REMTEC & EMERGING CONTAMINANTS SUMMIT

OCTOBER 3-5, 2023

TECHNOLOGIES FOR EFFECTIVE TREATMENT OF ULTRA-SHORT CHAIN PFAS

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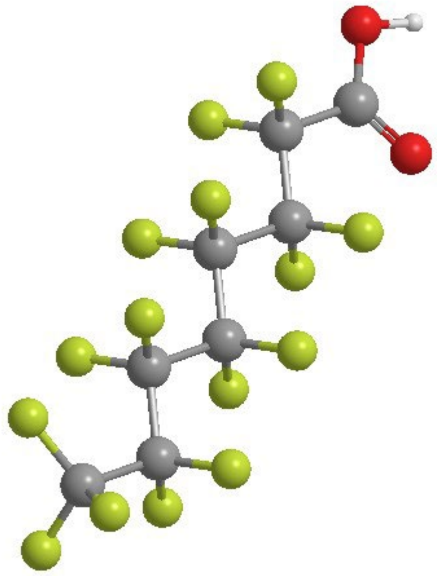
INTRODUCTION

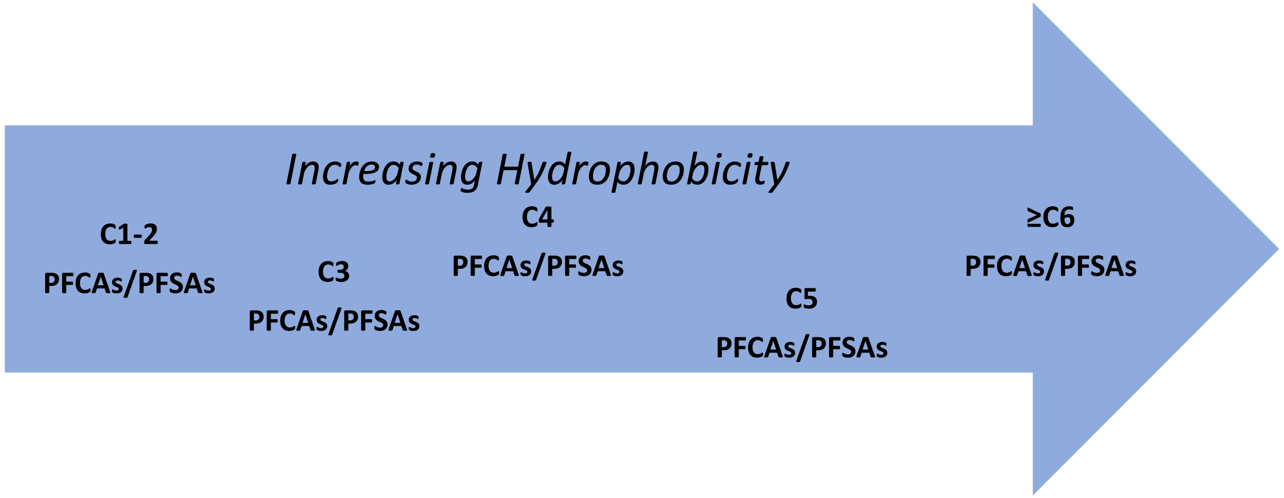
- Objectives
  - Develop a system for effective treatment of PFAS, including ultra-short chains, and demonstrate the capability through pilot testing
  - Minimize energy requirements and waste generated through treatment

- 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
- High volume reduction (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:

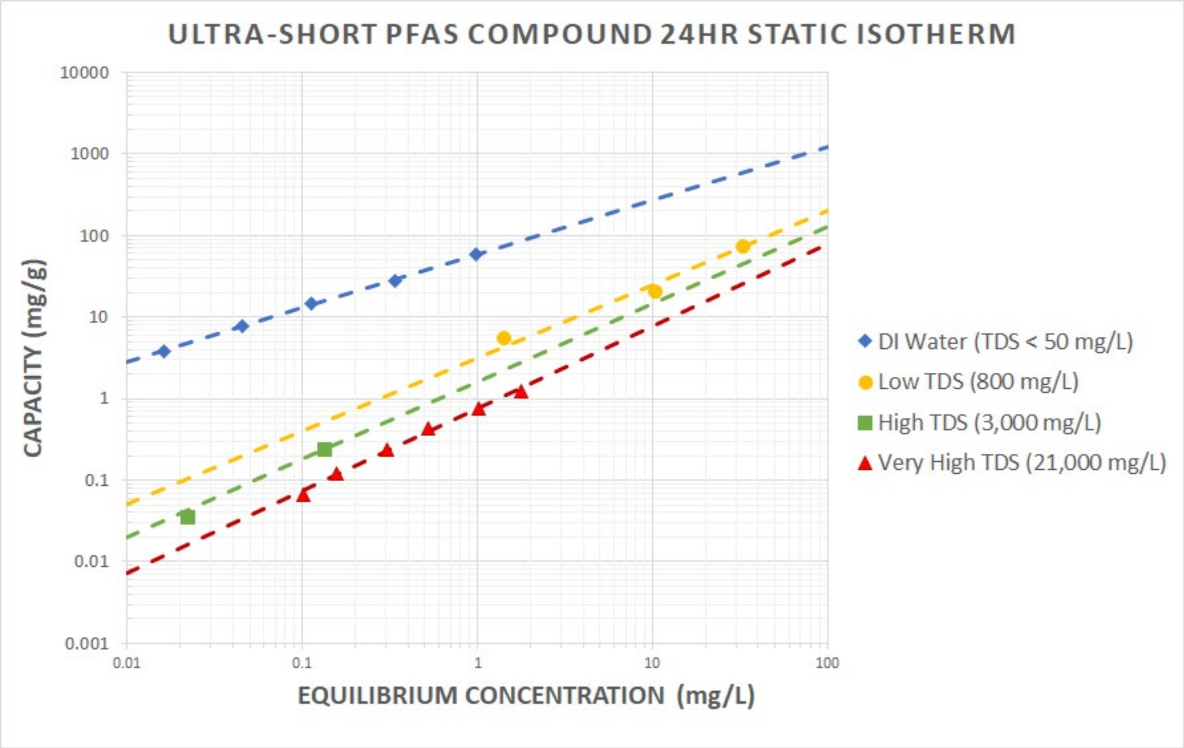
- Volume reduction is small compared to adsorption (3:1 to 7:1) depending on other constituents in the water
- Higher capital and operating costs
- Susceptible to fouling and required robust pre-treatment

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

PROJECT TARGET STREAMS

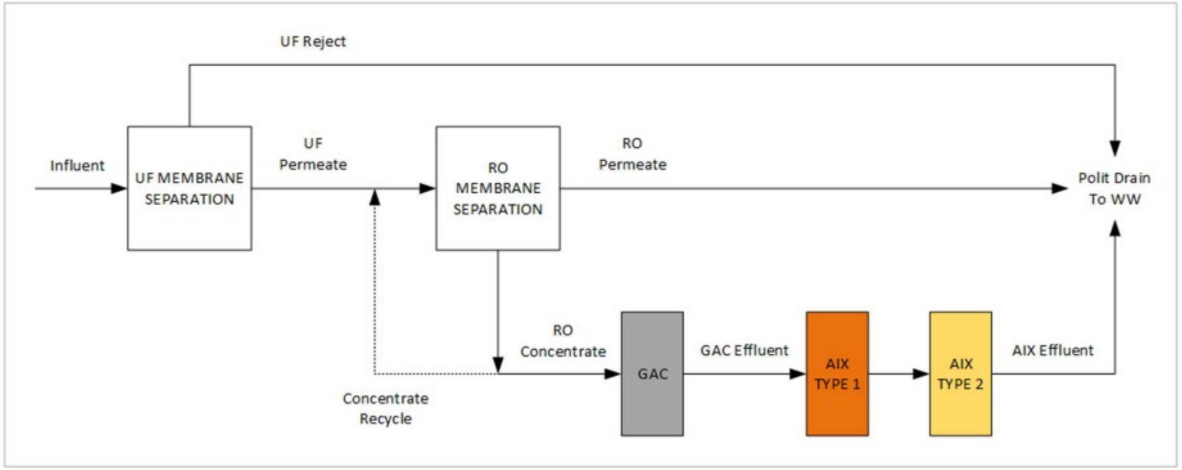
- Stormwater – runoff with minimal non-PFAS constituents and low levels of PFAS
- Remediation groundwater – low non-PFAS constituents and low to high levels of PFAS
- Industrial wastewater – Higher concentrations of non-PFAS constituents and low to high levels of PFAS

EFFECTS OF TDS ON AIX RESIN



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

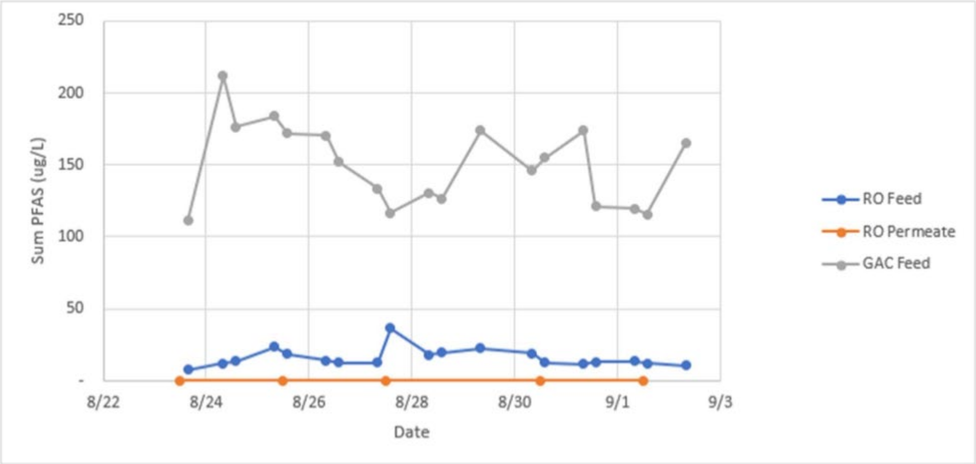
PILOT CONFIGURATION

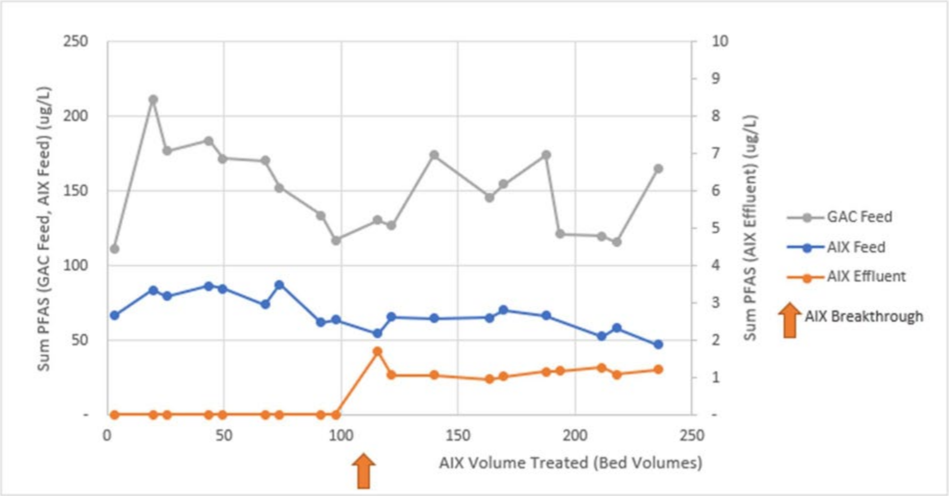


*Functional groups affect capacity and ability to regenerate

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

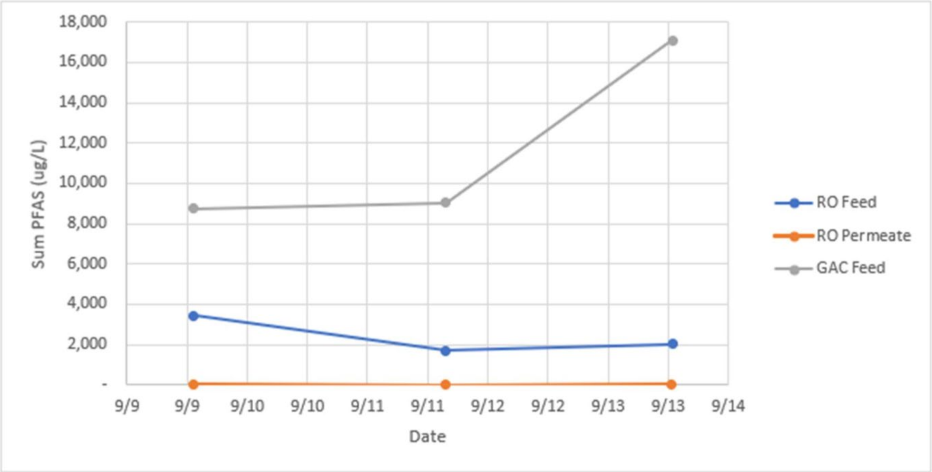
STORMWATER RESULTS

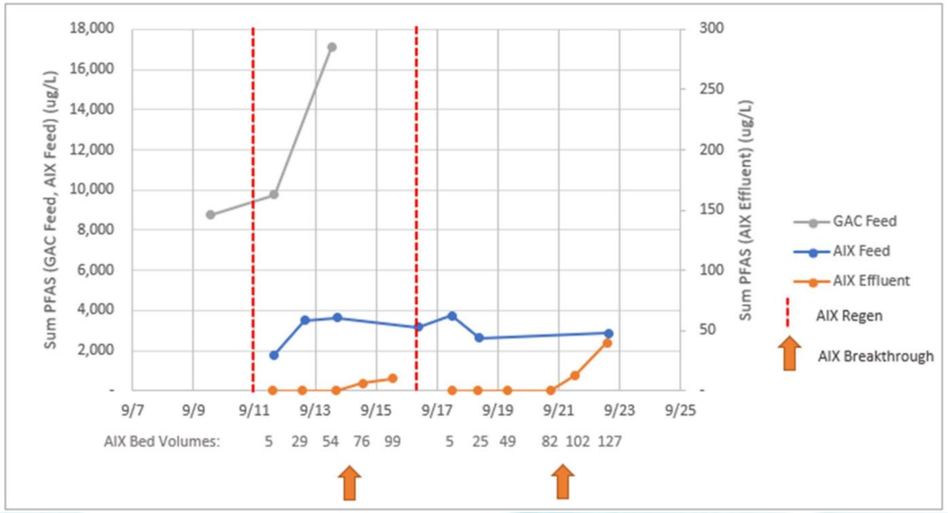




- TDS ~ 500 mg/L, PFAS ~ 25 ug/L
- RO permeate below detection limit
- GAC ~ 50% PFAS removal
- IX effluent PFAS below detection limit to 100 bed volumes

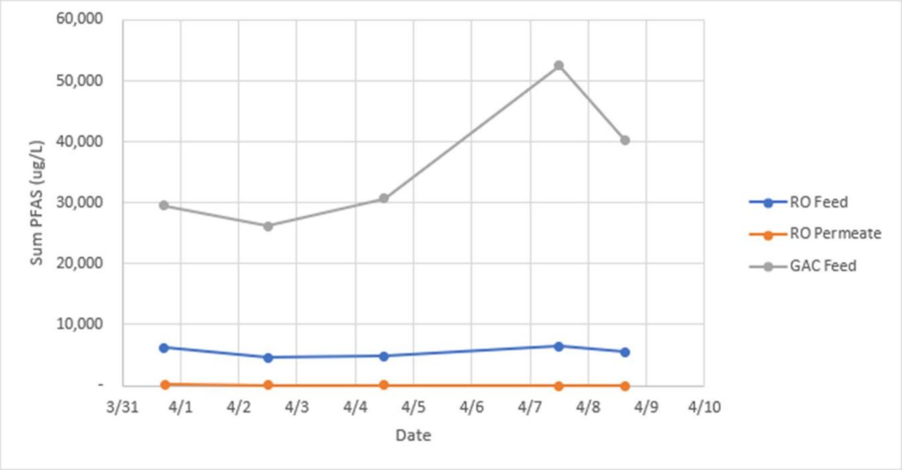
GROUNDWATER RESULTS

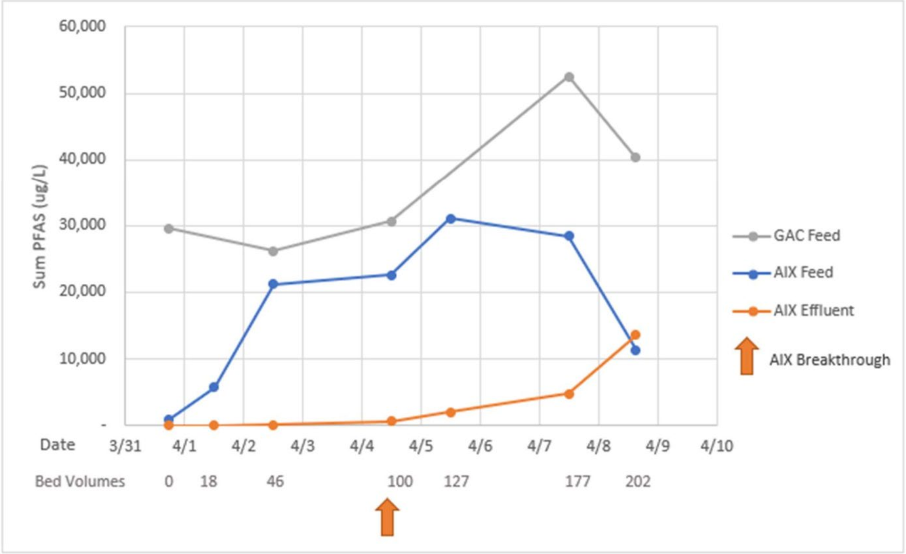




- TDS ~ 250 mg/L, PFAS ~ 3,000 ug/L
- RO permeate average 6.4 ug/L (99.8% rejection)
- GAC ~ 85% PFAS removal
- IX effluent PFAS below detection limit to 80 bed volumes
- Similar TDS range, PFAS 120x higher, IX breakthrough only slightly lower due to much higher capacity than stormwater

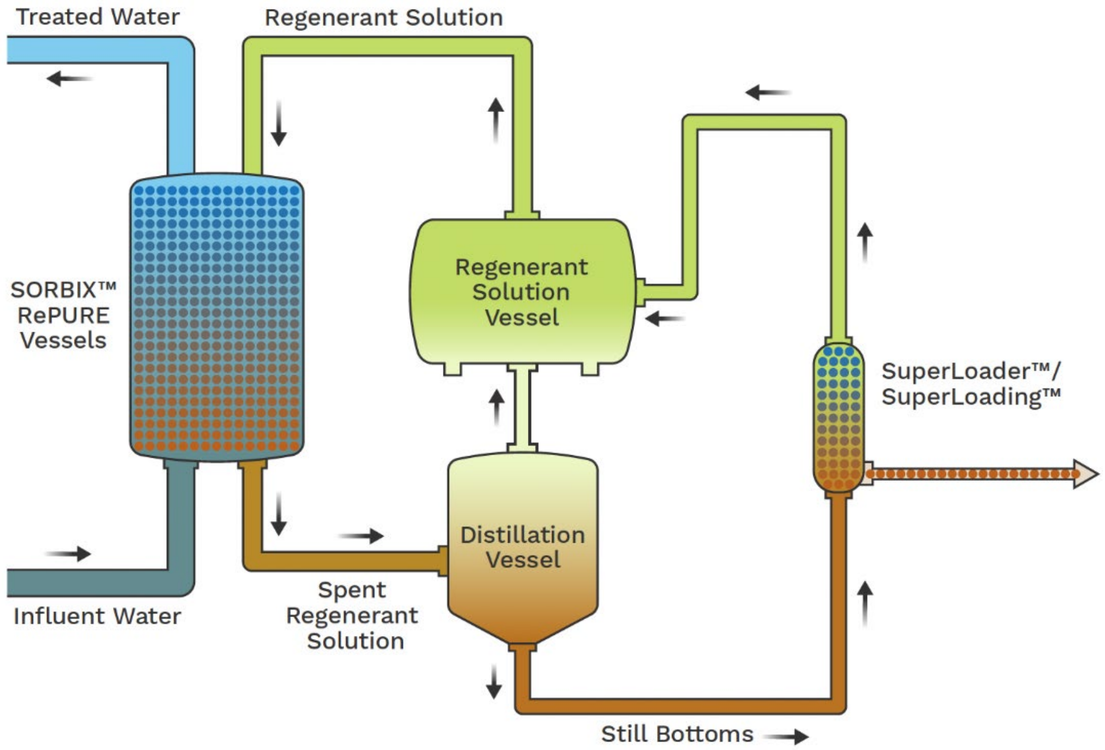
WASTEWATER RESULTS





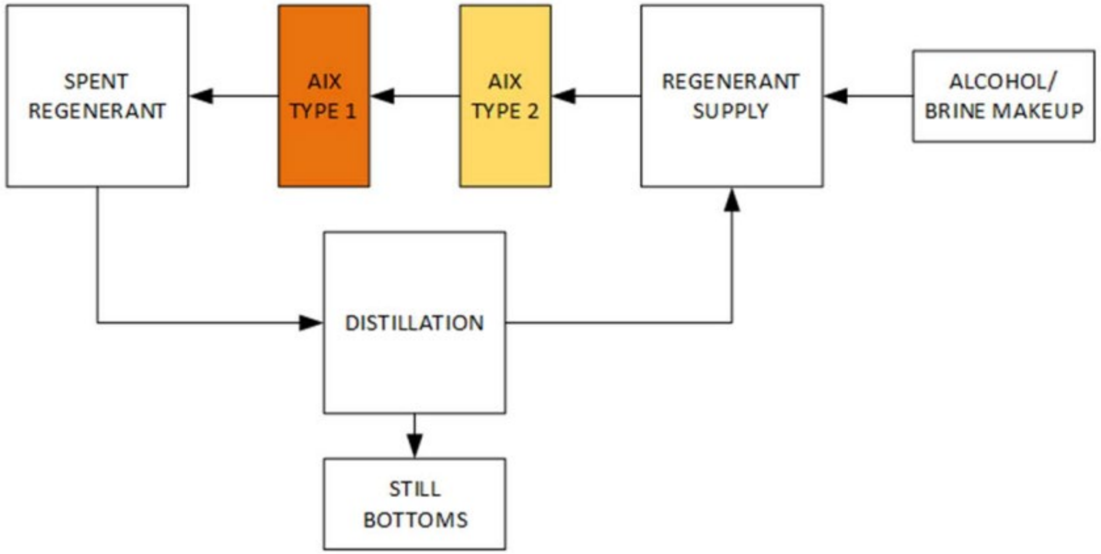
- TDS ~ 2800 mg/L (high sulfates), PFAS ~ 5,500 ug/L
- RO permeate below detection limits
- GAC ~ 33% PFAS removal (lower removal due to higher ultra-short chain composition)
- IX effluent PFAS below detection limit to 75 bed volumes
- TDS 10x higher than groundwater, resulted in IX capacity 5x higher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

AIX REGENERATION PROCESS



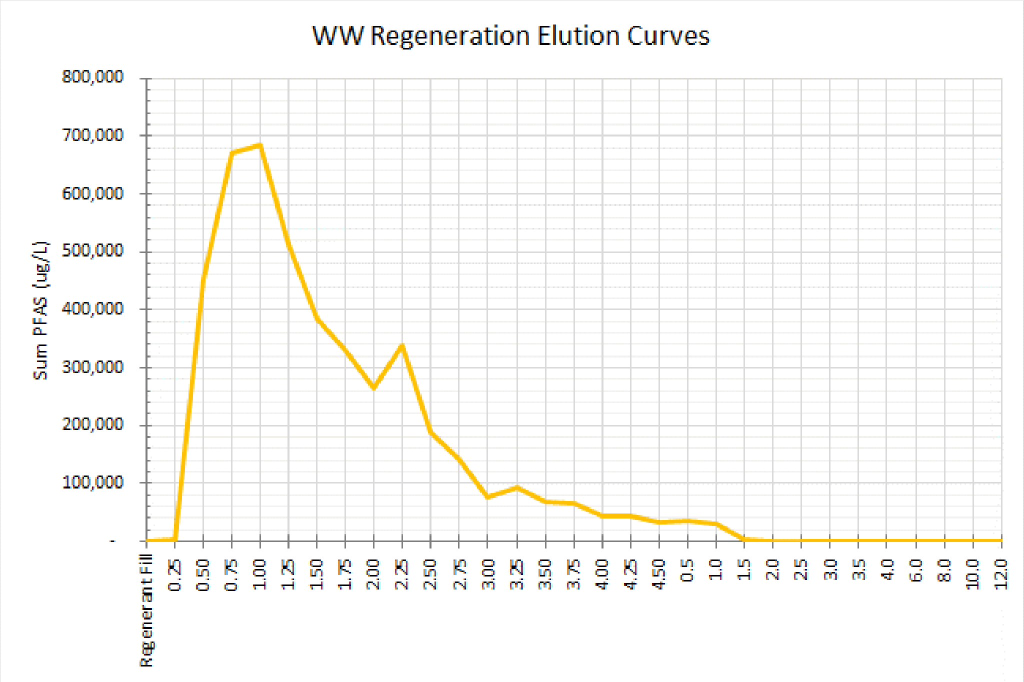
- Used to regenerate ion exchange media and reduce residual waste volumes
- Removes PFAS and recycles regenerant solution
- Reduces waste generation

REGENERATION 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 disposal

REGENERATION 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.

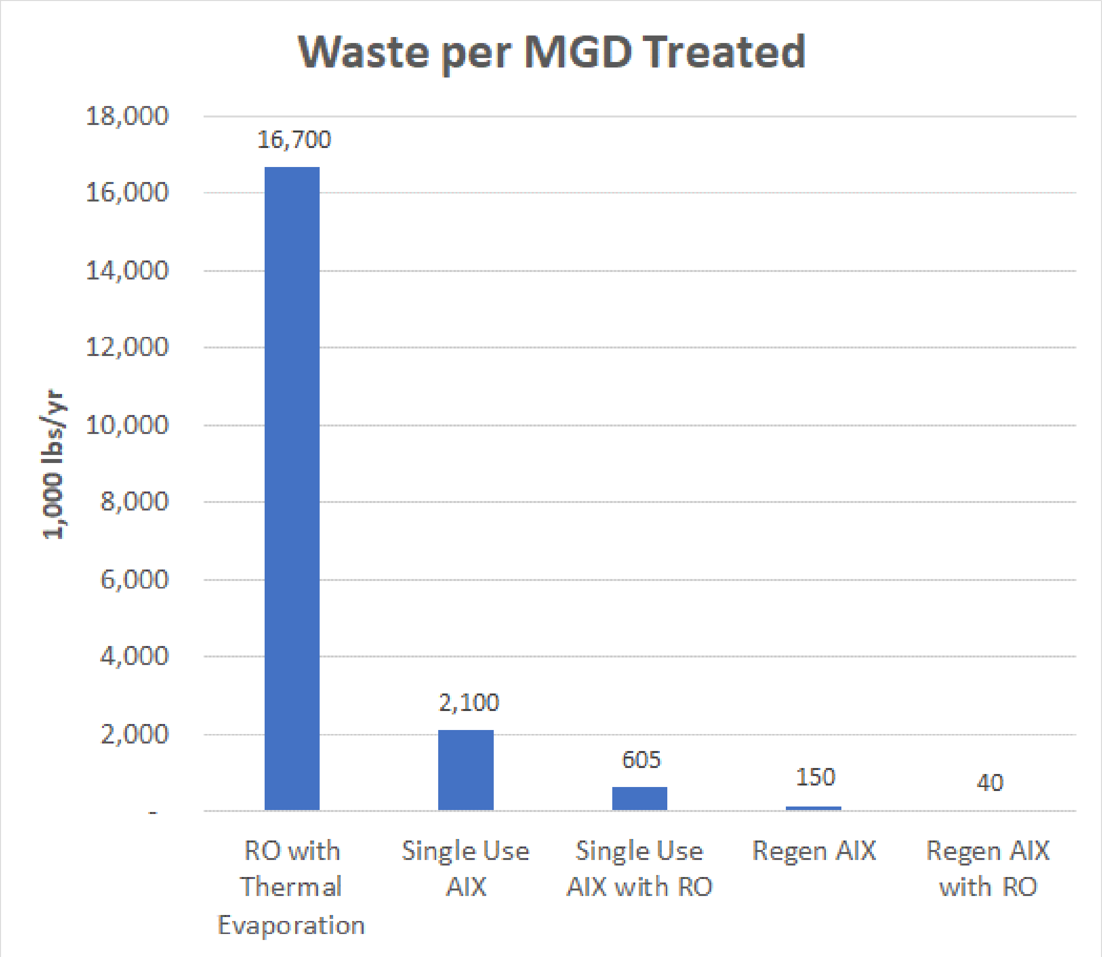
RESIDUAL WASTE VOLUMES

- 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 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 when using SuperLoading process

CONCLUSIONS

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

RemTec 2023

Regenerable IX Resin for PFAS Treatment - *4+ Years Later … What We've Learned…*

3 October 2023

ect2
Montrose Environmental Group

David Kempisty, Ph.D., P.E.
Director, Emerging Contaminants

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The PFAS Challenge

- PFAS substances are everywhere…
- They are hard to treat
- Limited case studies available

A Proven Solution: Regenerable IX

- Effective removal of short- and long-chain PFAS compounds
- Waste minimization
- Sustainability benefits
- Scalable
- Compounding cost savings over project lifetime

Photovoltaic cells	Medical
Wind turbine blades	- - Ultrasound contrast
Batteries	- - Video endoscopy
- - Lithium	- - Imaging
- - Zinc	- - Contact lenses
- - Vanadium redox	- - Eye drops
- - Alkaline manganese	- - Pharmaceuticals
Fuel cells	Paper
Coal power plants	Cosmetics
Nuclear power	Textiles
Oil production	Floor covering
Gas production	Glass treatment
Carbon capture	Toner and printer ink
Plastic production	Leather
Pharmaceutical industry	Guitar strings
Ultrapure water systems	Piano keys

REN & EMERG

Agenda

ect2 Montrose Environmental Group

- Regenerable IX process overview
- Case study – RAAF Base
  - Treatment effectiveness
  - Resin capacity trends
  - Waste generated
  - Leveraging data to optimize performance
- What we've learned - is Regenerable IX a silver bullet?

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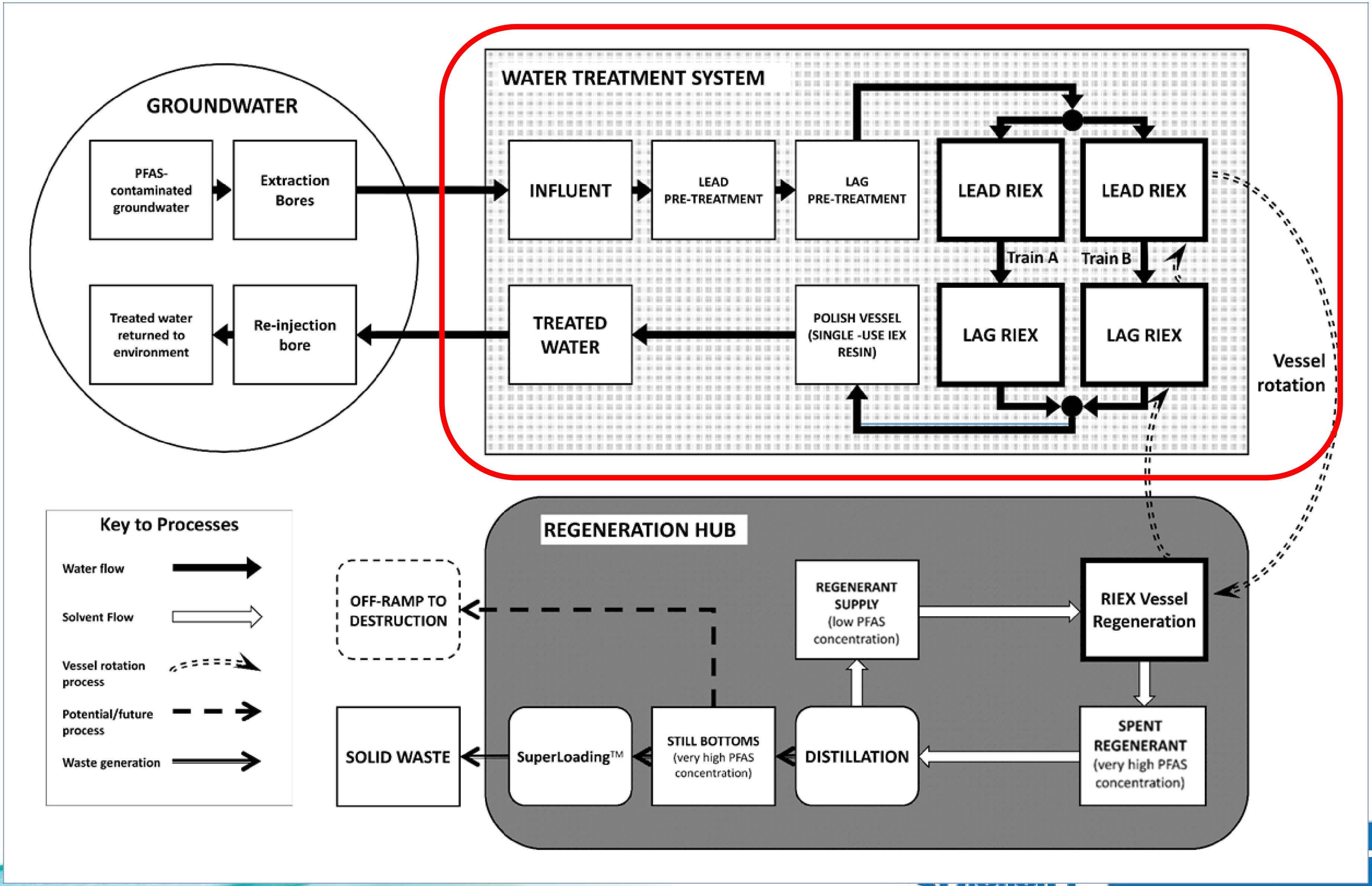
Regenerable IX Process



-5, 2023

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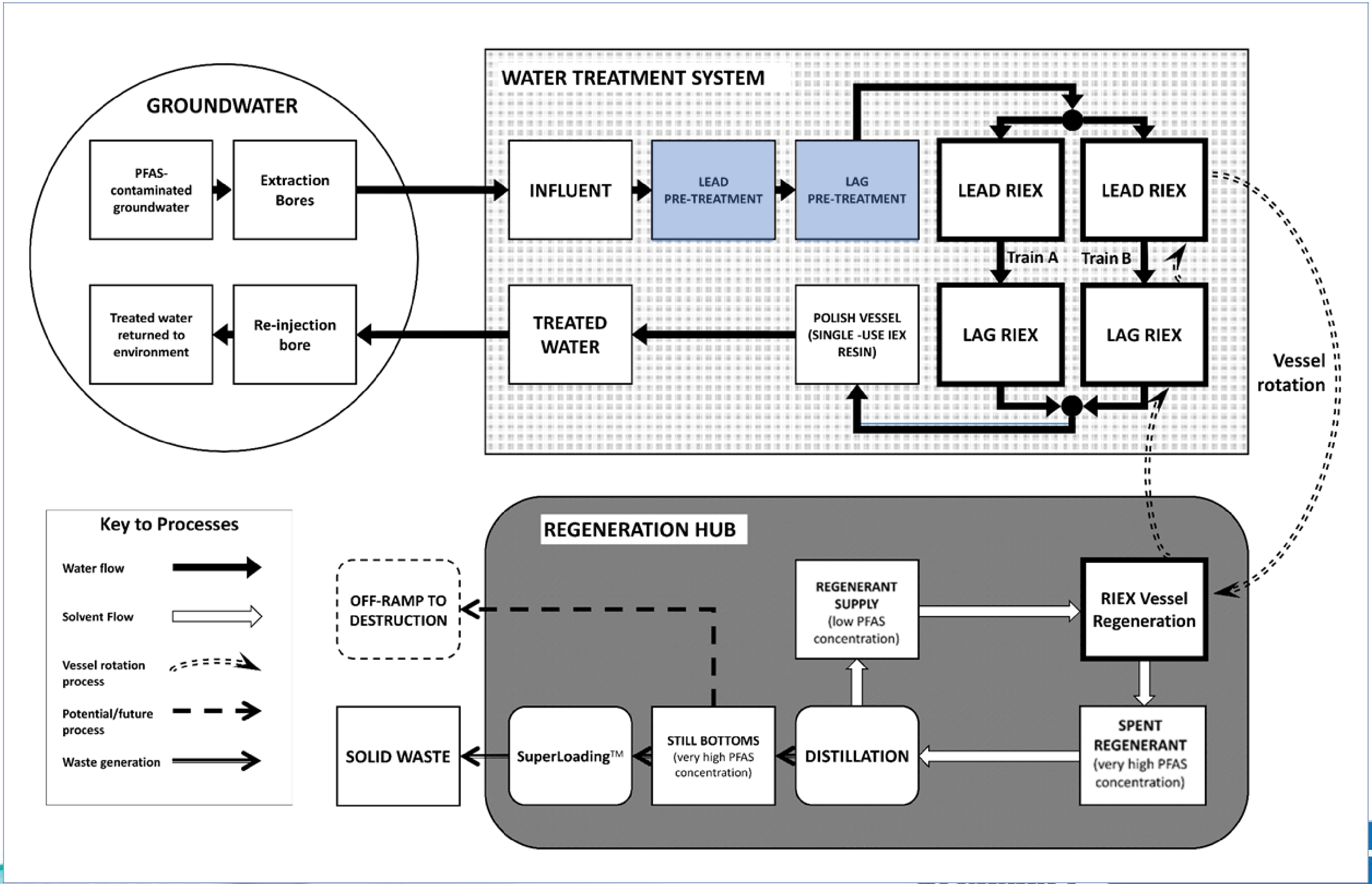
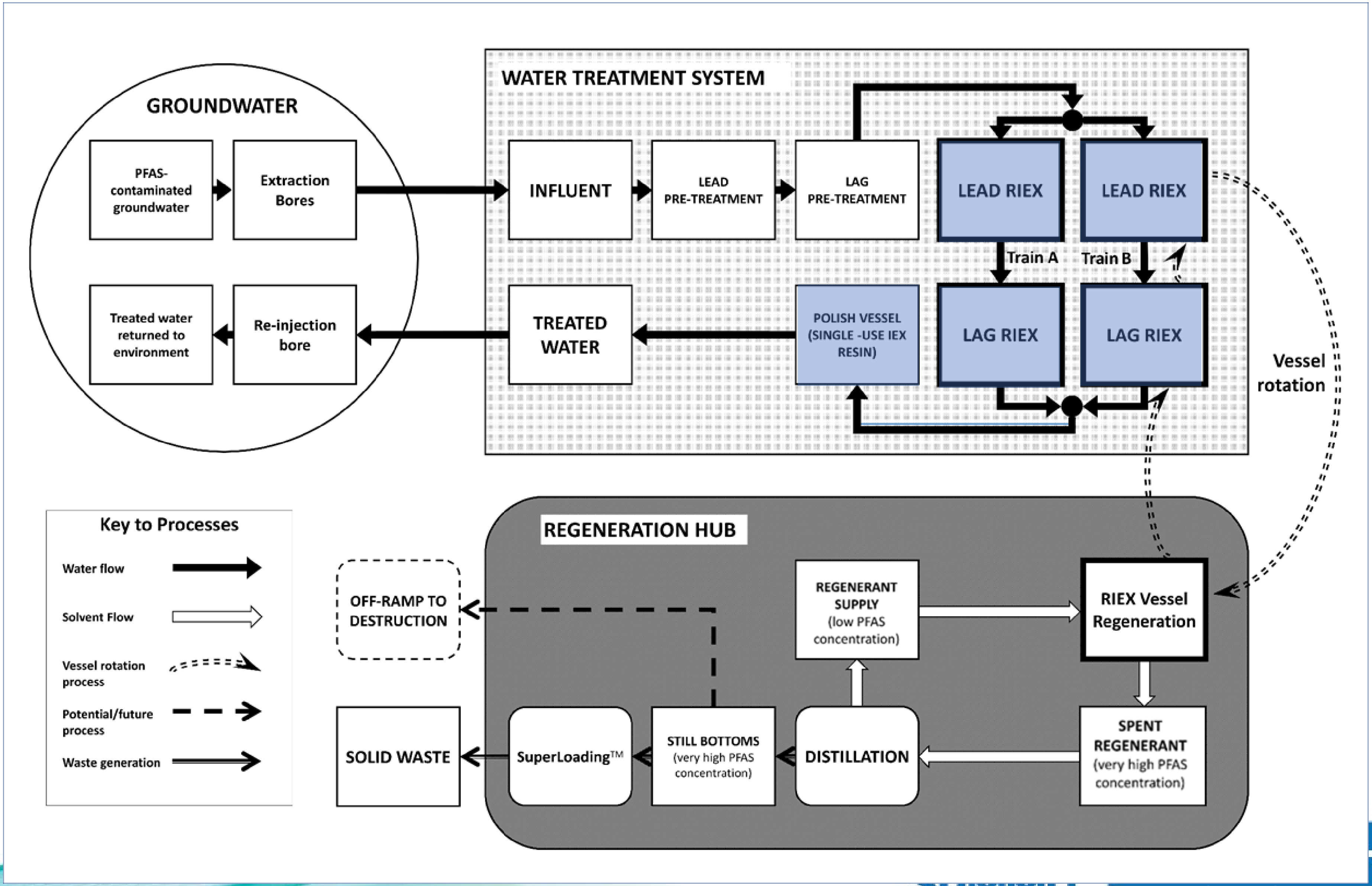
Stage 1: Pre-treatment



Stage 2: REIX Treatment



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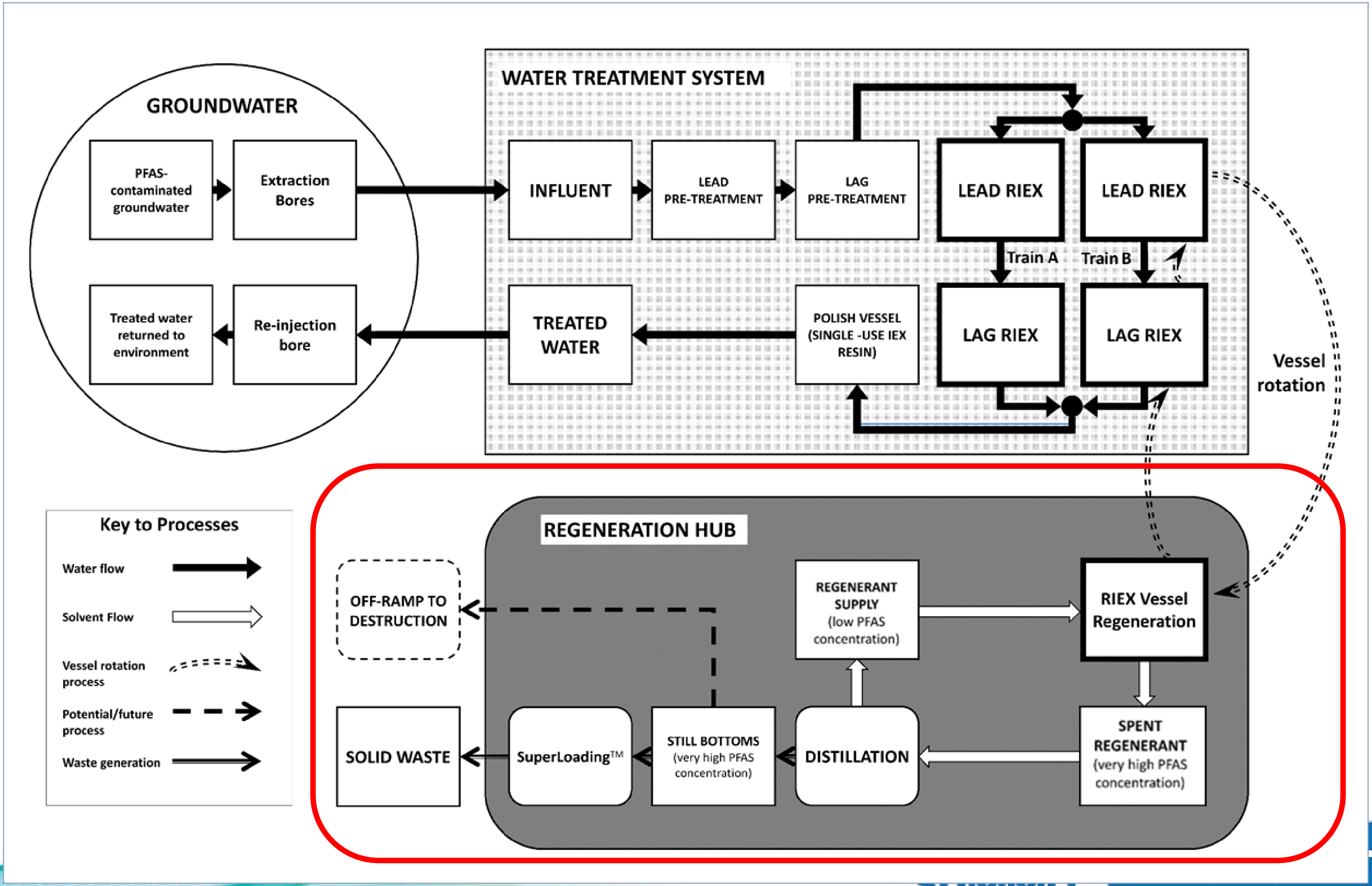
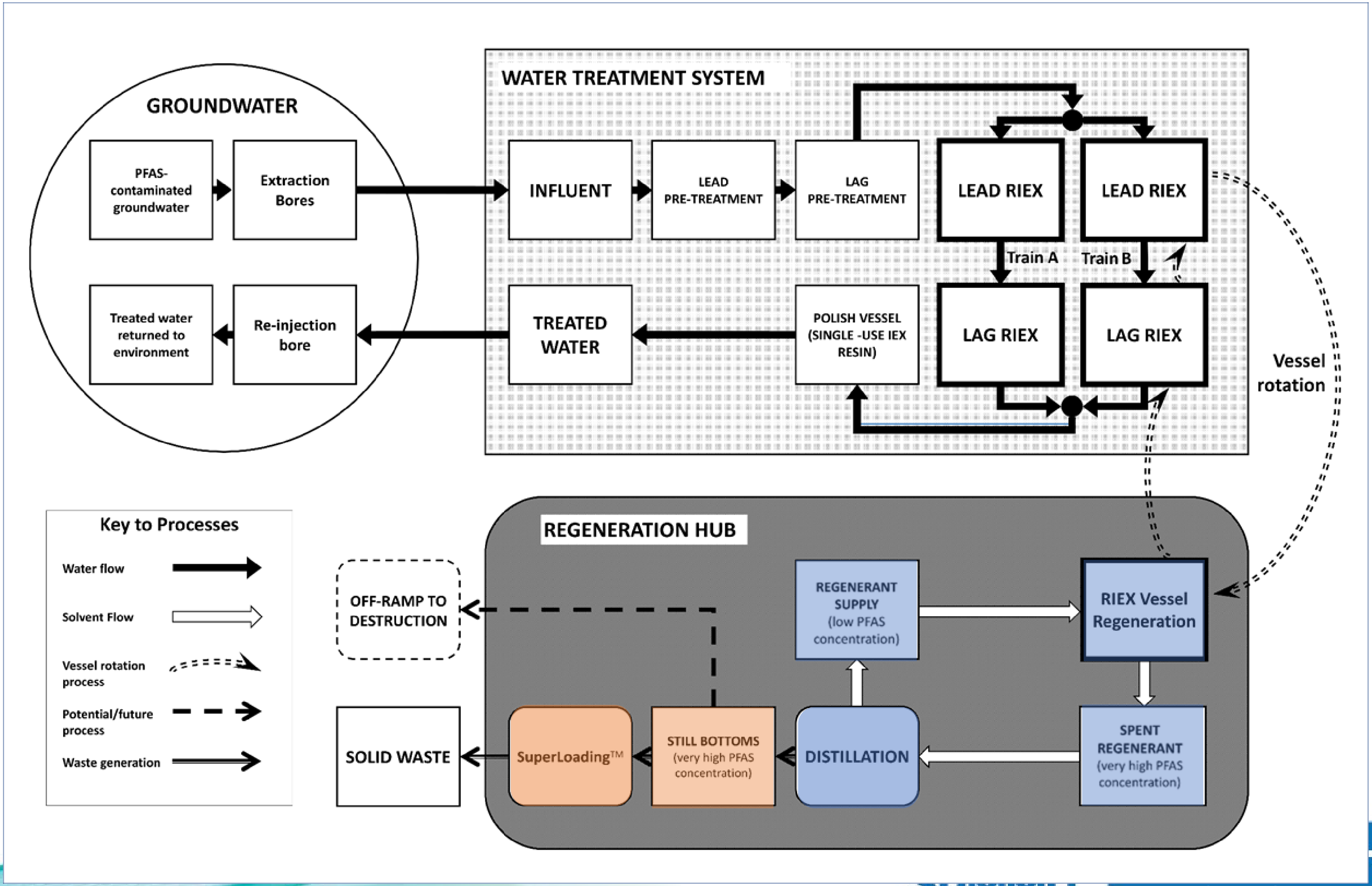
Regenerable IX Process

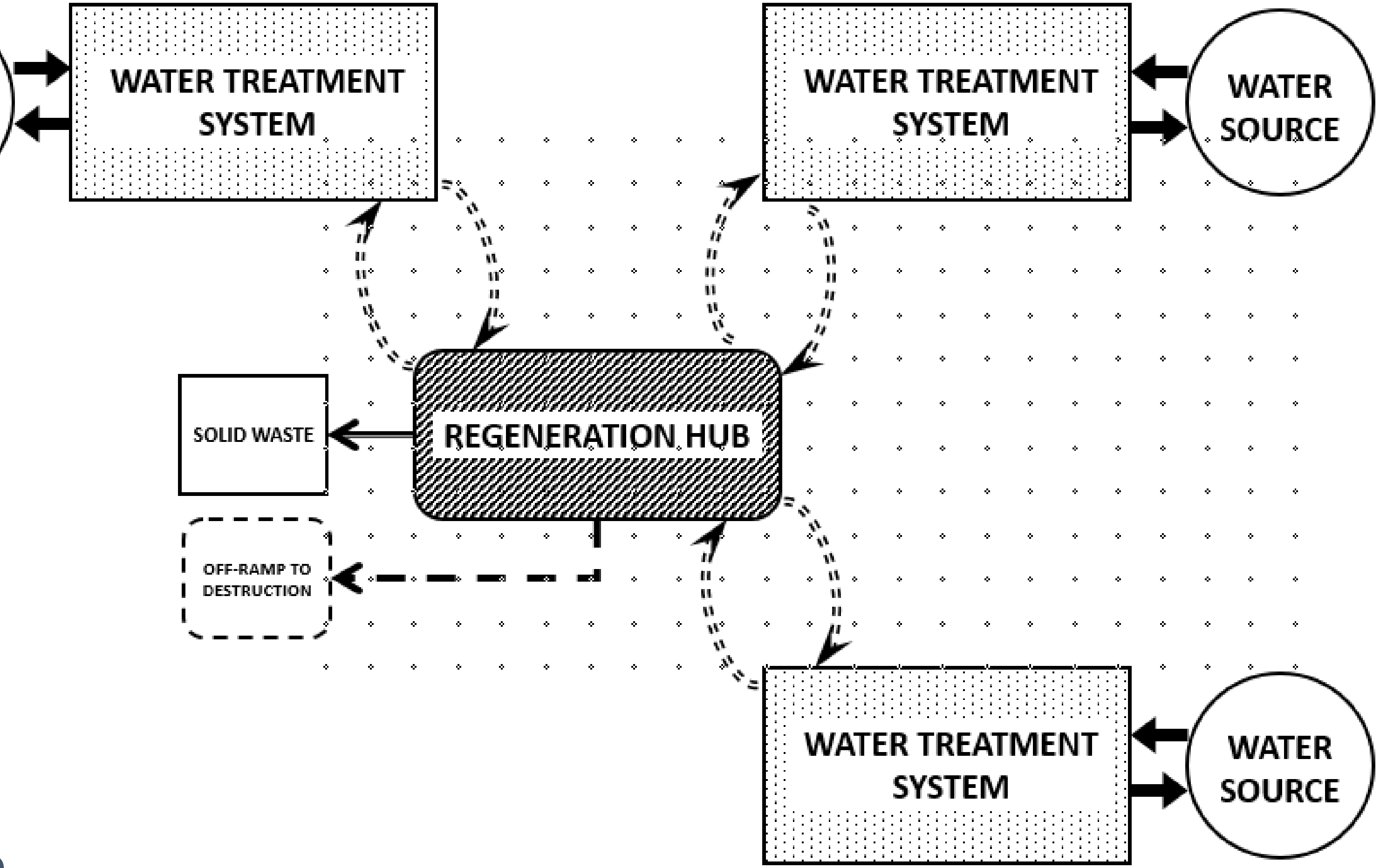


-5, 2023

Stage 3: Resin Regeneration



Regenerable IX Hub-and-Spoke Model



Transportable Regenerable IX Vessel

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Regenerable IX Case Study

RAAF Base, AU

- Legacy AFFF-impacted groundwater
- 12.6 L/s (200 gpm) treatment since 2019
- Influent: ΣPFAS up to 60 µg/L; mean: 14 µg/L
- Treatment criteria: Australian HBGVs
  - PFOS + PFHxS 0.07 µg/L
  - PFOA 0.56 µg/L
- 26 regenerations
- 19+ kg of PFAS removed

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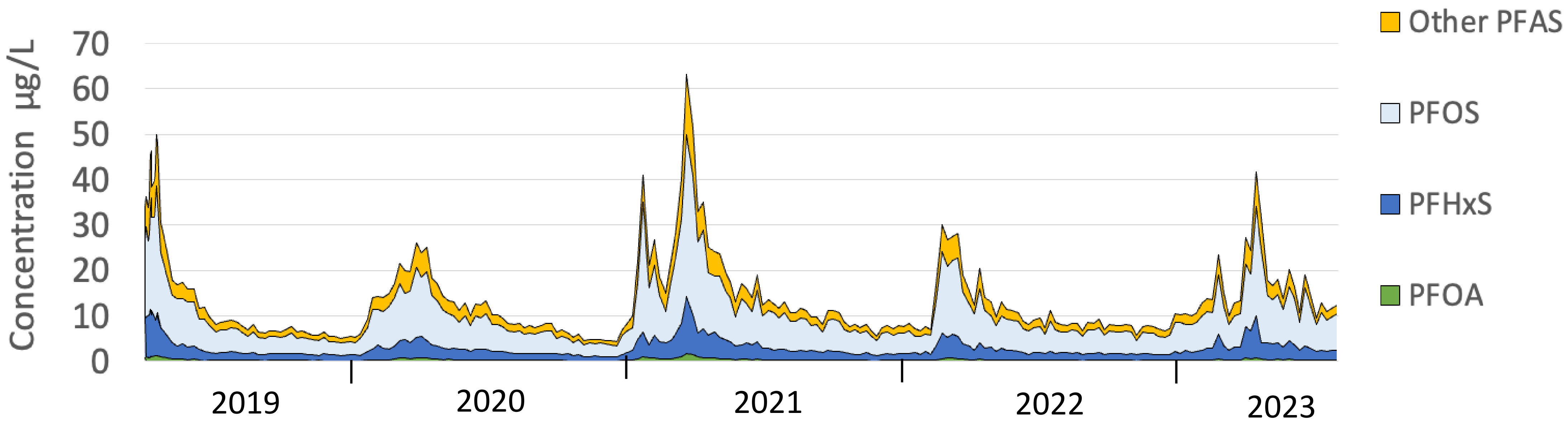
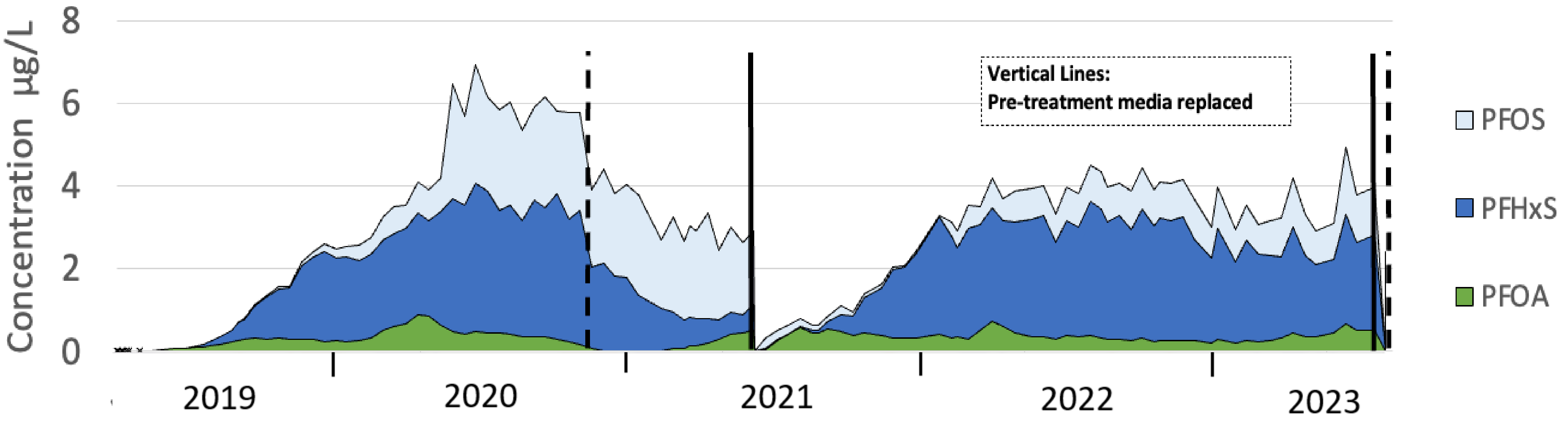
Influent Concentrations to WTP



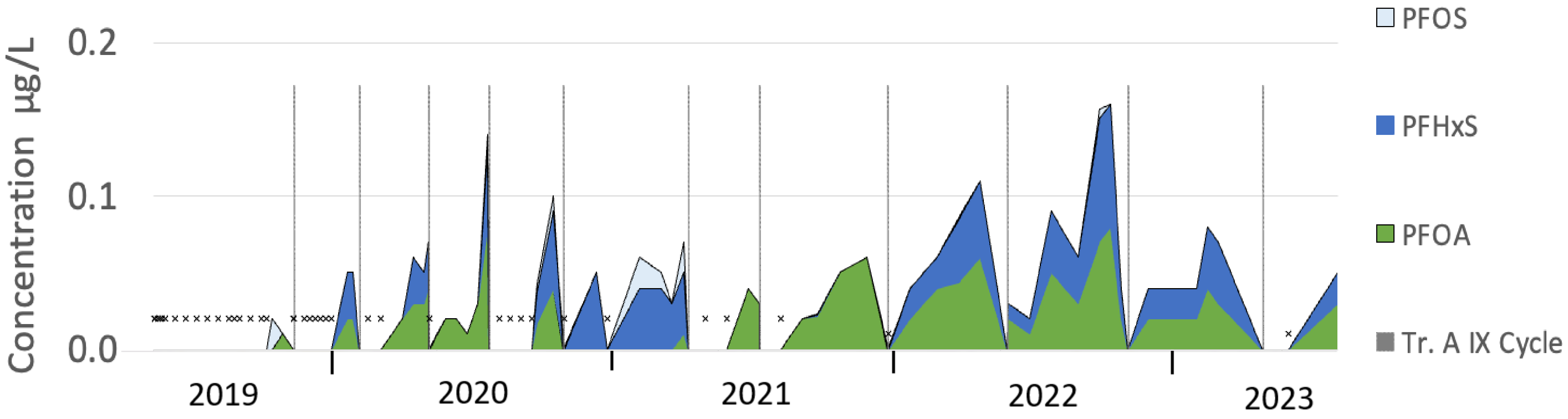
High influent concentrations → Consider regenerable resin

Influent Concentrations to REIX System



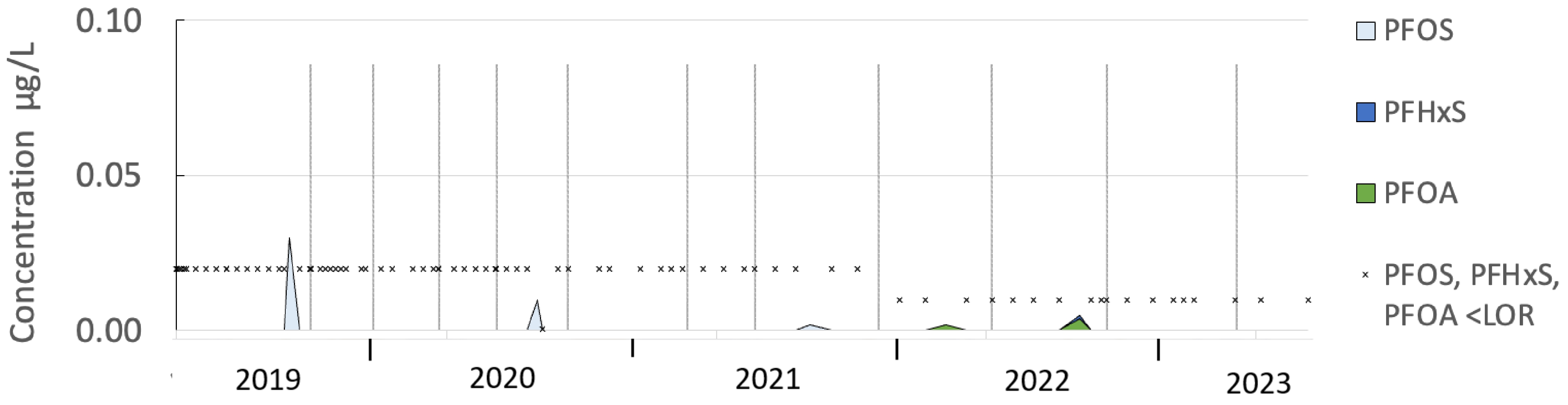
Pre-treatment removes some PFAS – goal is to protect the resin

Effluent from Lead IX Vessel



Concentrations < 200 ppt after first lead RIEX vessel

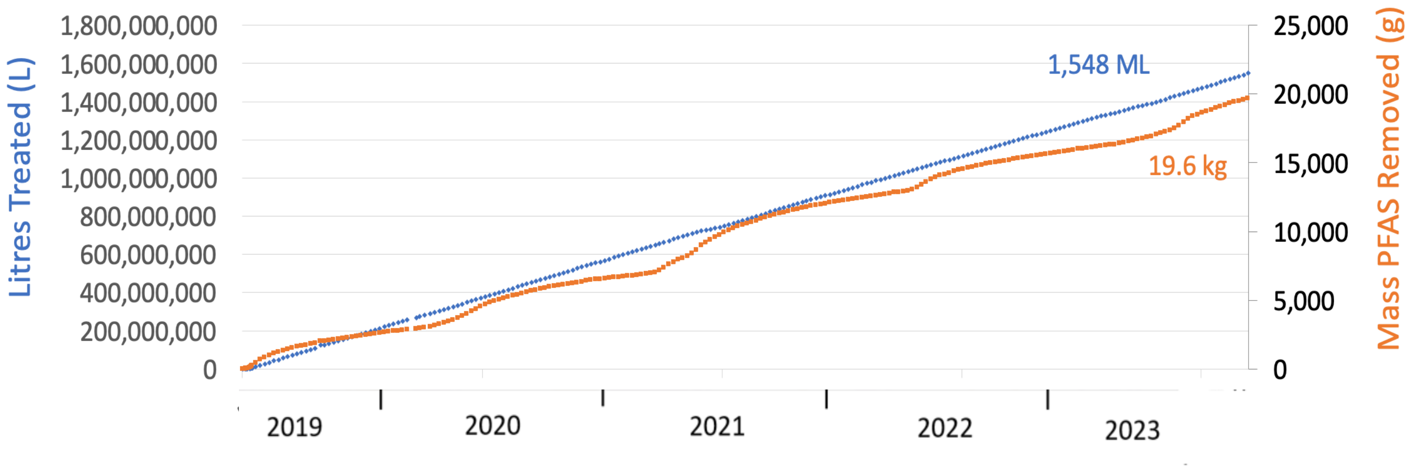
Effluent from Lag Vessel

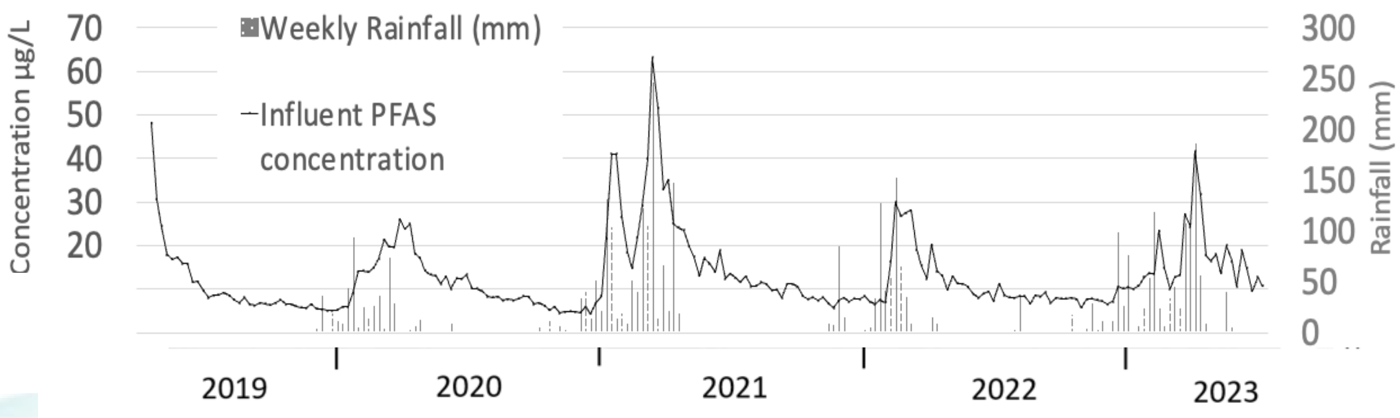


Consistent: 100% compliance with treatment objective; nearly non-detect in all sampling events

Consistent Performa

- Volume water treated
- PFAS removal
  - Pre-treatment media
  - Hydrogeological areas of greater concentration
  - Seasonal variation





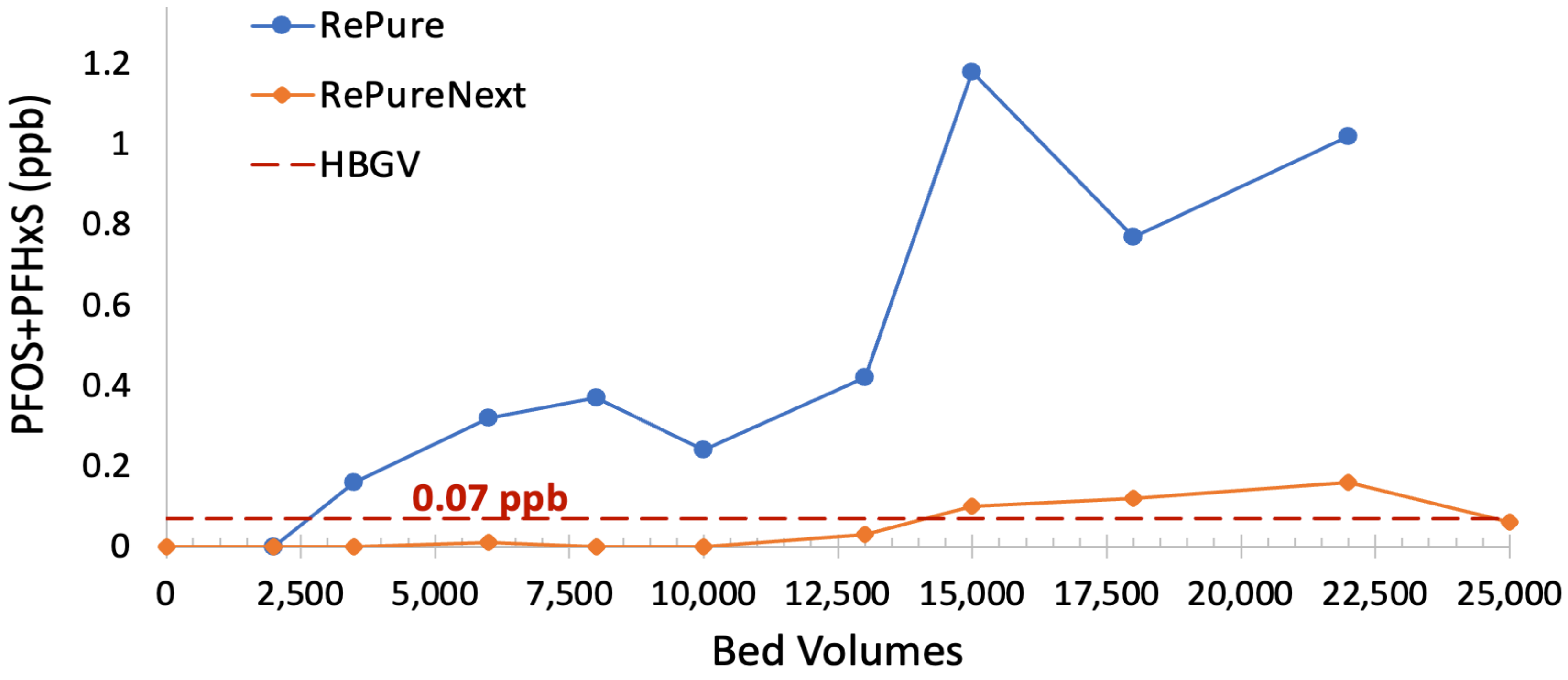
Regeneration Efficiency

- No obvious media degradation
- No increased regeneration frequency
- Consistent PFAS mass recovered

Criteria	5–Cycle Average	5-Cycle Standard Deviation
Treatment Days	245	56
Volume Water Treated (ML)	128	26
PFAS Removed (g)	330	112
PFAS Recovered (g)	369	173
Mass Balance (removed-recovered)	-39	77

Optimization Efforts Continue

New media evaluation



2.7x capacity with RePureNext;
>4x capacity for HBGV PFAS of interest

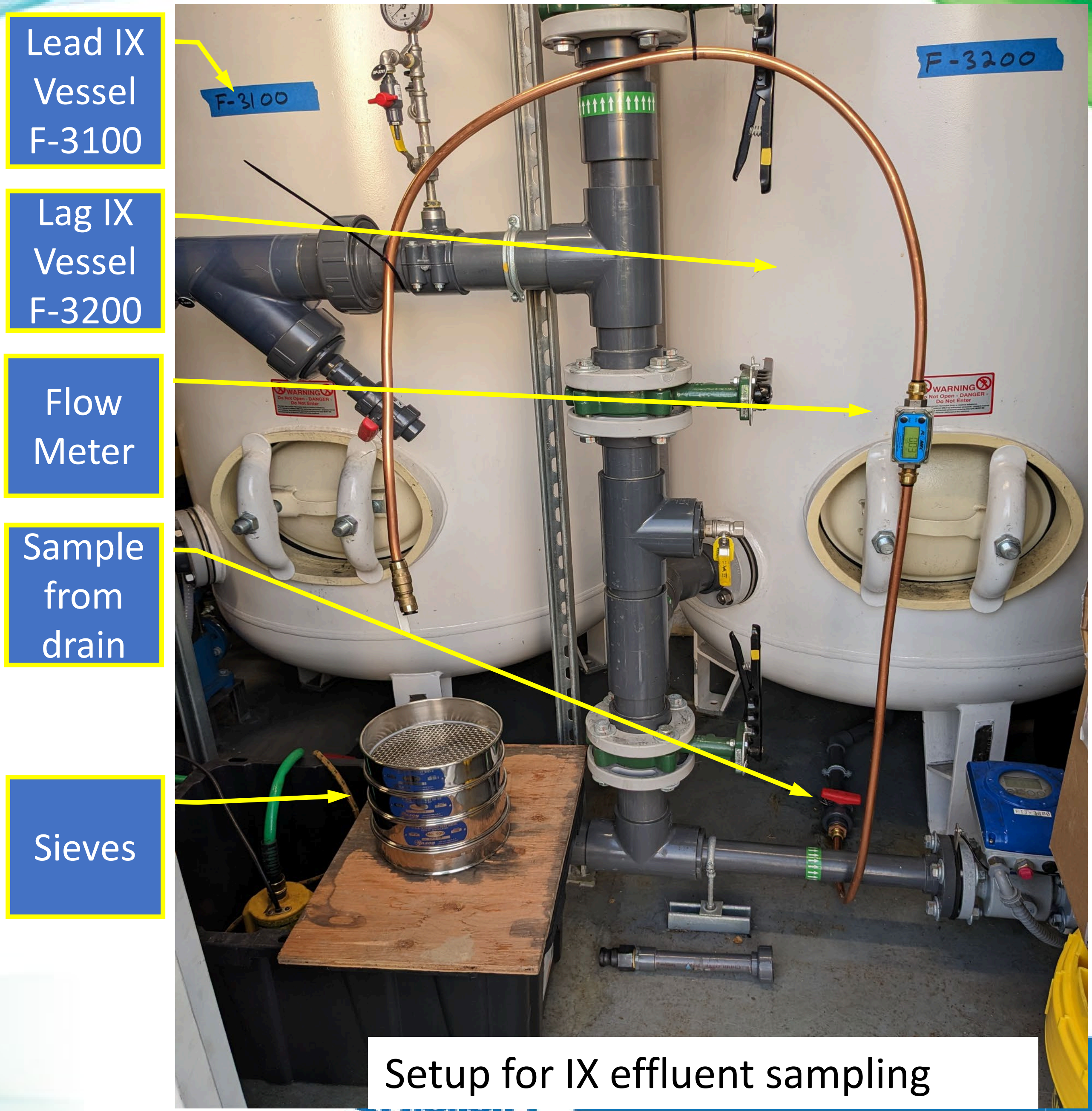
Investigation efforts

Microplastics

Are we putting microplastics into the environment by with technology involving large vessels of plastic media?

FIG. 2 Water Sampling Apparatus for Pressurized Systems

ASTM D8332-20
Standard Practice for Collection of Water Samples with High, Medium, or Low Suspended Solids for Identification and Quantification of



Setup for IX effluent sampling

Investigation efforts

Microplastics

Criteria	AU (Site #1)	US (Site #2 / Lab #1)	US (Site #2 / Lab #2)
Microplastic count (microplastics/L)	27 / 34	0.6 / 0	1.1 / 1.0
Sample collected	Grab	ASTM 8332-20	
Analysis performed	Microscopy/LDIR	PLM/Raman	Microscopy/LDIR
Plastics identified	No polystyrenic / PMMA		
Resin sample match	No	N/A	No

Findings do not suggest MP contribution to the environment from two IEX treatment locations

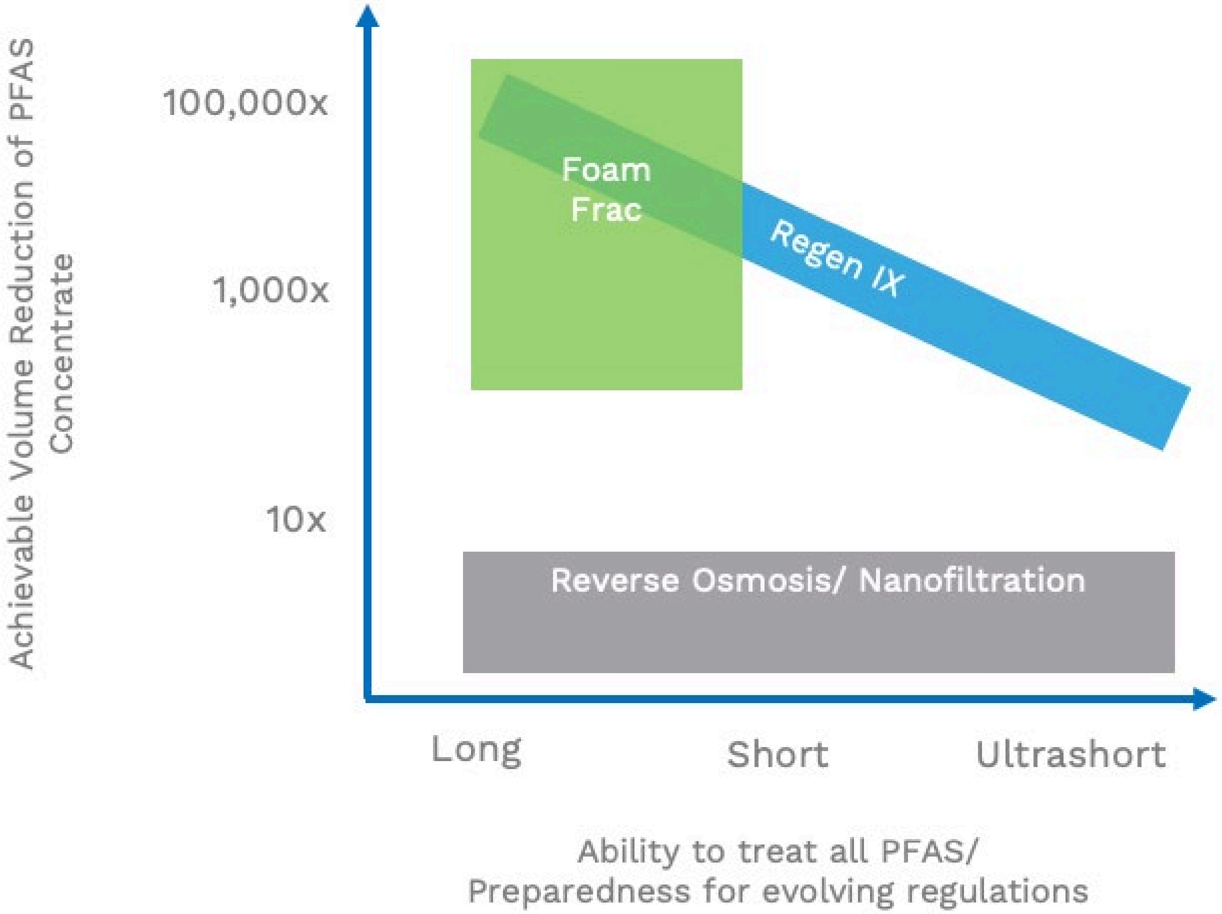
What We’ve Accomplished:

4 years full-time operation	1.5B Litres treated	HBGVs Achieved	19+ kg PFAS removed	20+ Regen Cycles

- Economics analysis – with high concentrations and longer operating times … regenerable resin should be considered
- Ancillary Benefits
  - ESG metrics, reduced future lability, waste minimization

What We've Learned

- Consistently works (PFAS removal and resin regeneration)
  - Higher concentrations; longer treatment times; bundled locations
- Not a silver bullet
- Optimization continues
- Future-proof
  - Tightening regulations
  - Off-ramp for destruction



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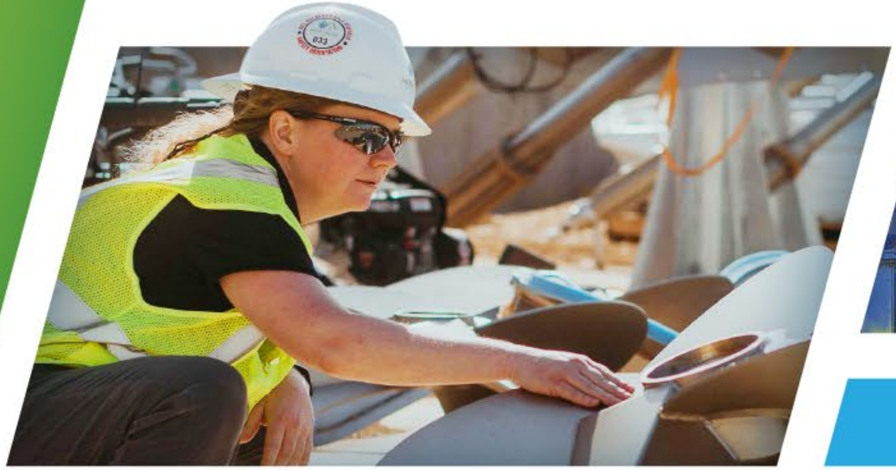
The Future of Environmental Solutions

MONTROSE
ENVIRONMENTAL

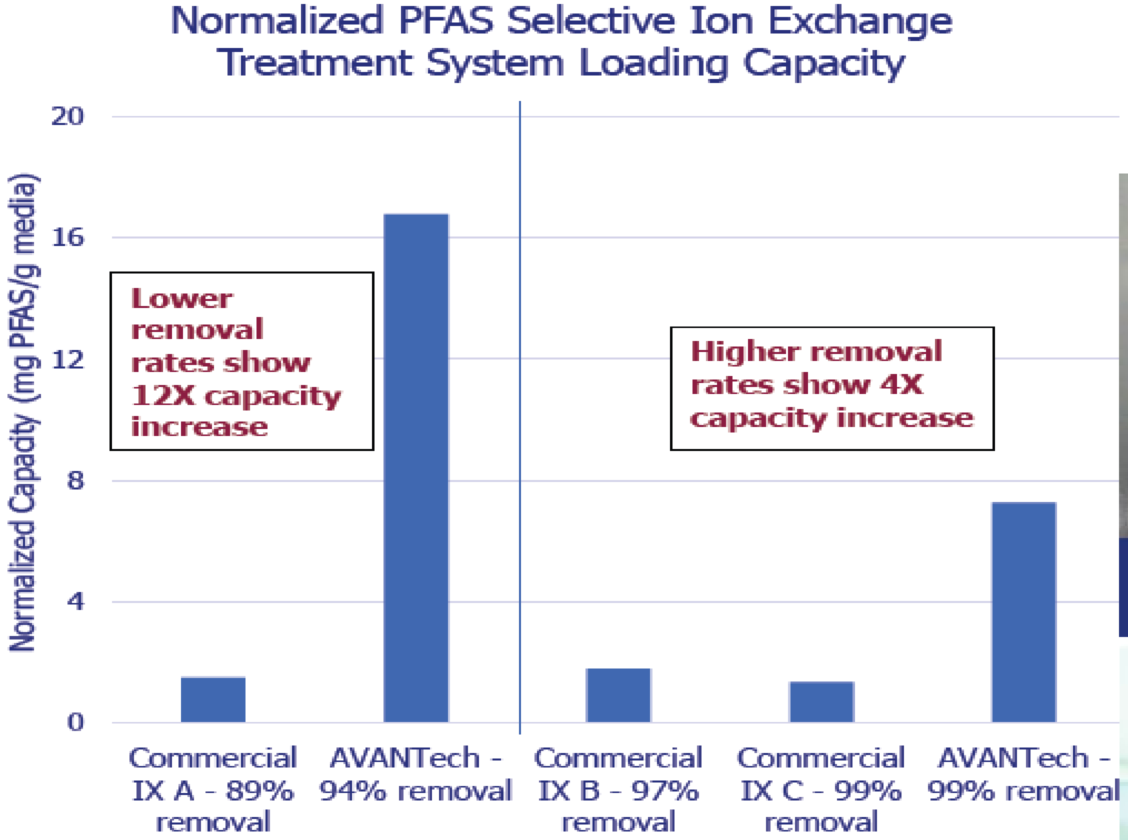


AVANTech PFAS Powdered Ion Exchange (APPIX) Removes PFAS from Leachate and AFFF Concentrate

Tracy Barker, Michael Reed, Frank Cerio, and Jaclyn Looper

• AVANTech APPIX

- Increased PFAS loading capacity compared to IX beads
- Customer savings on media, transportation, capital cost, disposal and shutdown time (NSF Approved)



• Advanced PFAS Polymerization (AP2)

- US Nuclear Regulatory Commission approved polymer
- Avoids future liabilities via immobilization
- Can be used for IX resin, carbon, or other adsorbents