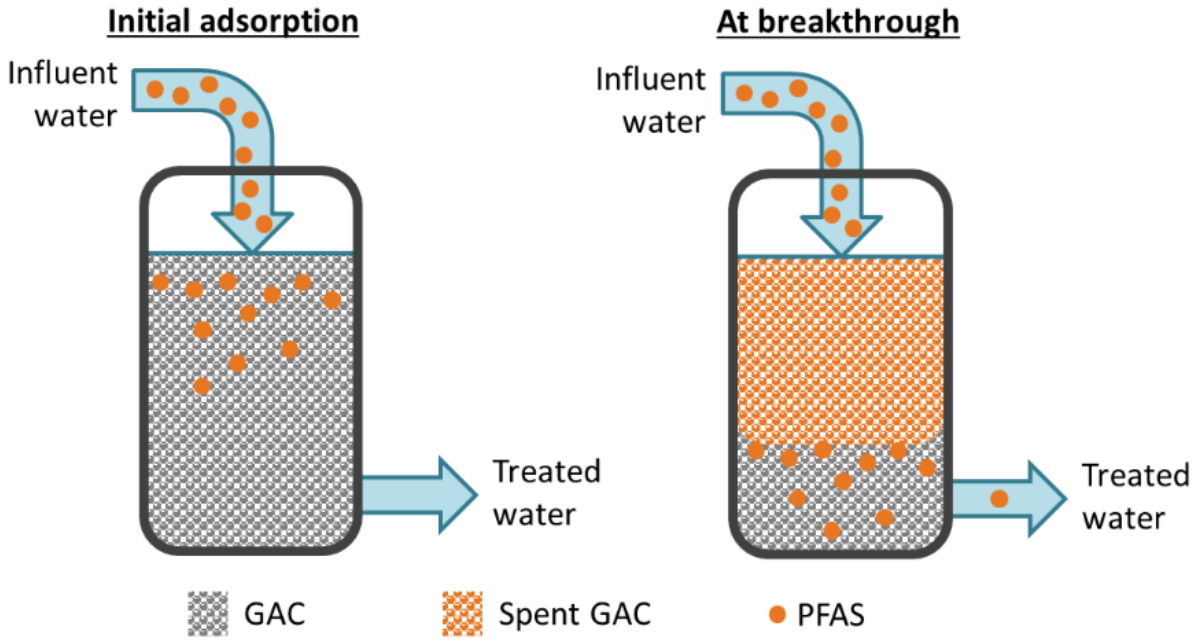


Figure 2-5. Linear Bed Life Estimate in Relation to a Typical Breakthrough Curve

https://www.epa.gov/system/files/documents/2024-04/2024-pfas-tech-cost_final-508.pdf

GAC – O&M and Residuals

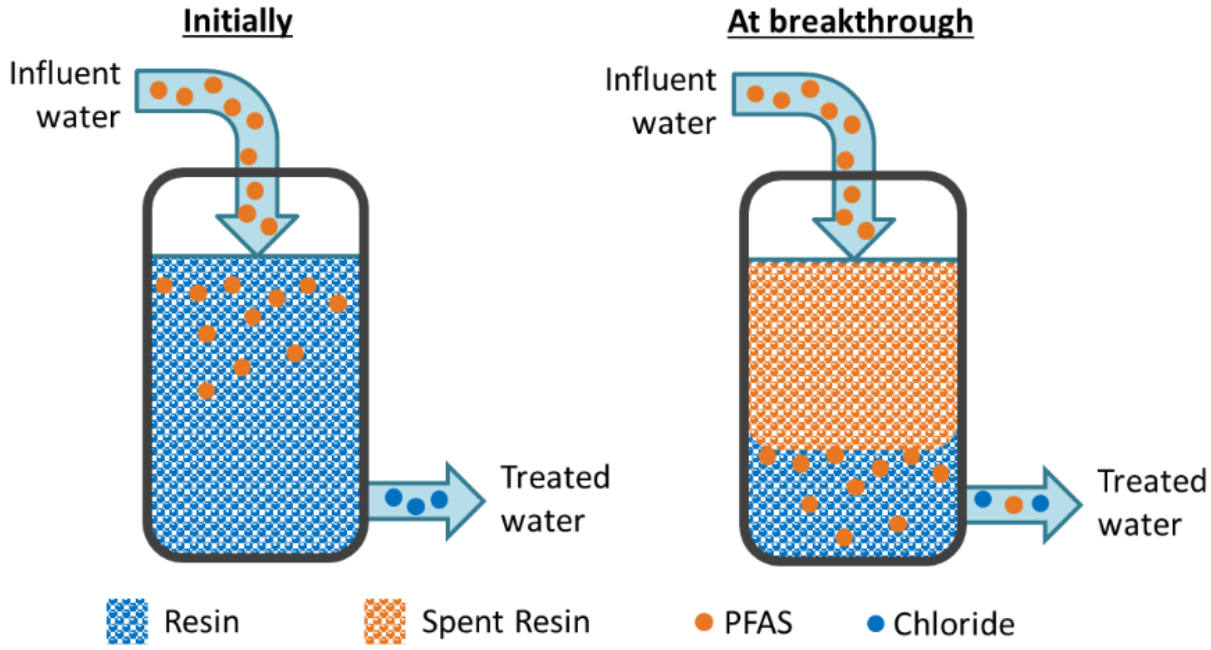
- Pretreat as needed
  - Solids, Fe, Mn
- Avoid pre-chlorinating ahead of GAC
- Fresh GAC may release fines / shift pH
  - Divert initial bed volume if necessary
- Spent GAC is typically regenerated offsite
- Intermittent backwashing required
  - Contains primarily suspended solids, **NOT** target contaminants



https://www.epa.gov/system/files/documents/2024-04/2024-pfas-tech-cost_final-508.pdf

IX – Raw Water Controls Performance

- Can also be impacted by NOM
- Competing anions dictate breakthrough
  - Nitrate, sulfate, bicarbonate, chloride
  - PFAS compete with each other
- Short-chain (<=C6) PFAS generally break through first
  - Carboxylates generally break through before sulfonates
- Pilot + monitor to determine media usage and breakthrough



https://www.epa.gov/system/files/documents/2024-04/2024-pfas-tech-cost_final-508.pdf

IX – Design Parameters

- Empty Bed Contact Time (EBCT)
  - Full scale data limited; Common vendor recommendation is 3-6 minutes; smaller
- Bed life
  - **Most accurately determined via piloting or RSSCTs**
- Residuals management
  - Media typically single use, disposal necessary
- # of vessels & configuration
  - Series or parallel; two vessels in series most common

Table 3-5. Estimated Parameter Values for IX Bed Life Equations

Parameter	IX Model Value
A_{PFAS}	-6.04
A_R	-198,242
B_{PFHxA}	212,867
B_{PFBS}	439,515
B_{PFHpA}	319,511
B_{PFHxS}	439,515
B_{PFOA}	390,787
B_{PFOS}	439,515

The parameter values result in the following order of breakthrough from earliest to latest, given a constant total influent PFAS concentration and target percent removal:

PFHxA > PFHpA > PFOA > PFBS = PFHxS = PFOS

https://www.epa.gov/system/files/documents/2024-04/2024-pfas-tech-cost_final-508.pdf

IX – O&M and Residuals

- Fresh IX may lower pH and raise corrosivity
- Avoid pre-chlorinating ahead of IX
- Resin should be rinsed during startup, replacement, or during downtime
  - Rinse water requires management
- Single use IX common for PFAS in drinking water
  - Spent IX is typically incinerated offsite
- Backwashing not recommended for IX resin for PFAS removal

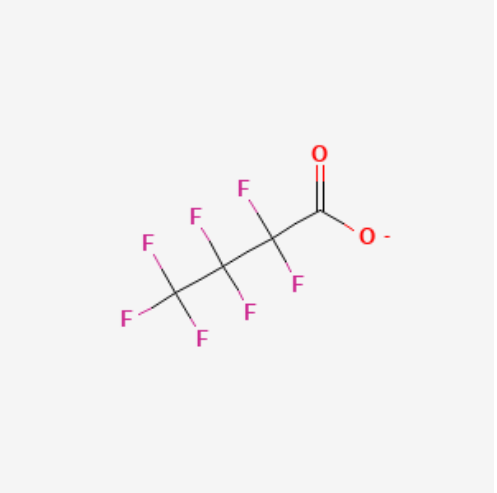
RO/NF – Membrane Selection Drives PFAS Removal

- Tighter membrane = higher PFAS removal
- RO generally reject more PFAS than NF (driven by membrane size)
- The smaller the PFAS, the smaller the membrane
- RO/NF generally do not show breakthrough
- Removal is steady over time

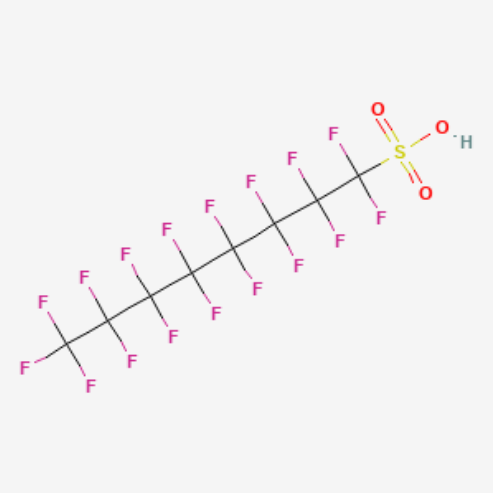
Table 4-1. Minimum Effective Ranges for RO/NF Membranes

Technology	Contaminant Size (microns)	Contaminant Molecular Weight (g/mol)
RO	0.0001 to ~0.0015	<100 to ~200
NF	0.001 to ~0.006	200 to 1,000

~ = approximately; g/mol = grams per mole; NF = nanofiltration; RO = reverse osmosis
Sources: Bergman et al., 2012; DuPont, 2021; Duranceau and Taylor, 2011



PFBA – C4, carboxylate; 214 g/mol



PFOS – C8, sulfonate; 500 g/mol

RO/NF – Design Parameters

- Pretreatment and cleaning requirements
  - Fouling from suspended solids, NOM, calcium carbonate, silica, etc.
- Membrane type
- Flux rate
  - Higher quality feed = higher possible flux
  - Higher flux can accelerate fouling
- Recovery rate
  - Higher recovery rate = higher TDS in reject water
- esidual management options

Table 4-6. Recovery Rates for PFAS Treatment Reported in the Literature

Study Scale and Membrane Type	Source Water	Recovery Rate	Source(s)
Full Scale RO	WWTP	85%	Thompson et al., 2011
Full Scale RO	WWTP	85%	Dickenson and Higgins, 2016
Full Scale RO	WWTP	80%	Dickenson and Higgins, 2016
Full Scale RO	Surface	90%	Wetzel, 2021; WHNT News, 2019
Pilot Scale NF	Ground	78%	Franke et al., 2019
Full Scale RO	Surface	85 to 92%	Dowbiggin et al., 2021
Bench Scale NF	Ground	84%	Boonya-Atichart et al., 2016

NF = nanofiltration; RO = reverse osmosis; WWTP = potable reuse facility receiving water from wastewater treatment plant

https://www.epa.gov/system/files/documents/2024-04/2024-pfas-tech-cost_final-508.pdf

RO/NF – O&M and Residuals

- Use prescreen / cartridge filtration
- Control scaling w/ acid or anti-scalant
- Finished water may be corrosive, blend or stabilize if needed
- Pilot to determine fouling and scaling risk
- Concentrate management
  - Assuming 95% removal efficiency, concentrate contains approx. 6-12x concentration of influent
  - High [PFAS] in residuals limit disposal options