Technologies for Effective Treatment of Ultra-short Chain PFAS

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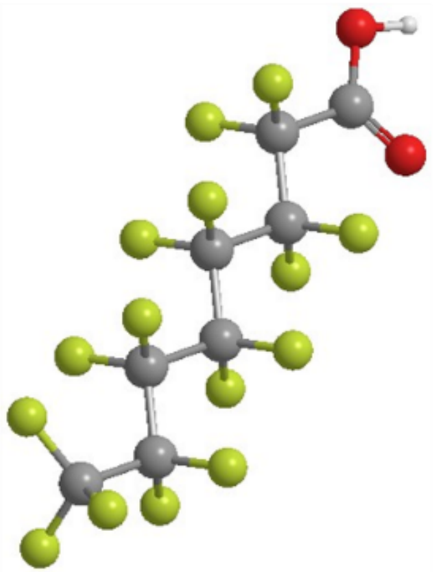
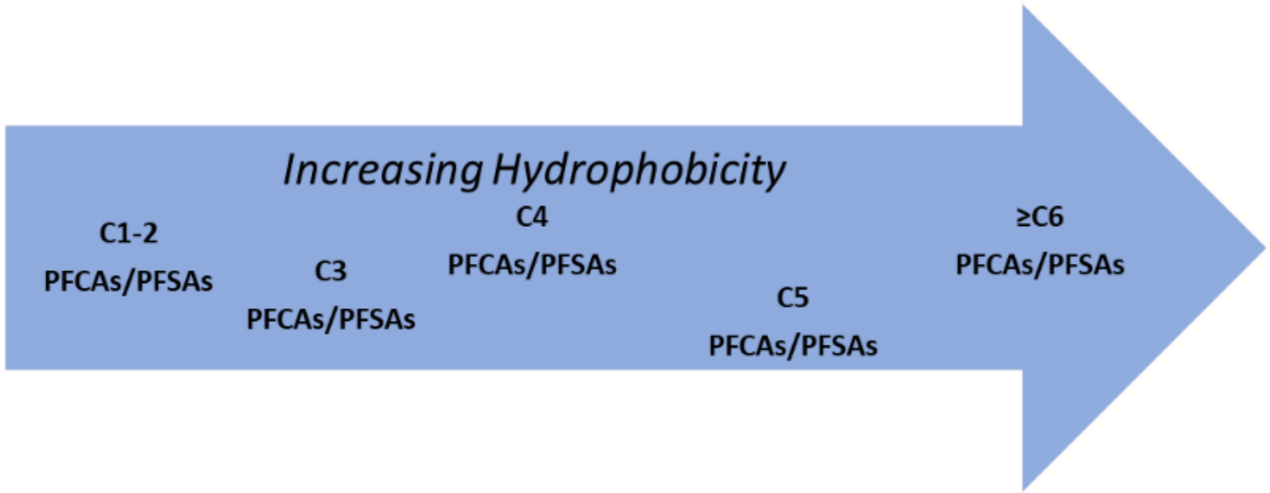
Introduction

- Objectives
  - Develop a system for effective treatment of PFAS, **including ultra-short chains**, and demonstrate the capability through pilot testing
  - Minimize energy requirements and waste generated through treatment
- Technology Screening
  - ITRC - Three field-implemented technologies for PFAS (GAC, AIX, and RO)
  - Limited data on treating ultra-short chain species

PFAS Classification for This Paper

	Ultra-short	Short	Long
PFCAs	≤ 4 carbons	≤ 7 carbons	≥ 8 carbons
PFSAs	≤ 3 carbons	≤ 5 carbons	≥ 6 carbons





Granular Activated Carbon (GAC)

Applicability:

- Effectively removes long chain species from water
- Ability to reactivate (offsite)
- High volume reduction (up to 100,000:1)

https://www.tehrantimes.com/news/446192/What-is-activated-carbon-or-activated-charcoal

Limitations:

- Effectiveness can decrease as chain length decreases
- Competition with natural organics and other contaminants
- Longer empty bed contact time (EBCT) requires large footprint

Long chain	Short chain	Flow rate	Reliability	Volume reduction
✓	L	✓	✓	✓

Ion Exchange (AIX)

Applicability:

- Effectively removes PFAS from water
- High volume reduction for long chain species (300,000:1)
- Lower EBCT than GAC; smaller equipment footprints

https://waterfilterssupplier.com/ion-exchange-resin/

Limitations:

- More expensive media unit cost; Media density may result in higher pumping costs
- Sensitive to site-specific geochemistry
- Regeneration is not widely used for PFAS and requires a regenerant solution made up of solvent, water and brine

Long chain	Short chain	Flow rate	Reliability	Volume reduction
✓	✓	✓	L	✓

Membranes (RO)

Applicability:

- Reverse osmosis (RO) proven for PFAS removal; Nanofiltration (NF) possible for PFAS removal
- High rejection of PFAS (~95-99+%)
- Equipment sizing not dependent on PFAS concentrations for total PFAS < 50 ug/L

https://www.toray.us/products/membranes/mem_0010.html

Limitations:

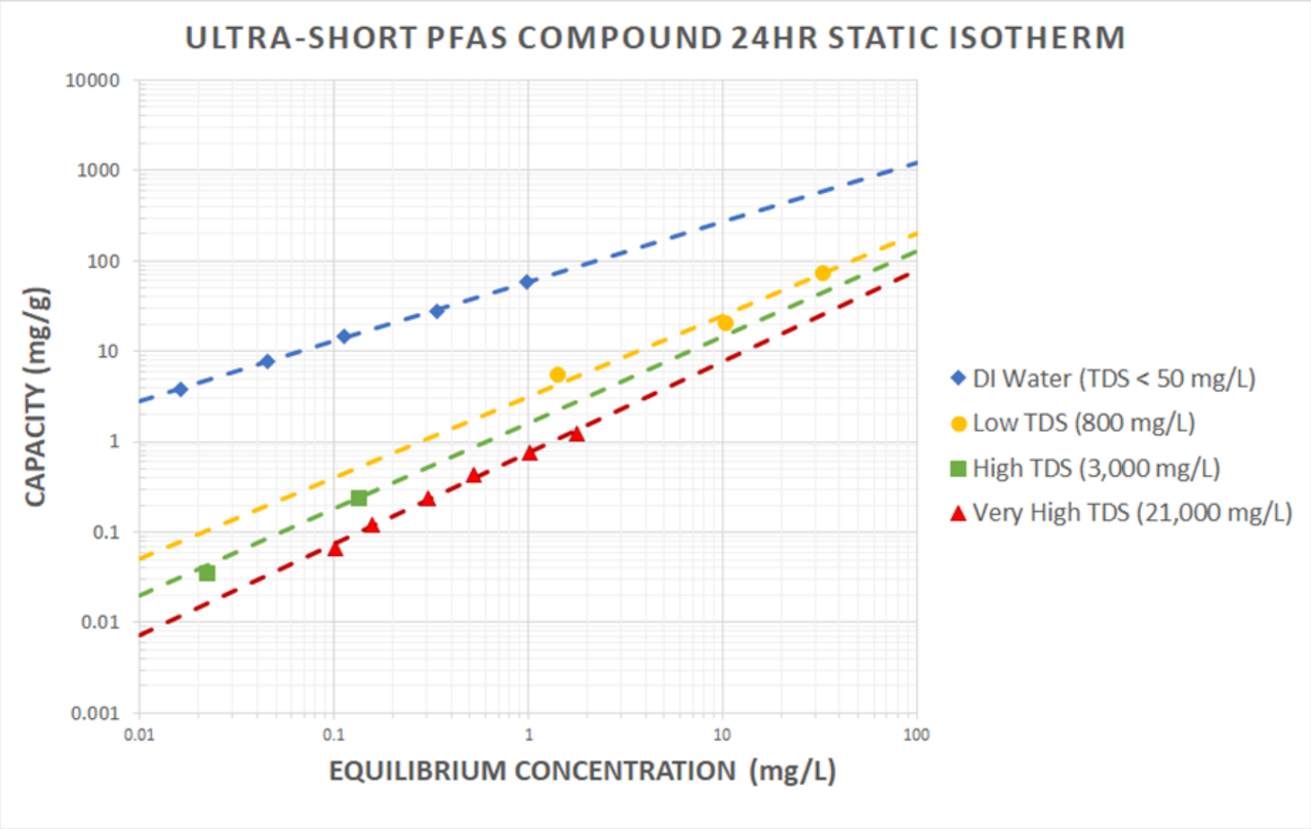
- Volume reduction is small compared to adsorption (3:1 to 7:1) depending on other constituents in the water
- Higher capital and operating costs
- Susceptible to fouling and requires robust pre-treatment

Long chain	Short chain	Flow rate	Reliability	Volume reduction
✓	✓	✓	✓	L

Project Target Streams

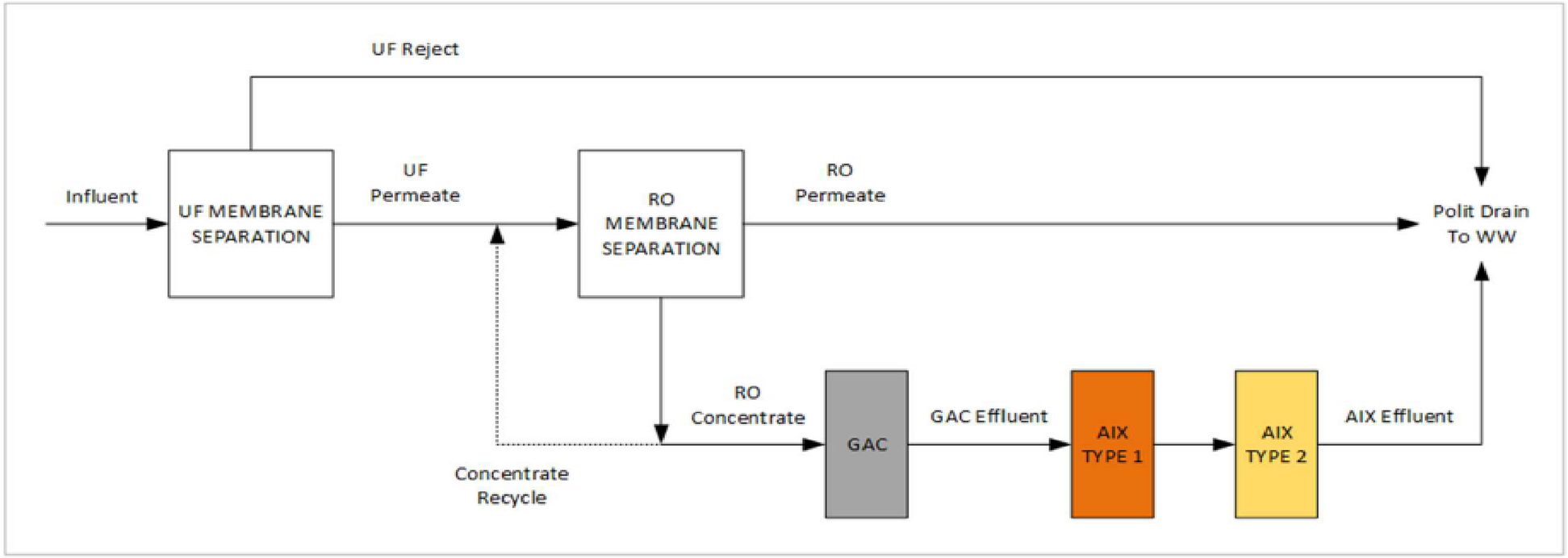
- Stormwater – Runoff with minimal non-PFAS constituents and relatively low levels of PFAS
- Remediation groundwater – Low non-PFAS constituents and elevated levels of PFAS
- Industrial wastewater – Higher concentrations of non-PFAS constituents and elevated levels of PFAS

Effects of TDS on AIX Resin



- PFAS removal is speculated to be predominantly via ion exchange
- Influent concentration and competing anions are most significant factors in resin's ultra-short chain capacity

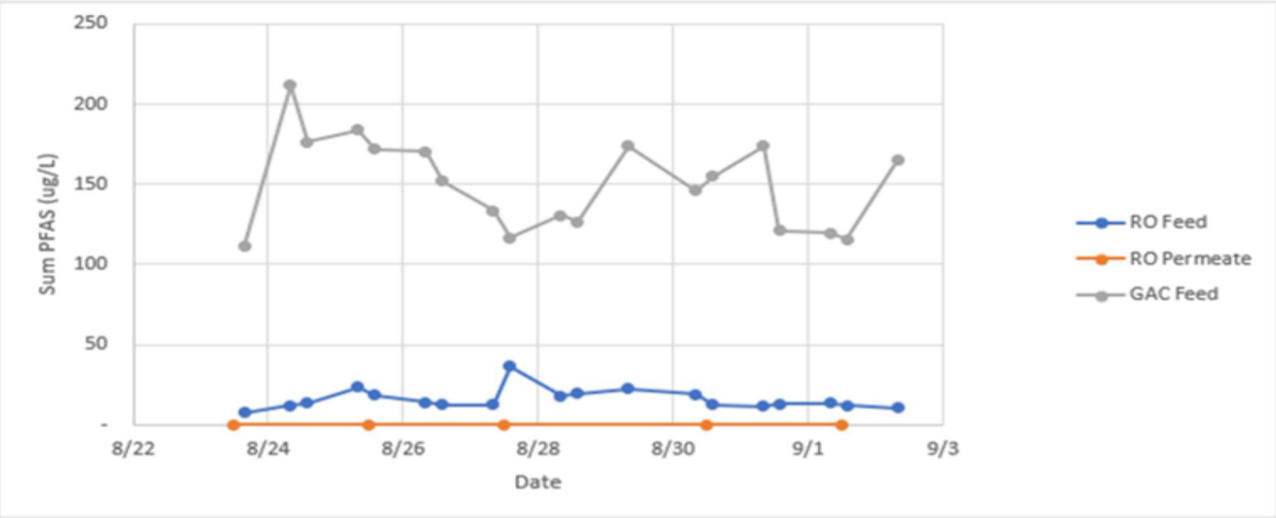
Pilot Configuration

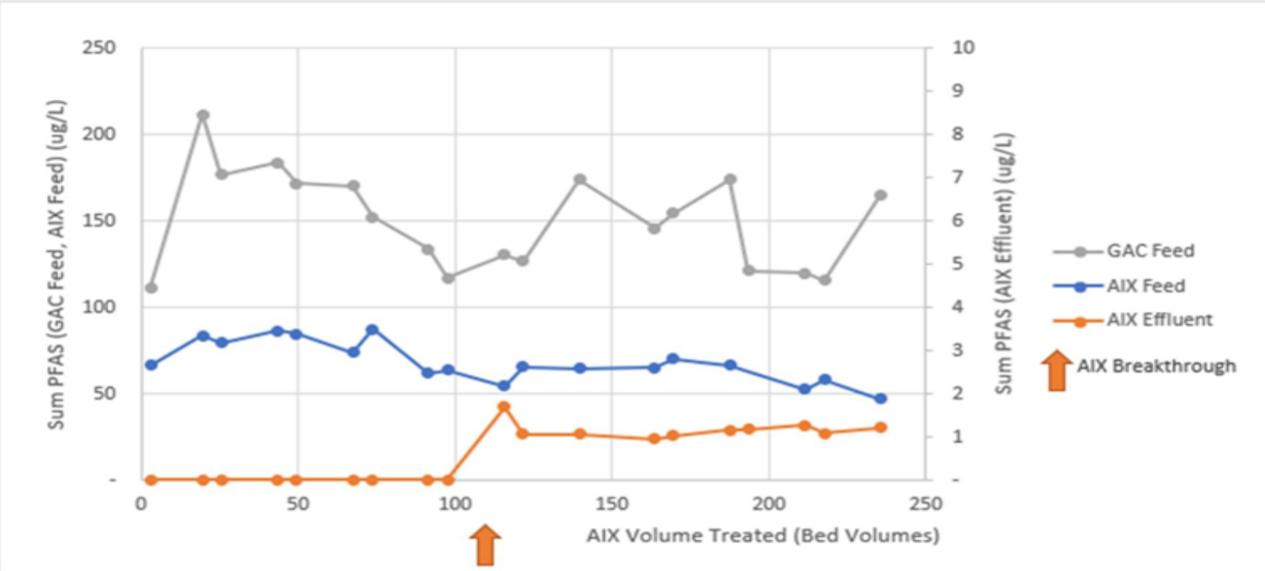


*Functional groups affect capacity and ability to regenerate

1. Pre-treat with UF
2. Concentrate with RO
3. GAC for TOC and long-chain PFAS removal
4. AIX resin: macroporous, SBA with different functional groups for short/ultrashort chain PFAS removal*

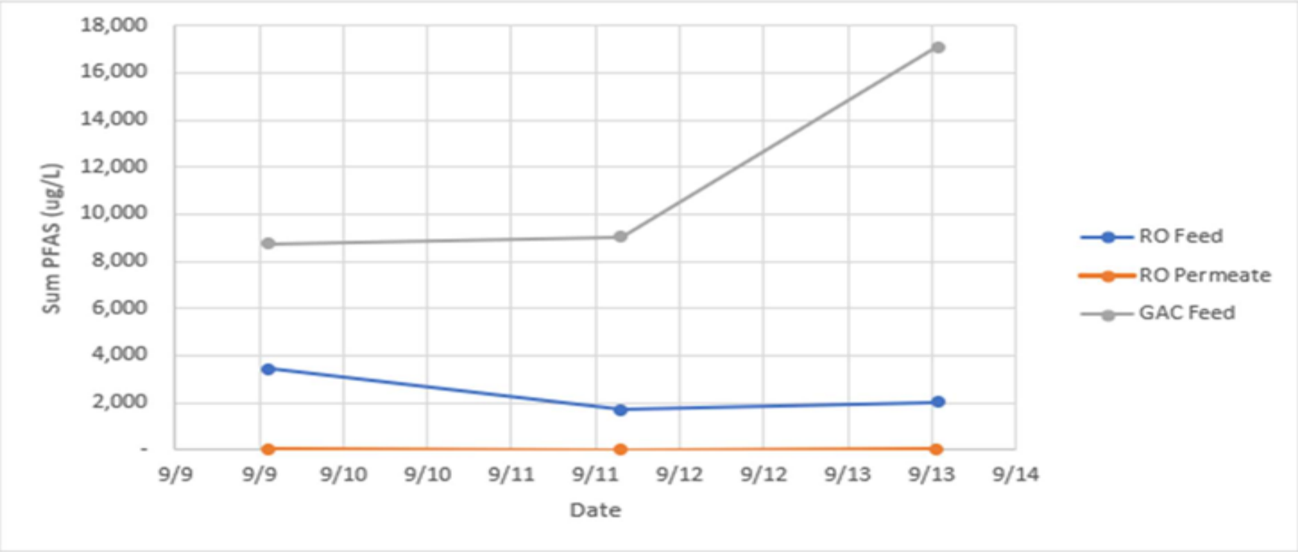
Stormwater Results

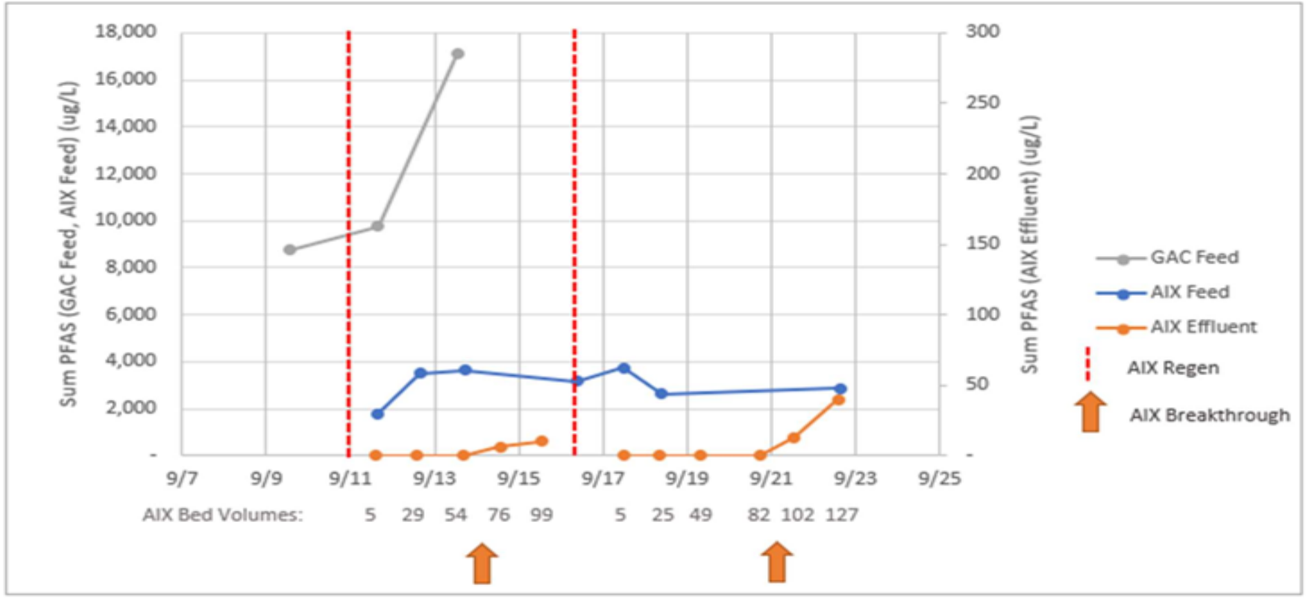




- TDS ~ 500 mg/L, PFAS ~ 25 ug/L
- RO permeate below detection limit
- GAC ~ 50% PFAS removal
- IX effluent PFAS below detection limit to 100 bed volumes

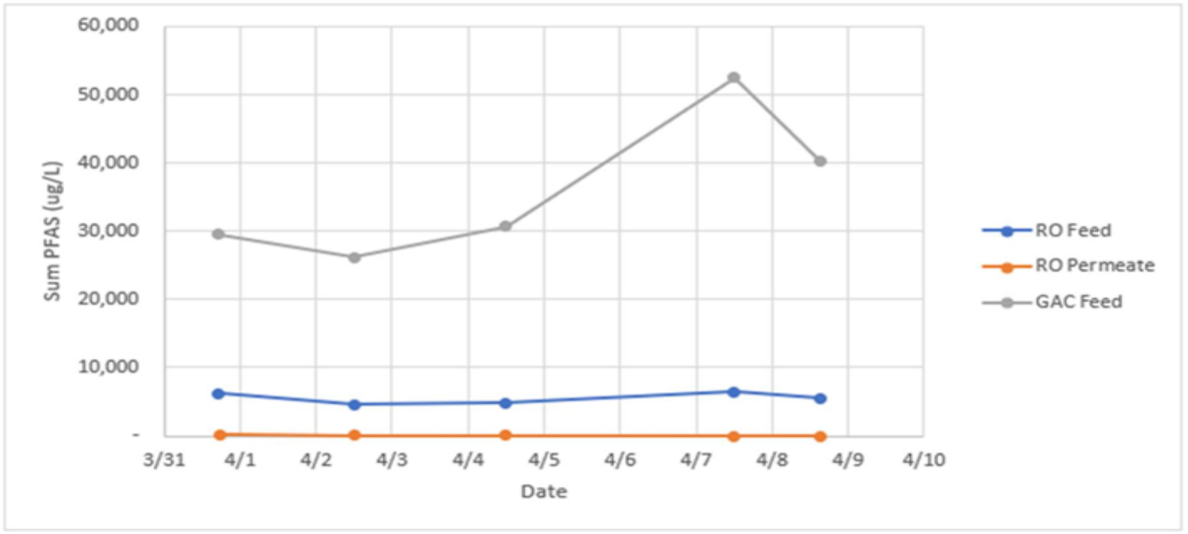
Groundwater Results

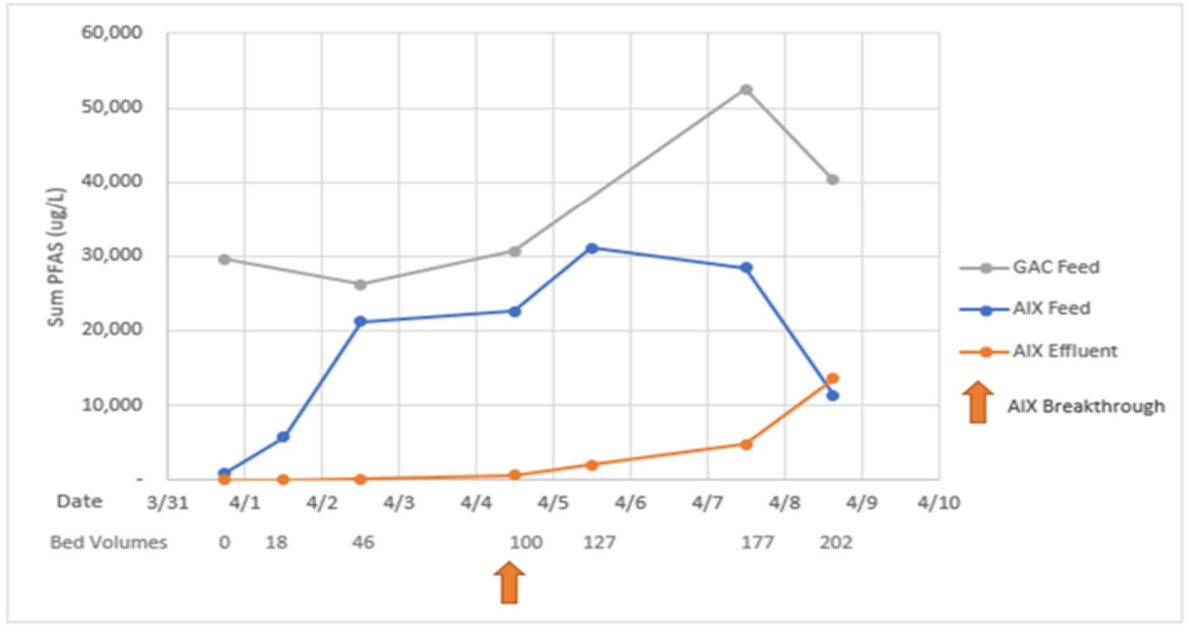




- TDS ~ 250 mg/L, PFAS ~ 3,000 ug/L
- RO permeate average 6.4 ug/L (99.8% rejection)
- GAC ~ 85% PFAS removal
- IX effluent PFAS below detection limit to 80 bed volumes
- Similar TDS range, PFAS 120x higher, IX breakthrough only slightly lower due to much higher capacity than stormwater

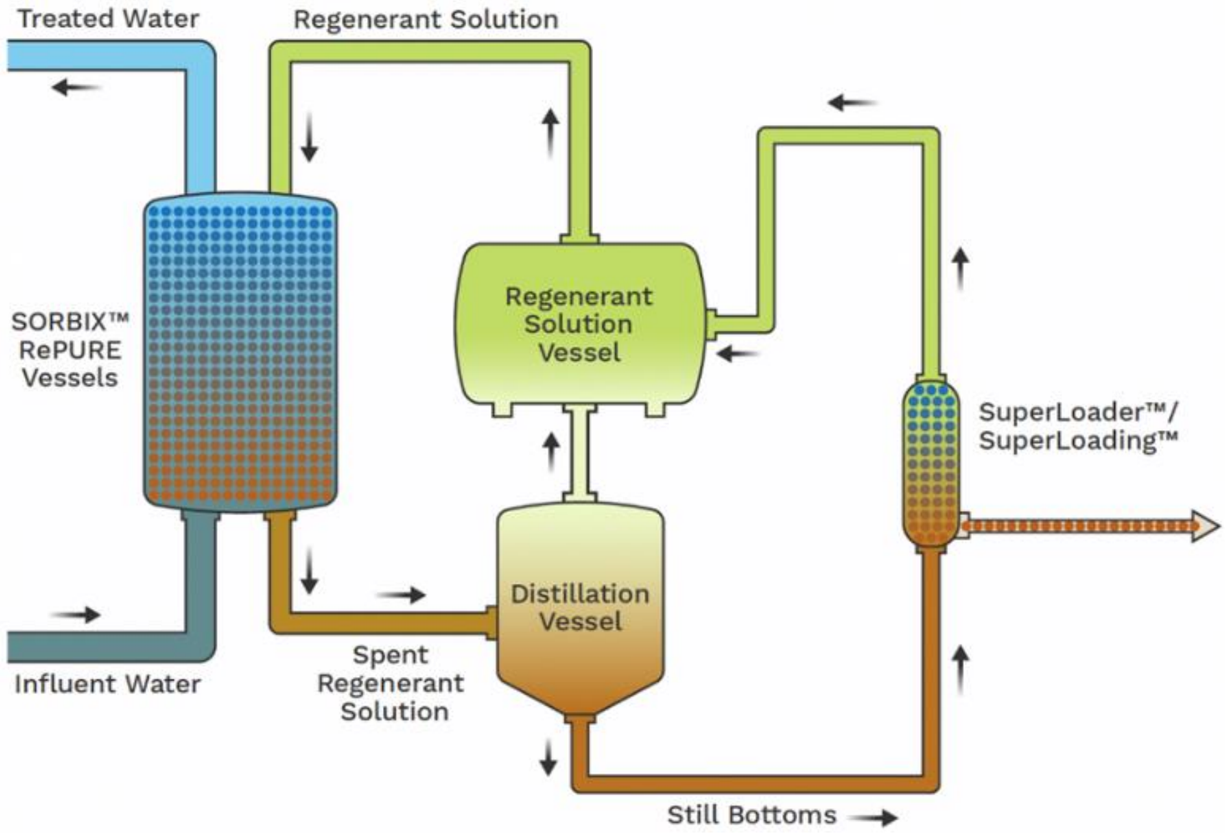
Wastewater Results





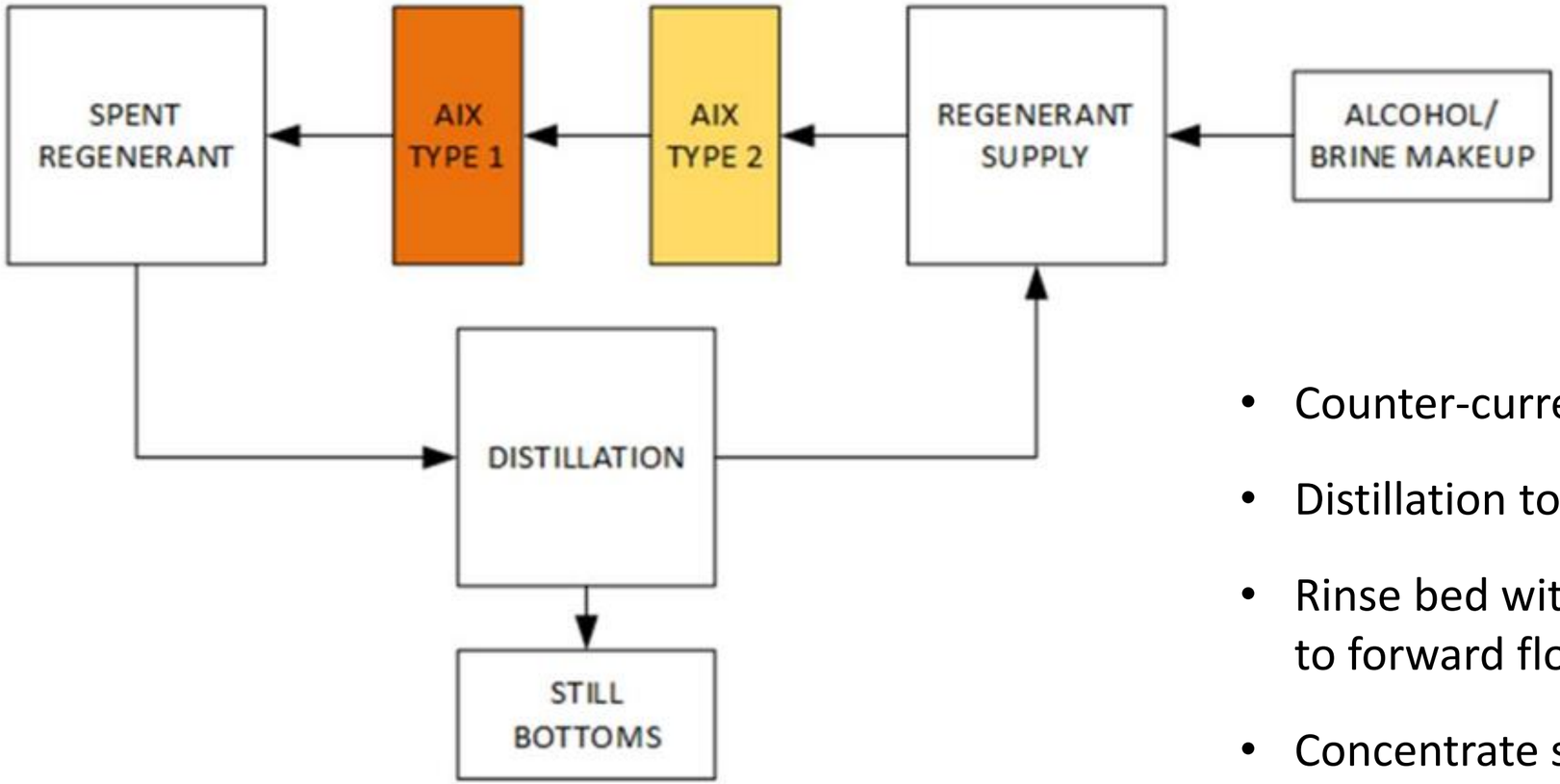
- TDS ~ 2800 mg/L (high sulfates), PFAS ~ 5,500 ug/L
- RO permeate below detection limits
- GAC ~ 33% PFAS removal (lower removal due to higher ultra-short chain composition)
- IX effluent PFAS below detection limit to 75 bed volumes
- TDS 10x higher than groundwater, resulted in IX capacity 5x higher than groundwater

AIX Regeneration Process



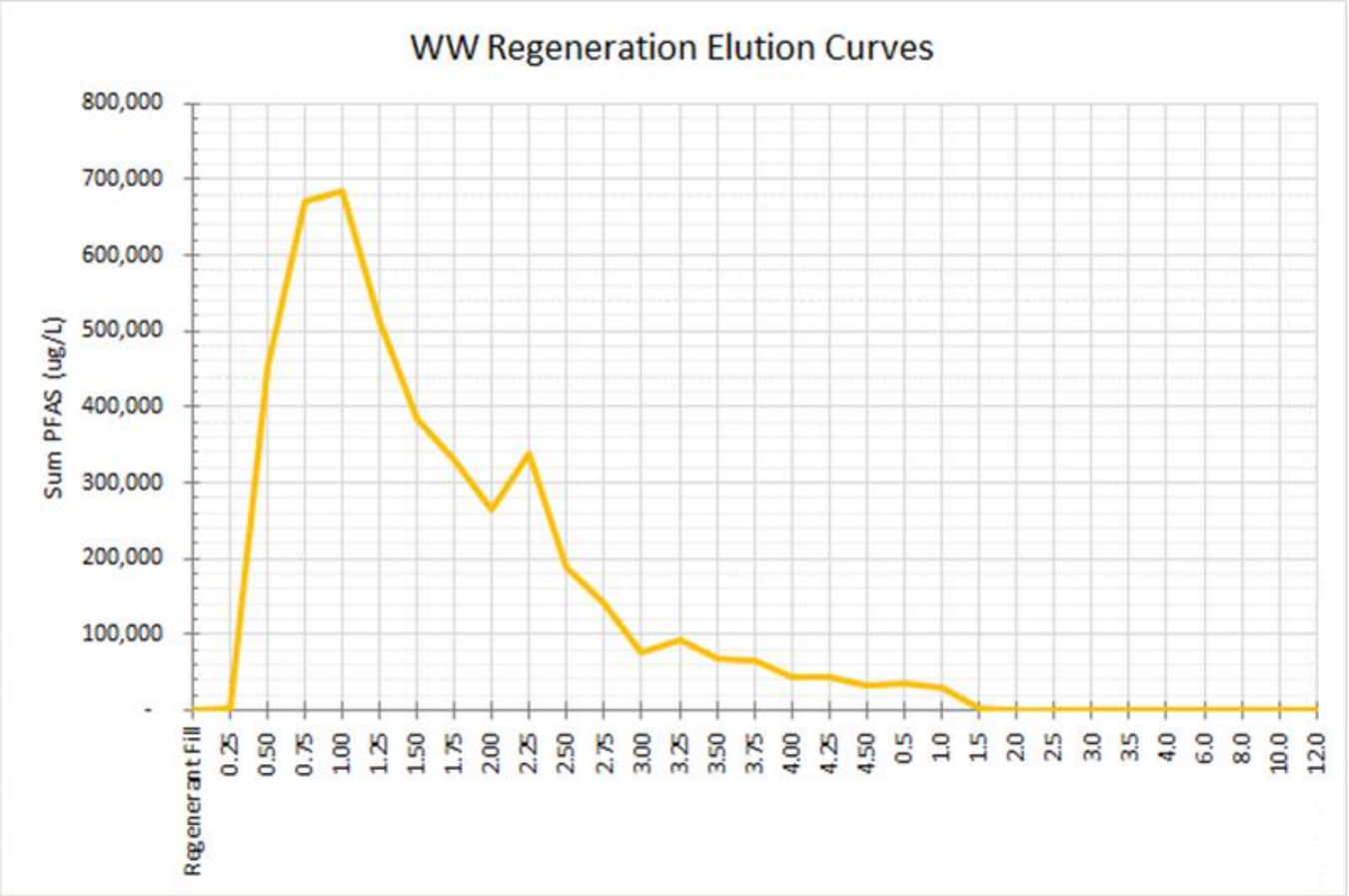
- Used to regenerate ion exchange media and reduce residual waste volumes
- Removes PFAS and recycles regenerant solution
- Reduces waste generation

Regen Test Configuration



- Counter-current flow regeneration
- Distillation to recover alcohol for reuse
- Rinse bed with RO permeate and return to forward flow
- Concentrate salt/PFAS solution in still bottoms for additional testing and disposal

Regen Test Results



- Initial peak @ 1 bed volume of regenerant
- 75% PFAS mass removed @ 2 BV of regenerant
- Target 5 BV of regenerant to get > 95% PFAS removal from resin

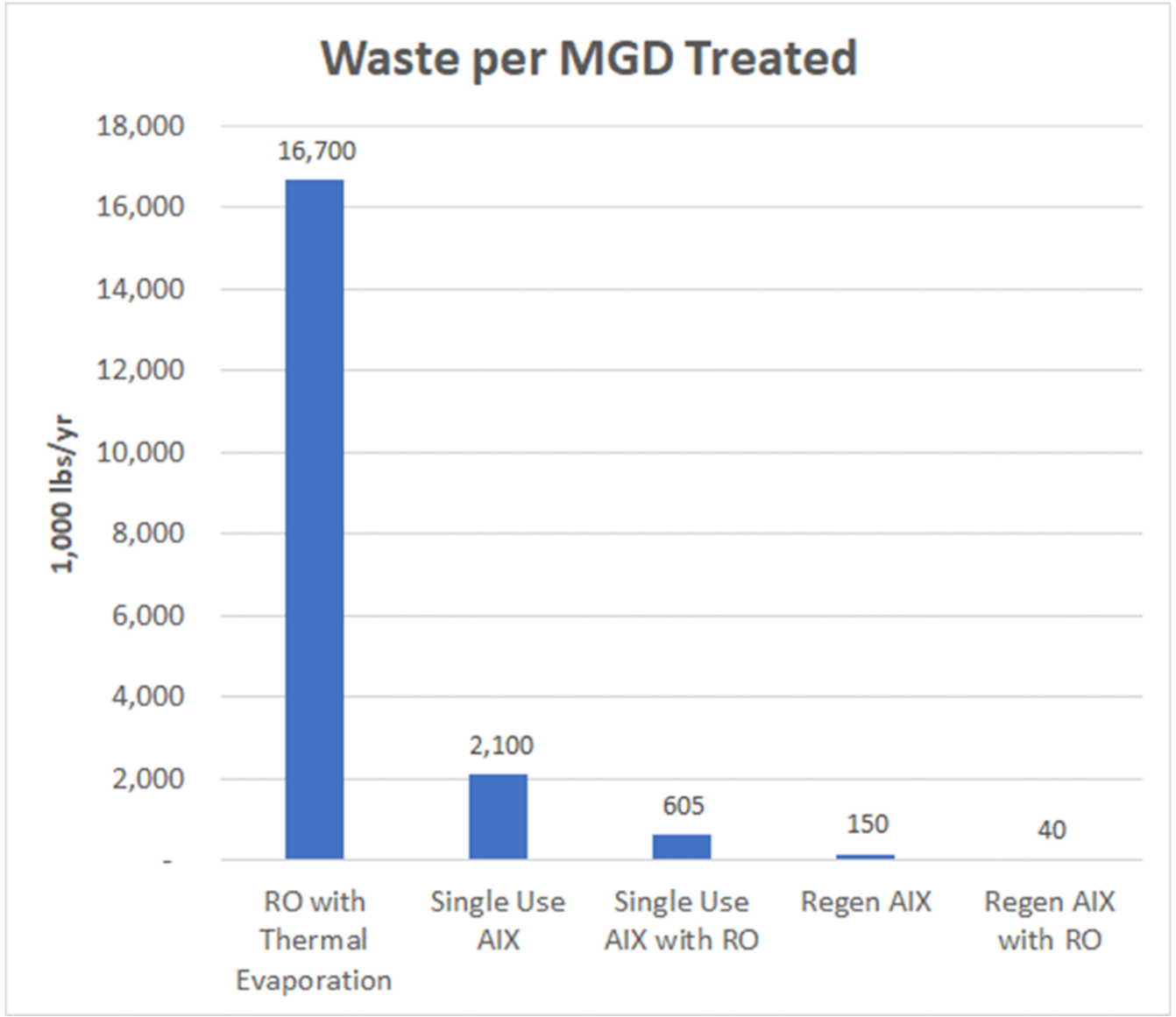
Residual Waste Volumes

Compare 5 unique scenarios: Single-Use IX (with and w/o RO), Regen IX (with and w/o RO), RO plus Thermal Evaporation

Design Basis

	Units	AIX Resin	AIX Resin w/RO
Flow Rate	MGD	1.0	1.0
Total Dissolved Solids (TDS)	mg/L	2,750	2,750
PFAS Concentration	mg/L	1.0	1.0
RO Recovery	percent	0%	85%
Flow Rate to AIX Vessels	gpm	695	105
AIX EBCT	minutes	30	30
AIX Bed Volume	gal	20,850	3,150
	ft3	2,790	420
TDS to AIX Vessels	mg/L	2,750	18,333
PFAS Concentration to AIX Vessels	mg/L	1.0	6.7
Capacity (mg PFAS/g AIX Resin)	mg/g	1.5	5.0
Bed Volumes to AIX Breakthrough	BVs	1,000	520

Residual Waste Volumes



- Use of thermal evaporation results in highest residual (waste) generation attributed to non-PFAS constituents
- Low capacity for ultra-short chain PFAS results in significant single-use AIX resin waste and high raw material cost
- Regeneration minimizes residuals, especially when using SuperLoading process

Conclusions

- AIX and RO are effective at removing ultra-short chain PFAS
- Competing anions in the target water stream reduce the capacity of the AIX resin when treating ultra-short chain PFAS
- Concentrating the PFAS using RO upstream of the AIX increases the capacity when treating ultra-short chain PFAS
- Regenerating AIX resin significantly reduces the volume of residual waste generated when treating ultra-short chain PFAS