Use of Advanced Technologies to Mitigate the Impact of PFAS on Water Supplies

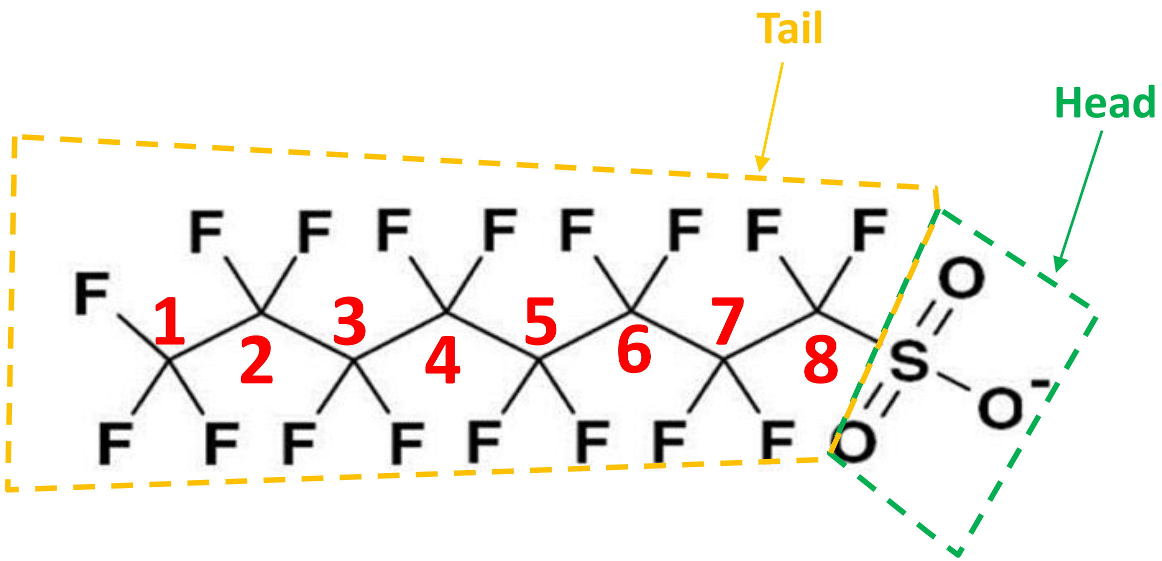
Steve Woodard, Ph.D., P.E.

President

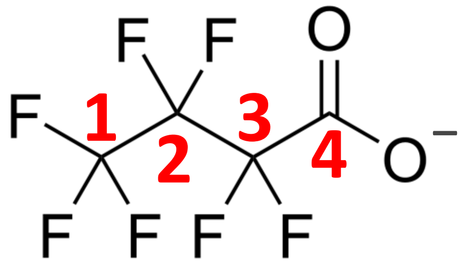
Presentation Outline

- Primer on properties of PFAS compounds
- PFAS removal technologies: what are the options?
- Mechanisms of PFAS removal for each technology
- Advantages and disadvantages of each
- How do you select a technology?
- Example applications for each
- Case study

Properties of PFAS – Important for Treatment



PFOS



PFBA

- Hydrophobic fluorinated carbon chain – “tail”
- Anionic sulfonate or carboxylate group – “head”

PFAS Treatment Options – From Fayetteville Regional Summit

ect2

EPA Drinking Water Treatment for PFOS

Ineffective Treatments

Conventional Treatment
Low Pressure Membranes
Biological Treatment (including slow sand filtration)
Disinfection
Oxidation
Advanced oxidation

PAC Dose to Achieve

50% Removal	16 mg/l
90% Removal	>50 mg/L

Dudley et al., 2015

Effective Treatments

Effective Treatments	Percent Removal	
Anion Exchange Resin (IEX)	90 to 99	- **Effective**
High Pressure Membranes	93 to 99	- **Effective**
Powdered Activated Carbon (PAC)	10 to 97	- **Effective for only select applications**
Granular Activated Carbon (GAC)		
Extended Run Time	0 to 26	- **Ineffective**
Designed for PFAS Removal	> 89 to > 98	- **Effective**

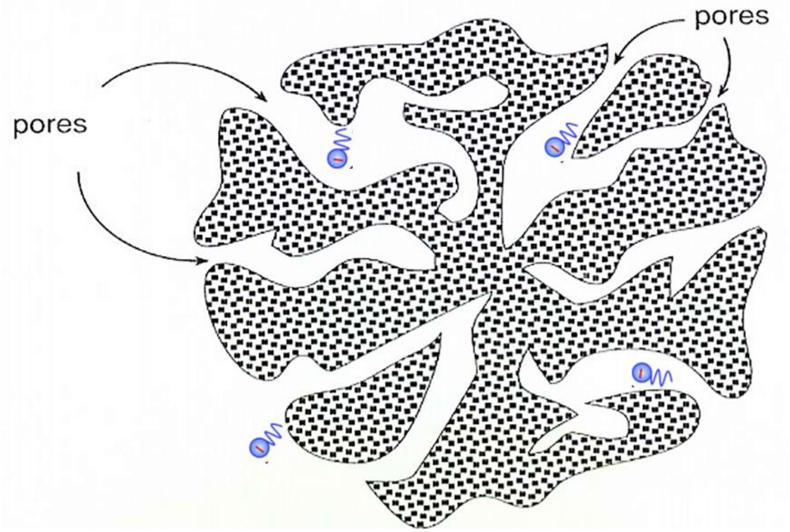
Proven Technologies for PFAS Removal

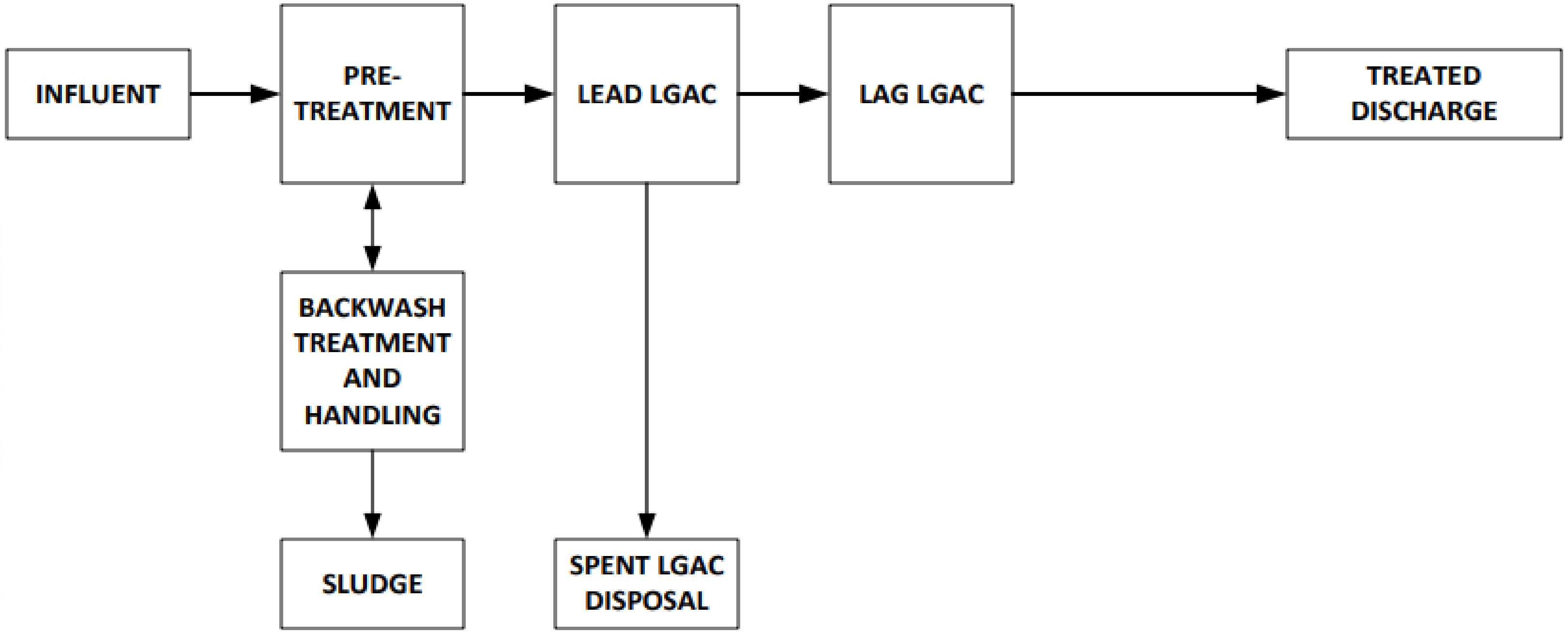
- GAC (or LGAC)
- Reverse osmosis (RO)
- Single-use IEX resin
- Regenerable IEX resin

Mechanisms of PFAS Removal

- GAC: Adsorption
- Reverse osmosis (RO): Size exclusion
- Single-use ion exchange (IEX) resin: Adsorption and IEX
- Regenerable IEX resin: Adsorption and IEX

How Does GAC Remove PFAS?



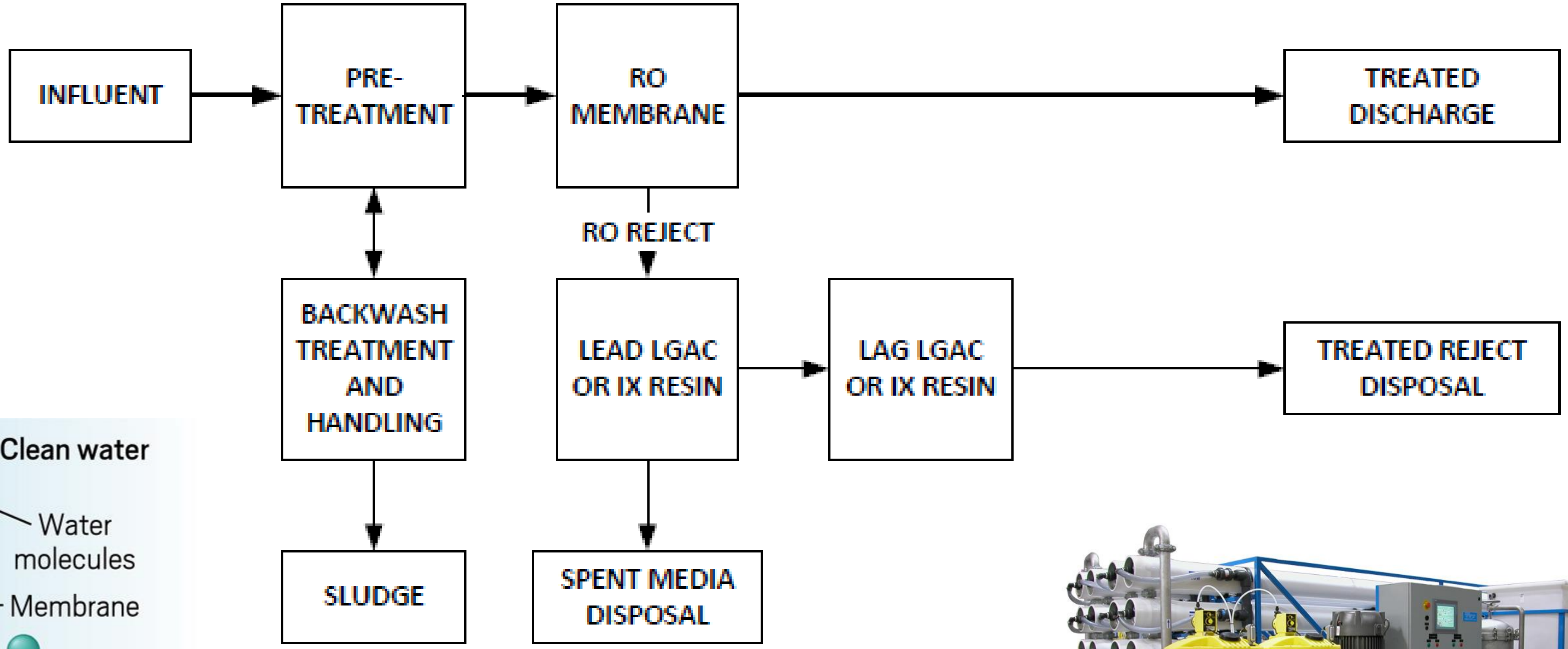


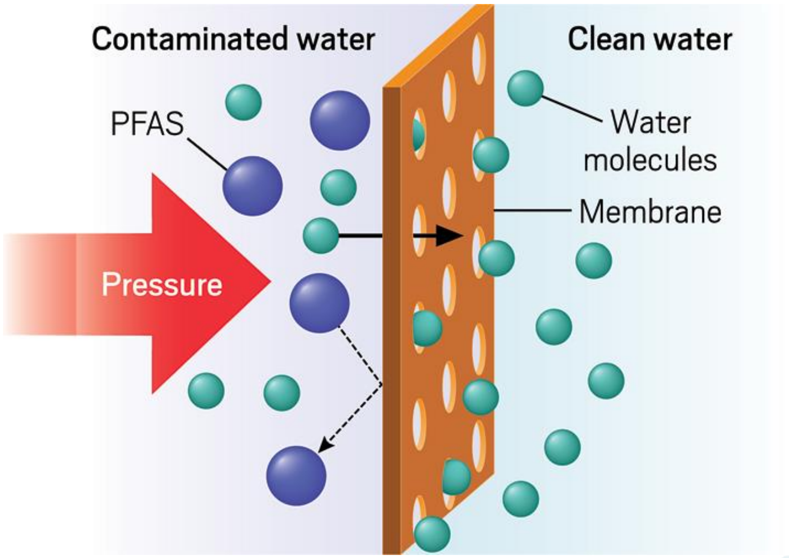
GAC Advantages and Disadvantages

GAC is currently the most commonly used technology for drinking water applications

- Advantages
  - Effective on PFAS, especially long-chain compounds
  - Not adversely impacted by elevated chloride concentrations
  - Effectively removes a variety of co-contaminants, including VOCs, SVOCs, TPH, etc.
  - Can be regenerated (however, regenerated carbon not typically used in drinking water applications)
- Disadvantages
  - PFAS removal capacity is generally much lower than IEX resins
  - Significantly larger footprint than IEX resin
  - Carbon regeneration occurs offsite; requires vessel evacuation and transportation
  - Breakthrough requires periodic replacement of the GAC

How Does RO Remove PFAS?





RO Advantages and Disadvantages

RO is currently the least commonly applied technology for treating PFAS. Primarily used for residential applications

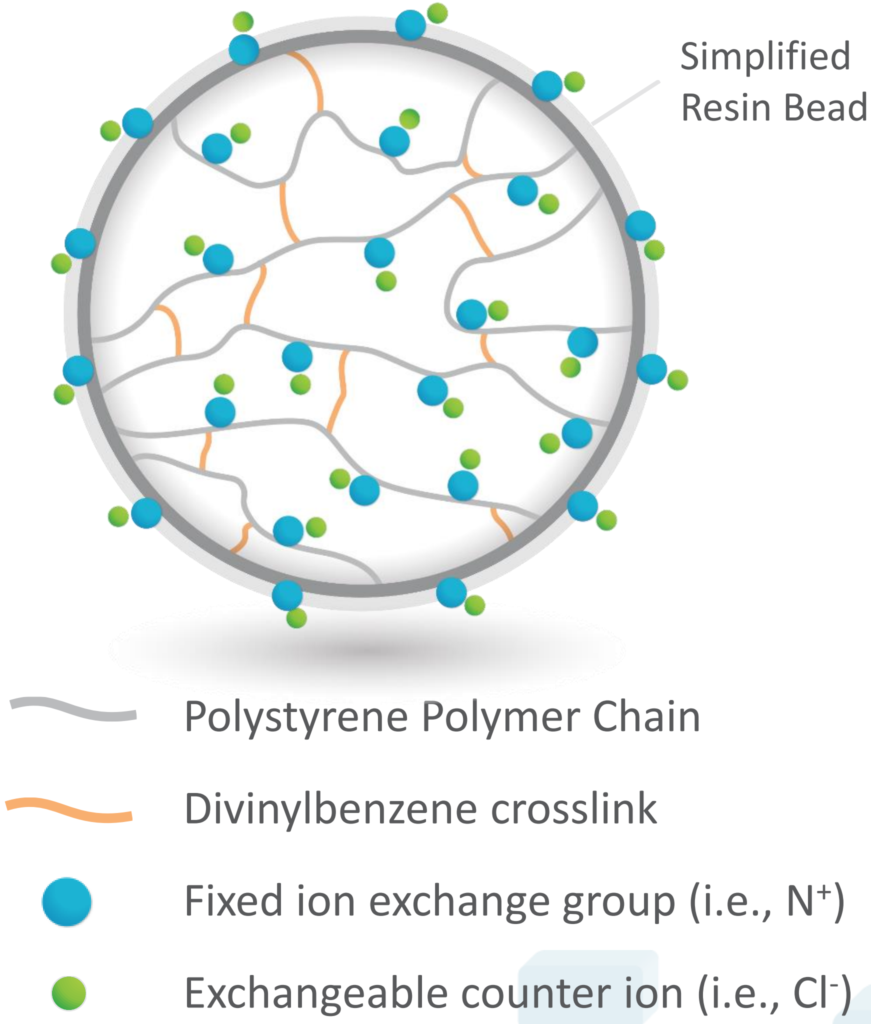
- Advantages
  - Effective on broad range of PFAS, including short chains
  - Not adversely impacted by elevated chloride concentrations
  - Effectively removes a variety of co-contaminants, including SVOCs, TPH, TOC, ammonia, hardness, etc.
- Disadvantages
  - What to do with the concentrated reject stream?
  - High energy cost
  - Corrosion control required in downstream water distribution system
  - Need to add minerals back into treated water stream for drinking water applications

How Does Ion Exchange Resin Remove PFAS?

Dual Mechanism of Removal

Ion Exchange (IEX) and adsorption

Regenerable IEX Resin SORBIX™ RePure



How Does Ion Exchange Resin Remove PFAS?

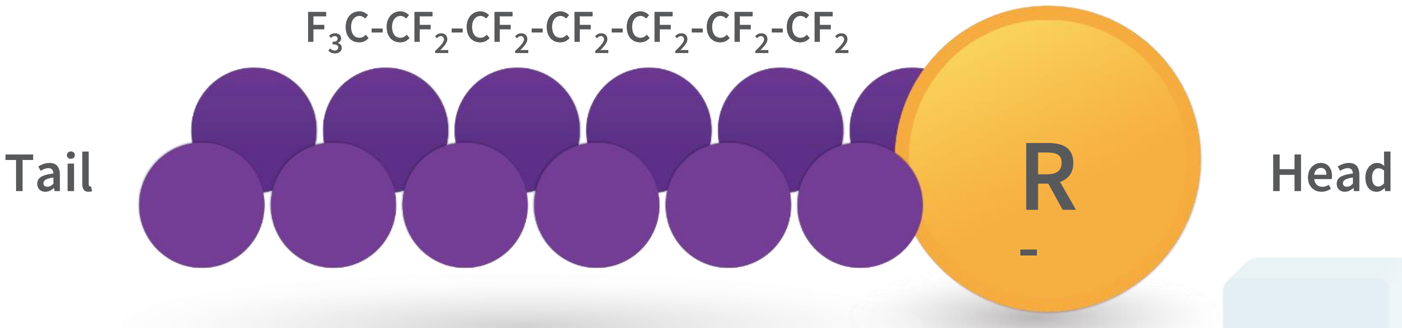
Dual Mechanism of Removal

Adsorption

Adsorbing to polystyrene polymer chain or divinylbenzene cross link via Van der Waals forces

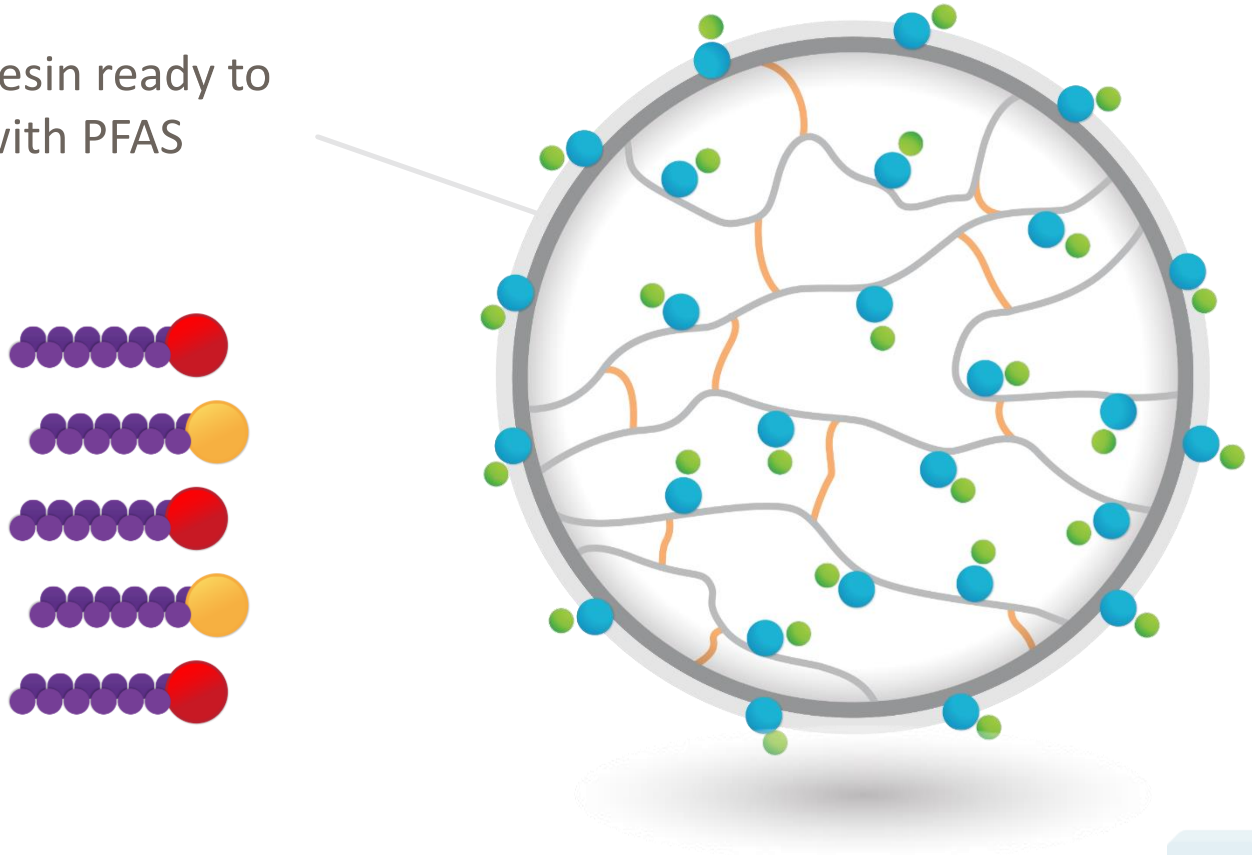
Ion Exchange (IEX)

Replacing exchangeable counter ion and attaching to fixed ion exchange group



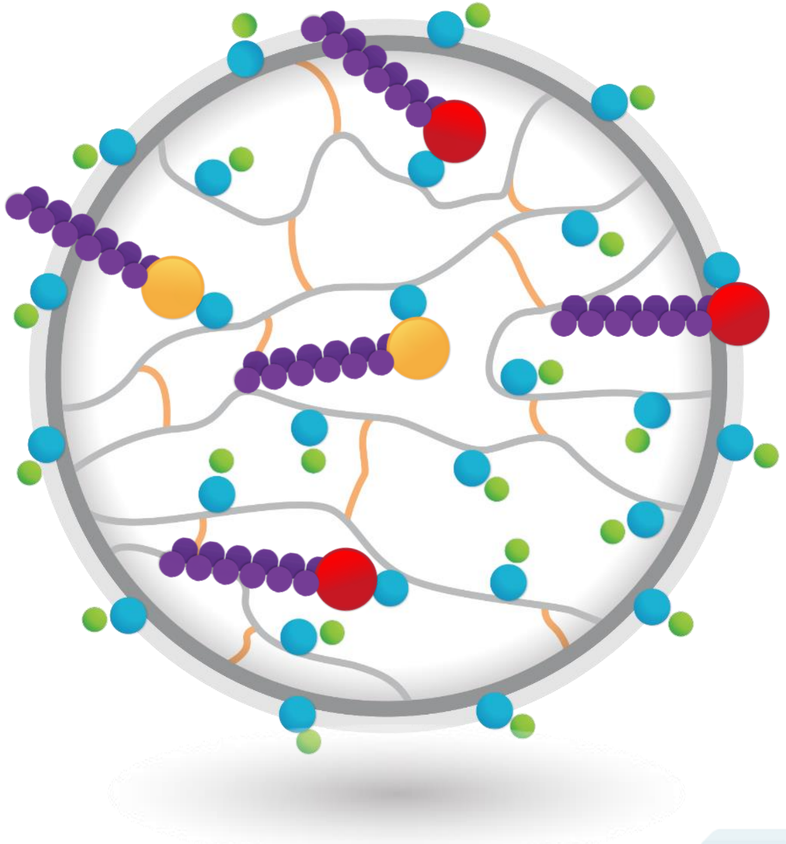
How Does Ion Exchange Resin Remove PFAS?

Fresh resin ready to bond with PFAS

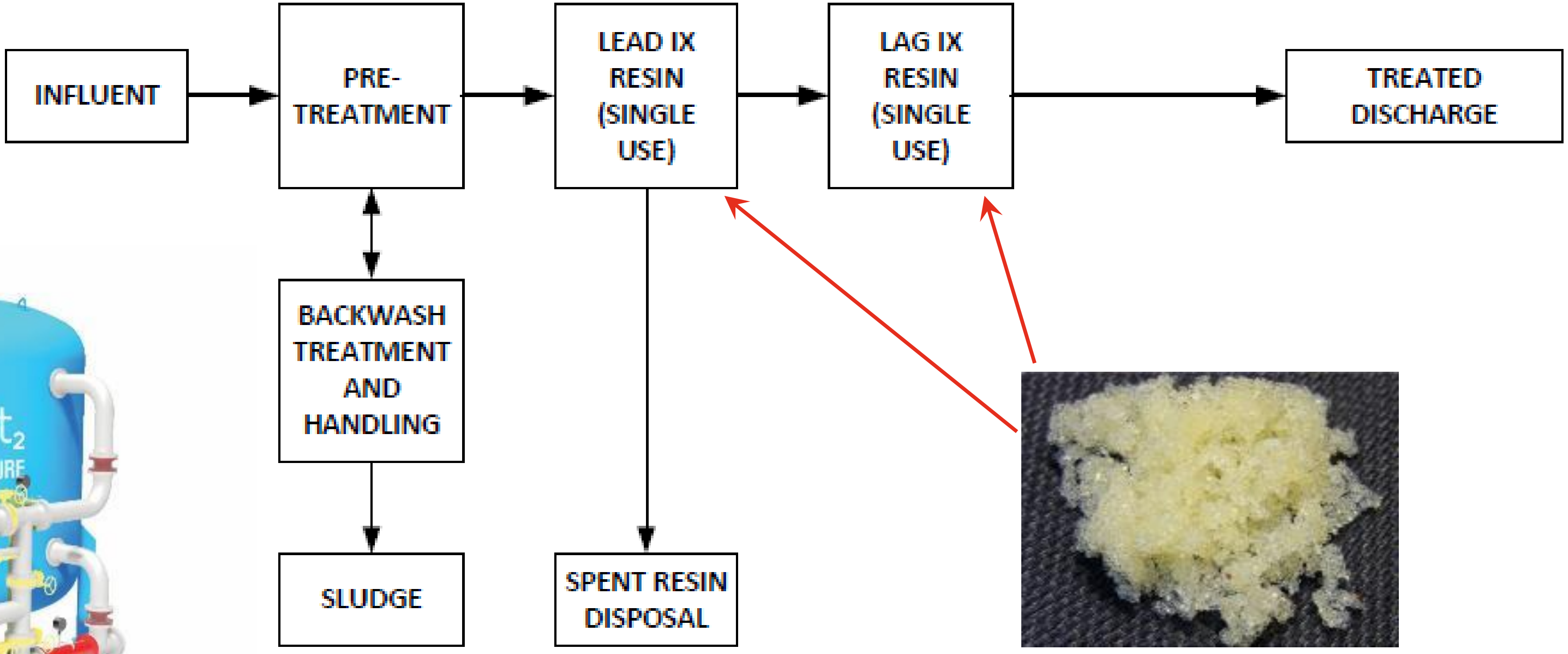


How Does Ion Exchange Resin Remove PFAS?

PFAS bonding to resin by displacing the Cl- ion and attaching to N+



Single-Use IEX Resin Process Flow



SORBIX PURE IEX Resin

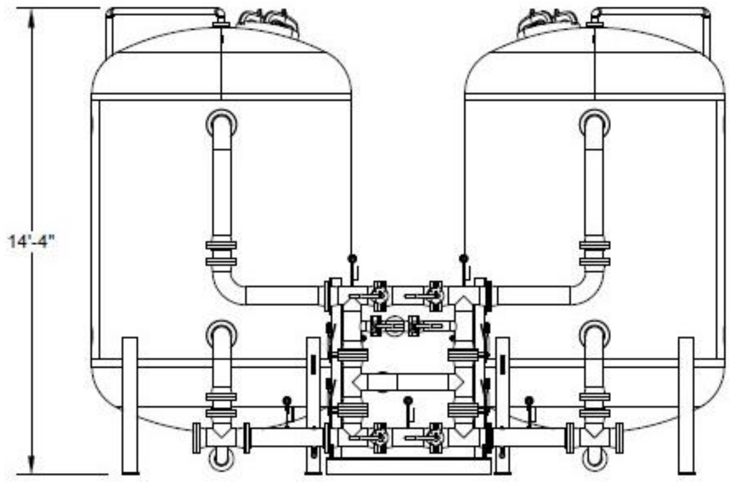
Single-Use IEX Resin Advantages and Disadvantages

Single-use IEX resin is commonly used in drinking water and groundwater remediation applications

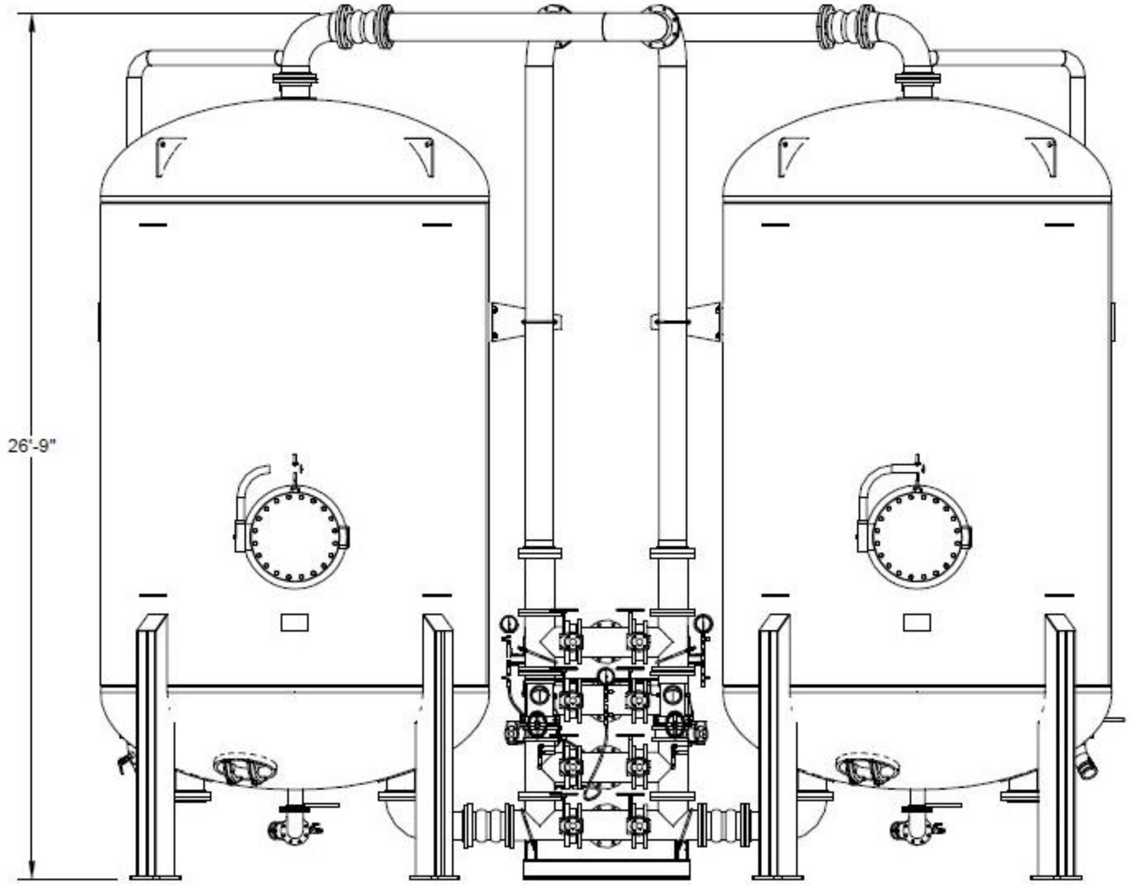
- Advantages
  - Effective on broad range of PFAS, including short chains
  - Significantly smaller footprint than GAC
  - Significantly higher PFAS removal capacity than GAC (in most situations) – lasts longer between media replacements
- Disadvantages
  - Can't be regenerated
  - Short chain PFCA removal efficiency decreased by elevated chloride concentrations (PFBA, PFPeA, PFHxA)
  - Generally doesn't remove co-contaminants

Single-Use Resin vs. GAC Size Comparison

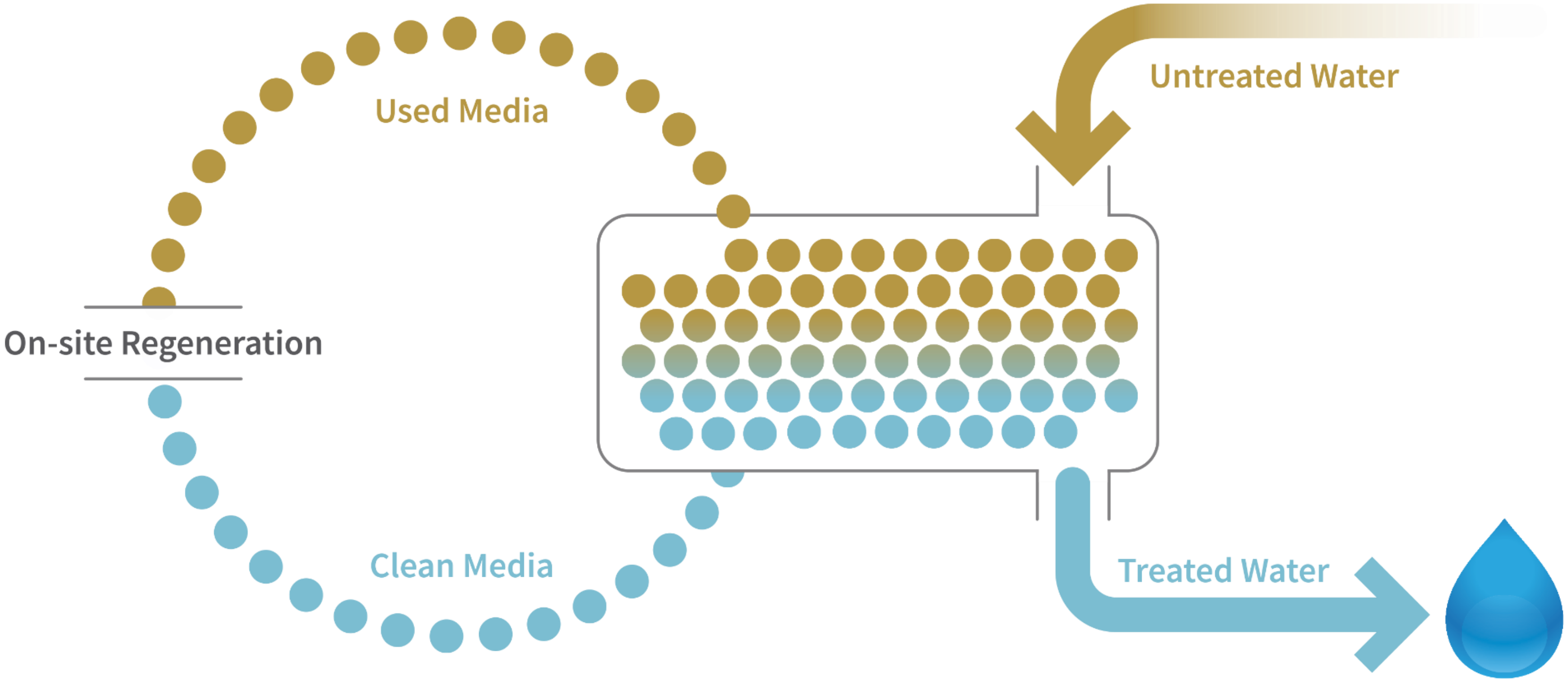
Single-use Resin
3 min EBCT



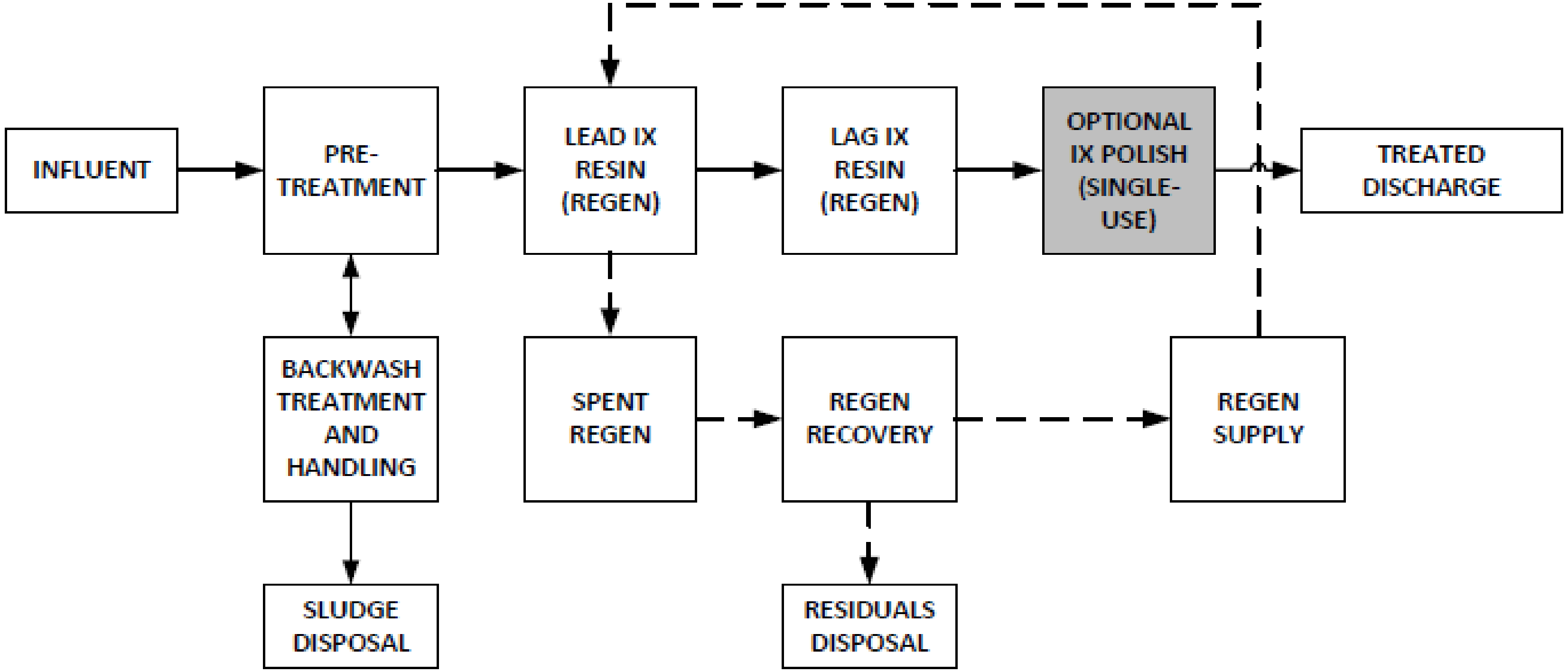
LGAC
10 min EBCT



Patented Regeneration Process



Regenerable IEX Resin Process Flow

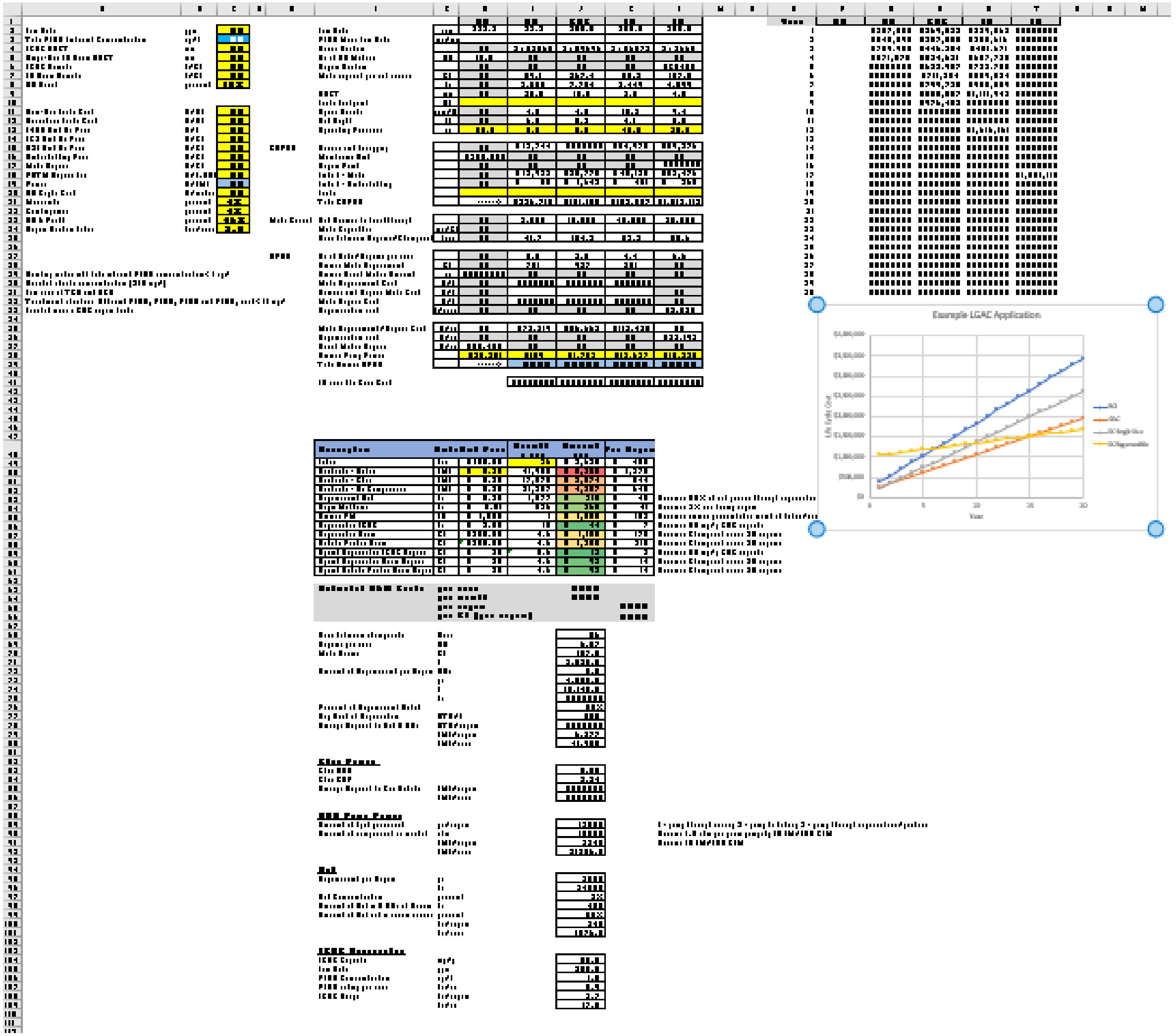


Regenerable IEX Resin Advantages and Disadvantages

Regenerable IEX resin is most commonly used in high PFAS concentration applications, including groundwater remediation, wastewater and landfill leachate

- Advantages
  - Effective on broad range of PFAS, including short chains
  - Higher PFAS removal capacity than GAC
  - Typically lowest lifecycle cost for high-concentration PFAS applications
  - Resin is regenerated on site, in the vessel. Multiple treatment systems can share a central regeneration system
  - Lowest waste generation
- Disadvantages
  - Power required for distillation process
  - Generally doesn't remove co-contaminants
  - Not approved for drinking water use in the US (NSF 61)

How Do You Select a Technology?

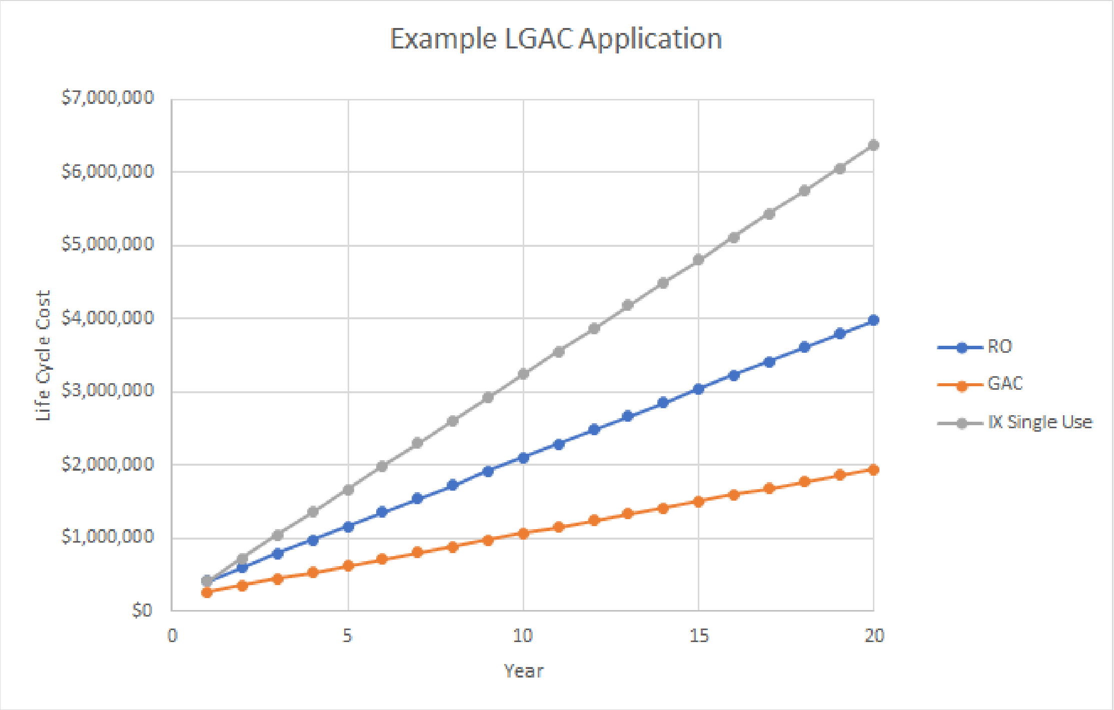


- Influent PFAS compound mix and concentrations
- Effluent PFAS regulations/treatment objectives
- Unit cost of power ($/kWh)
- Co-contaminants and foulants
- Inorganic anion concentrations, esp. chloride
- Disposal type/location/cost
- Liability management
- Footprint

Example Applications

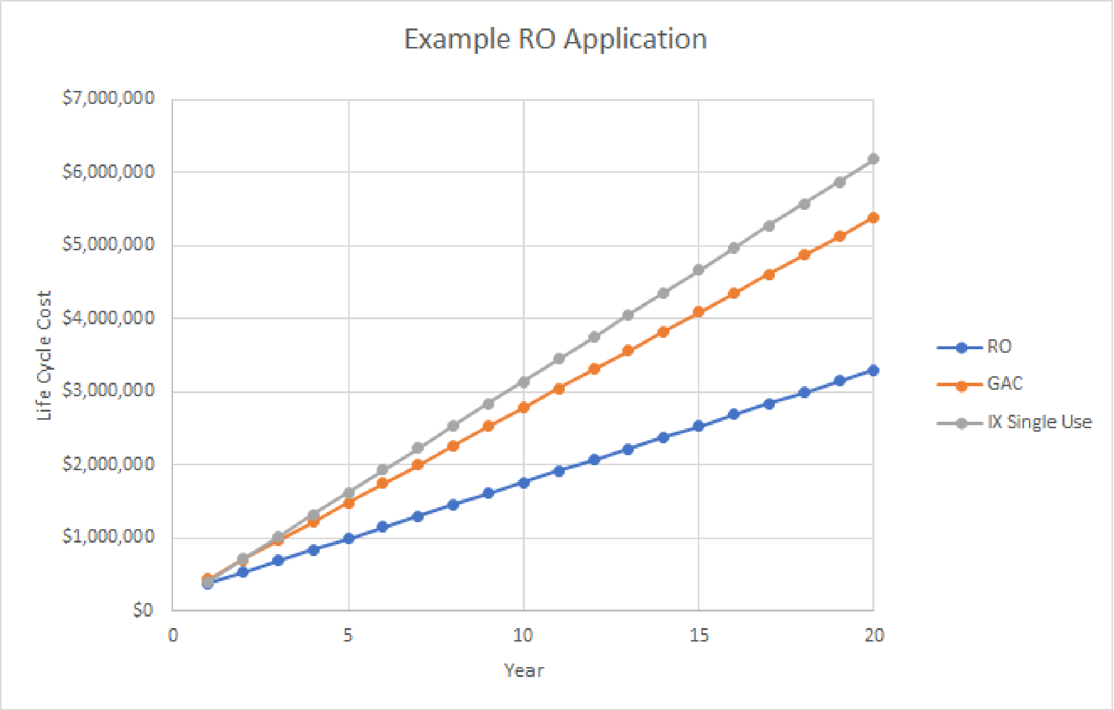
Example GAC Application

- Drinking water with total influent PFAS concentration < 1 ug/l
- Elevated chloride concentration (210 mg/l)
- Low levels of TCE and PCE that require treatment
- Treatment objective: Effluent PFOS, PFOA, PFNA and PFBA, each < 11 ng/l



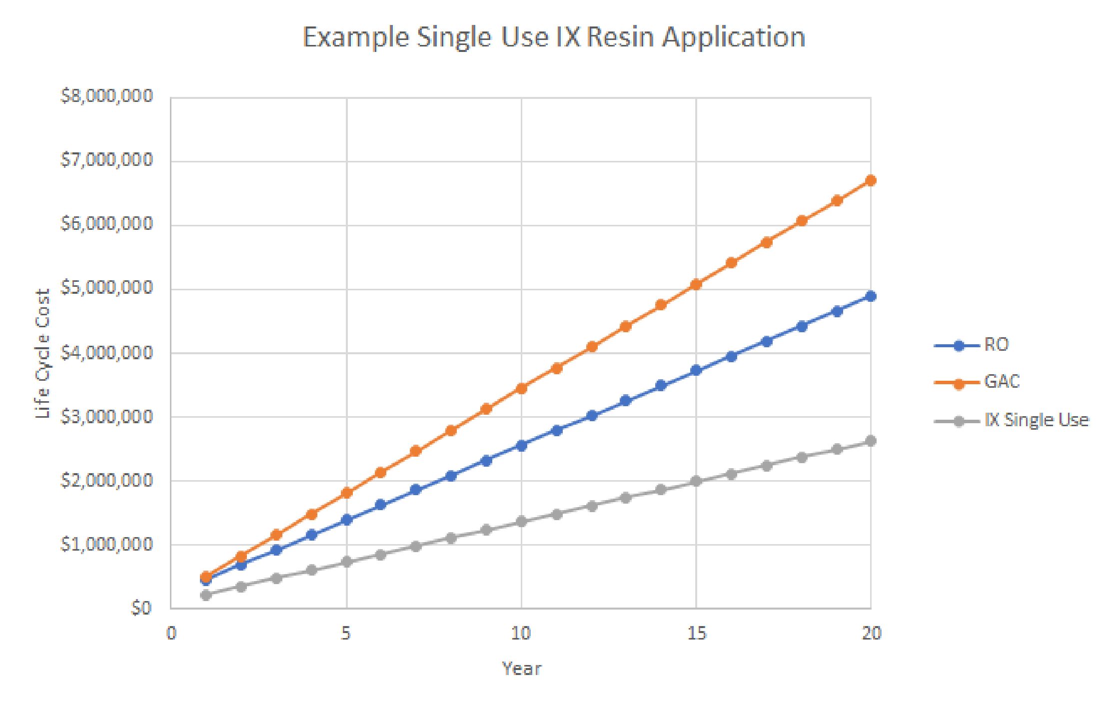
Example RO Application

- Drinking water with total influent PFAS concentration < 1 ug/l
- Elevated chloride concentration (210 mg/l)
- TOC = 12 mg/l (natural organic matter)
- Treatment objective: non-detect for all monitored PFAS compounds
- Low electricity rate
- **Ability to treat and dispose of RO reject stream**



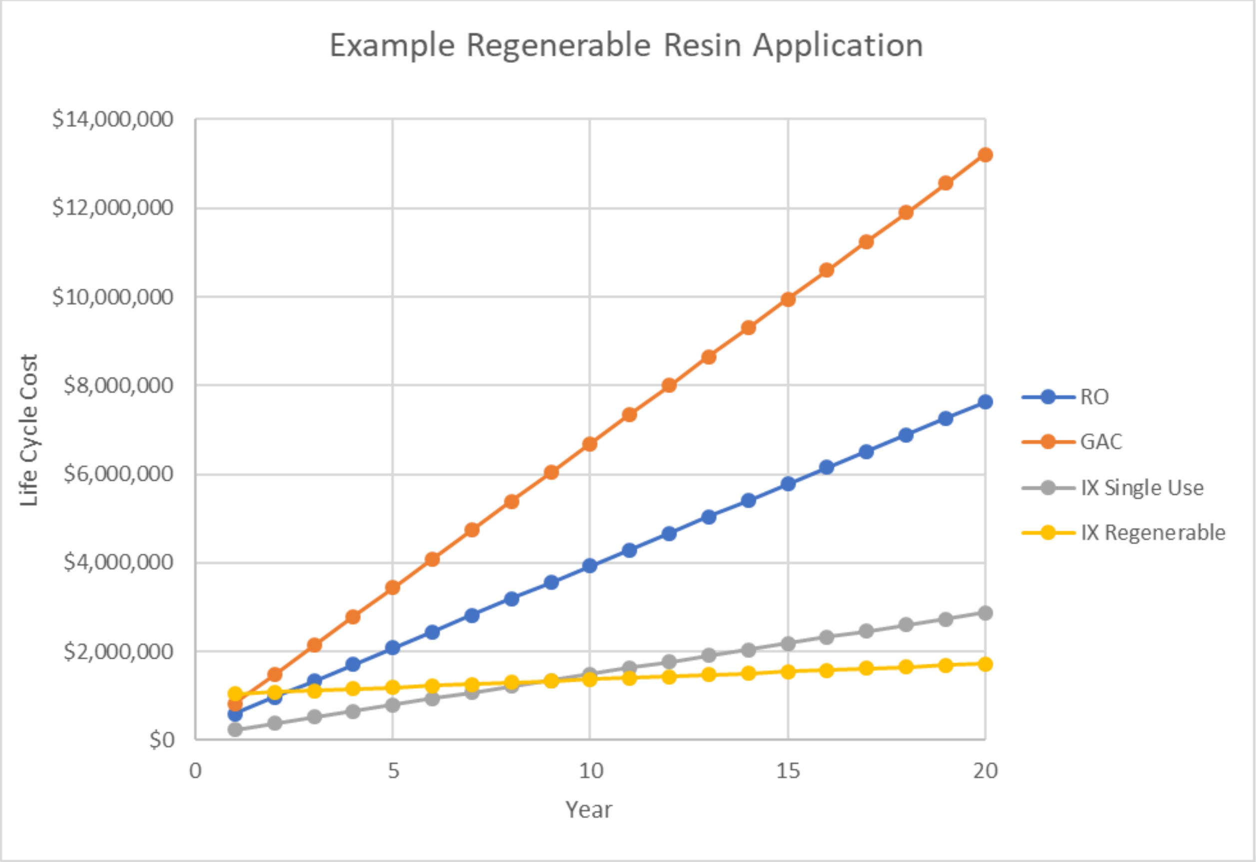
Example Single-Use Resin Application

- Drinking water with total influent PFAS concentration 3.5 ug/l
- Chloride concentration = 45 mg/l
- Treatment objective: non-detect for all monitored PFAS compounds



Example Regenerable Resin Application

- Groundwater remediation at former firefighting training area
- Total influent PFAS concentration = 100 ug/l
- Chloride concentration = 150 mg/l
- Treatment objective: PFOS + PFOA < 70 ng/l
- Client wants to minimize waste transport off site



Note: economics become even more compelling at higher PFAS concentrations or when using central regeneration

Case Study:

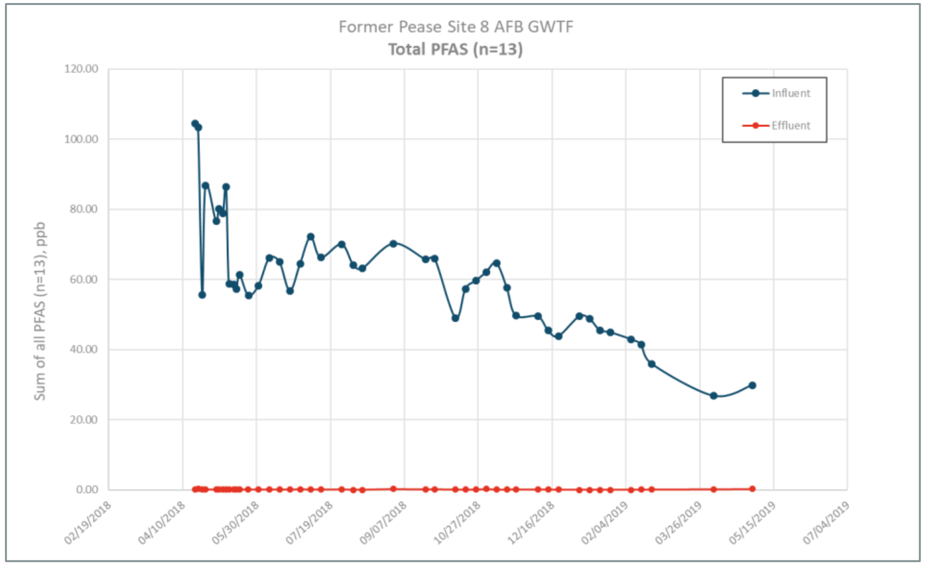
Portsmouth, NH Remediation and Drinking Water

Pease Site 8 Case Study

Opportunity:
- Former Pease Air Force Base, Portsmouth, NH
- 200-gpm Ground Water Treatment System
- Incoming PFAS = 60-100 ppb
- Contaminating local drinking water supply

Challenge:
- High PFAS levels from source zone
- Other contaminants – Iron and TOC
- GAC system already onsite
- Minimize waste generation

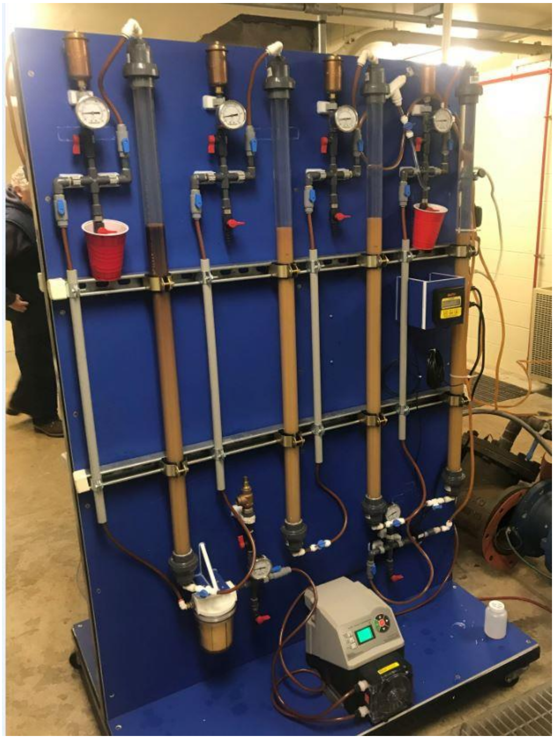
Solution:
- Side-by-side pilot test vs GAC
- Regenerable resin system more effective
- Lower lifecycle cost
- Full-scale treated effluent ND since day one
- No waste taken off-site since startup in April 2018



Down-Plume Drinking Water Treatment

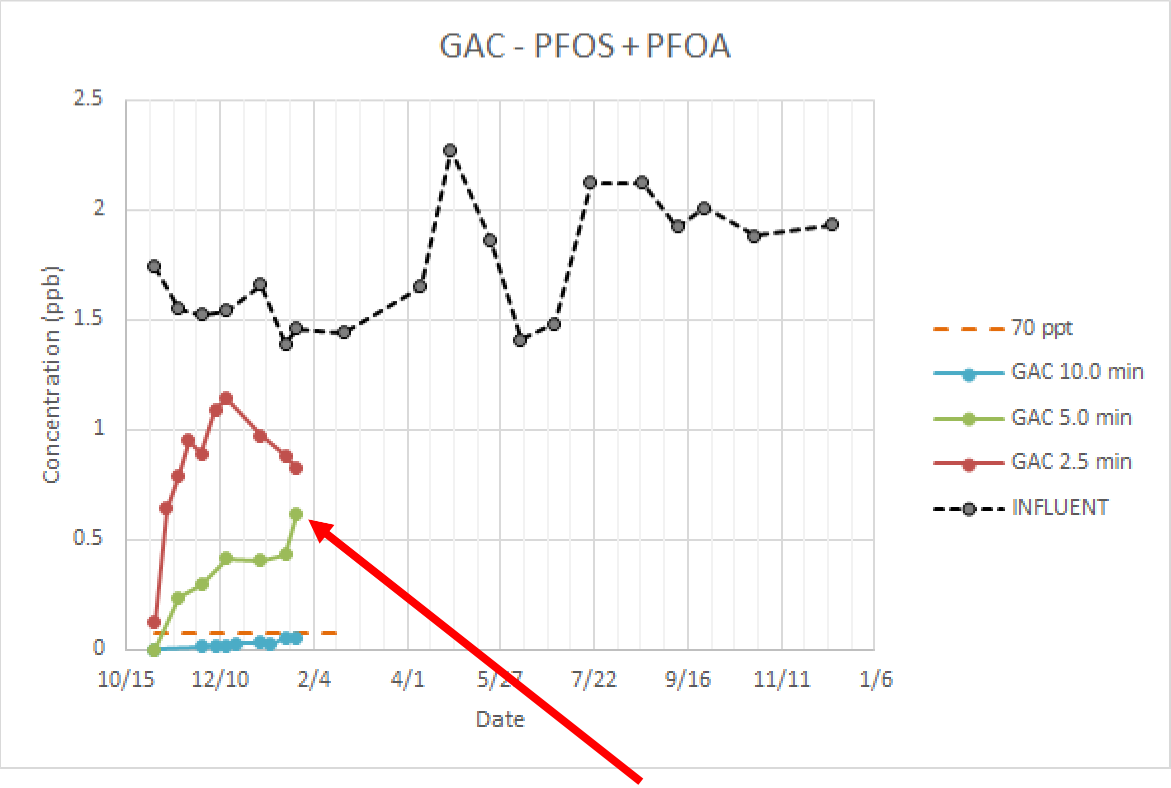
City of Portsmouth, NH

- Weston & Sampson – City's consulting engineer
- Utilized dual sided pilot skid for side-by-side testing: IX Resin vs. GAC
- Sampled & analyzed for 23 PFAS compounds out of each column
- Plotted breakthrough curves to compare effectiveness of IX Resin vs. GAC

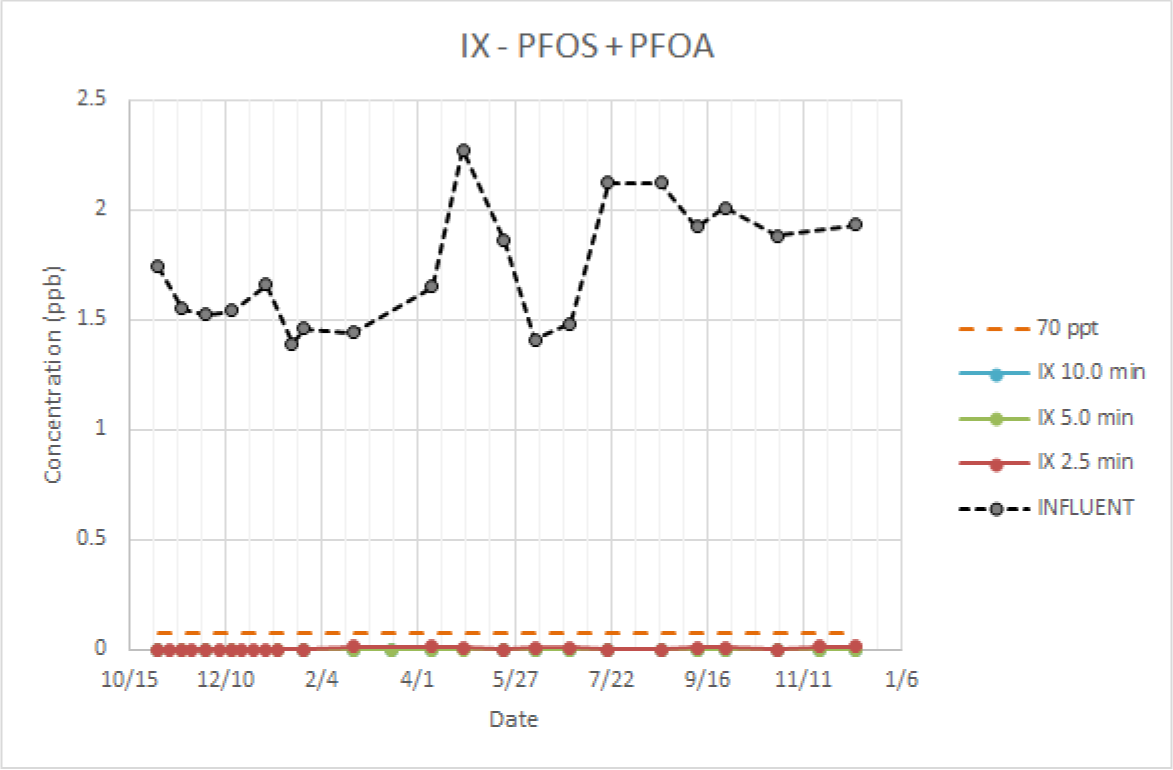


Removal Comparison – PFOS + PFOA

GAC



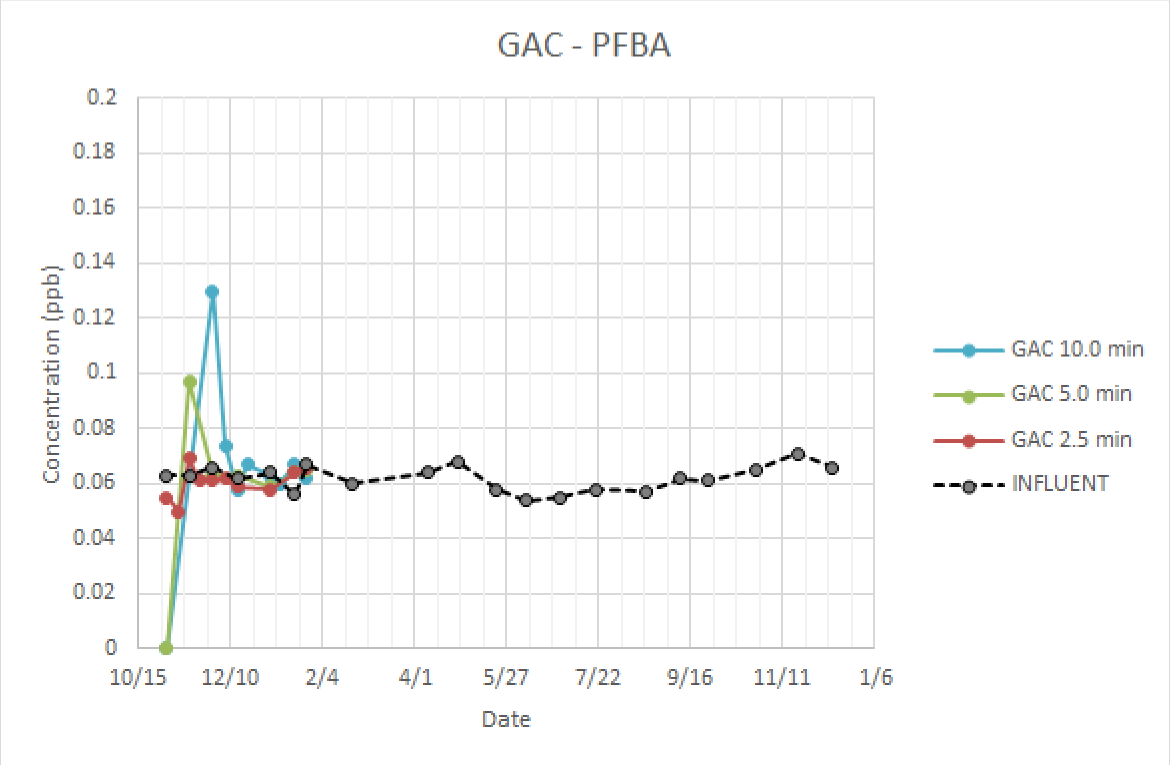
IX Resin



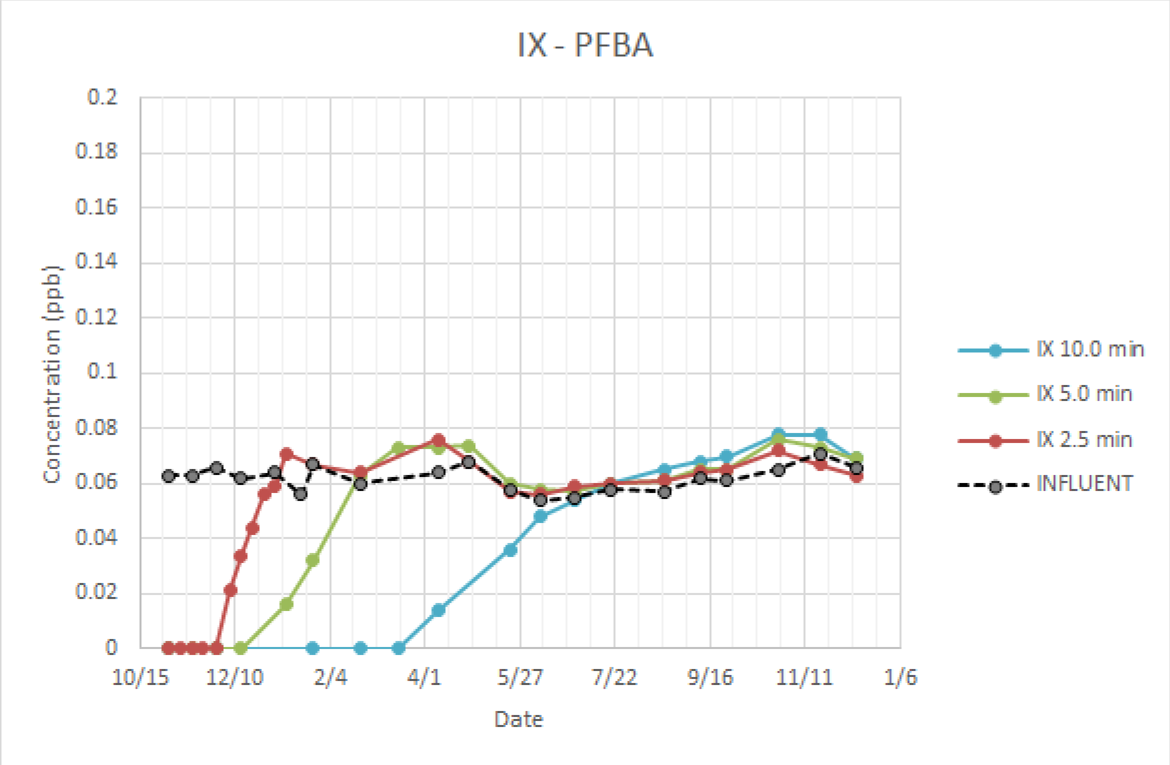
City Stopped GAC at 10,400 gal Treated

Removal Comparison – PFBA

GAC

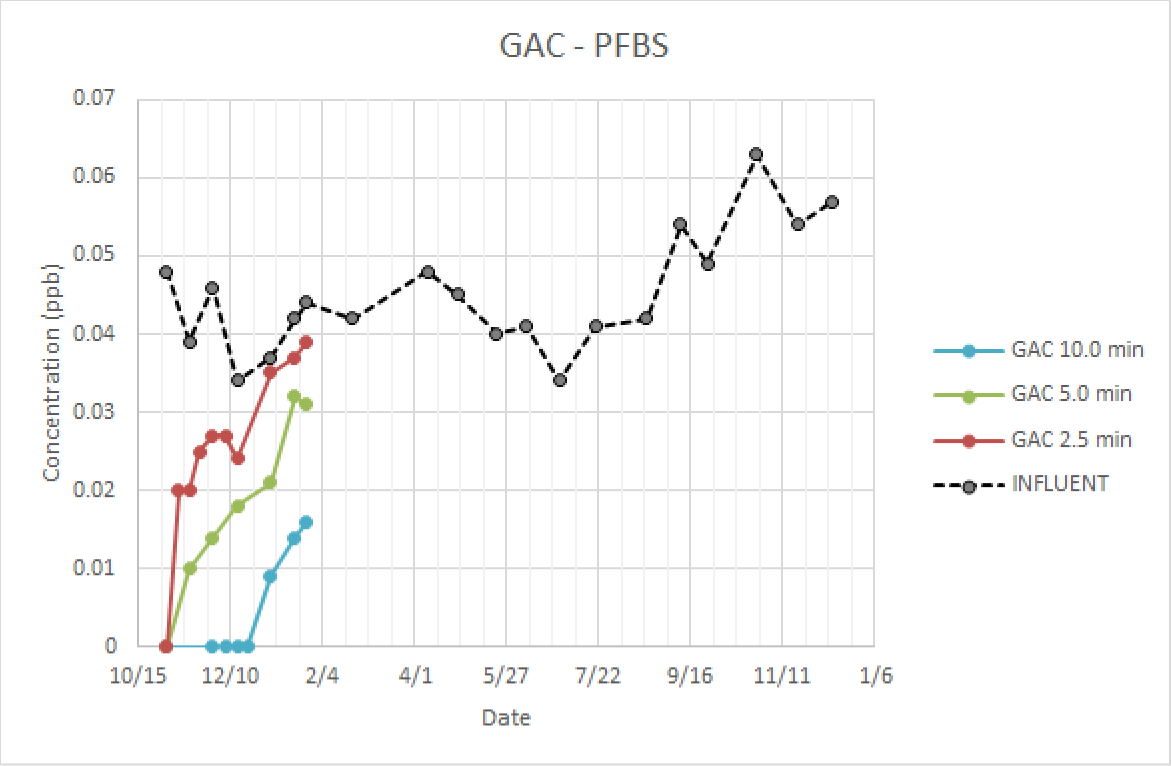


IX Resin

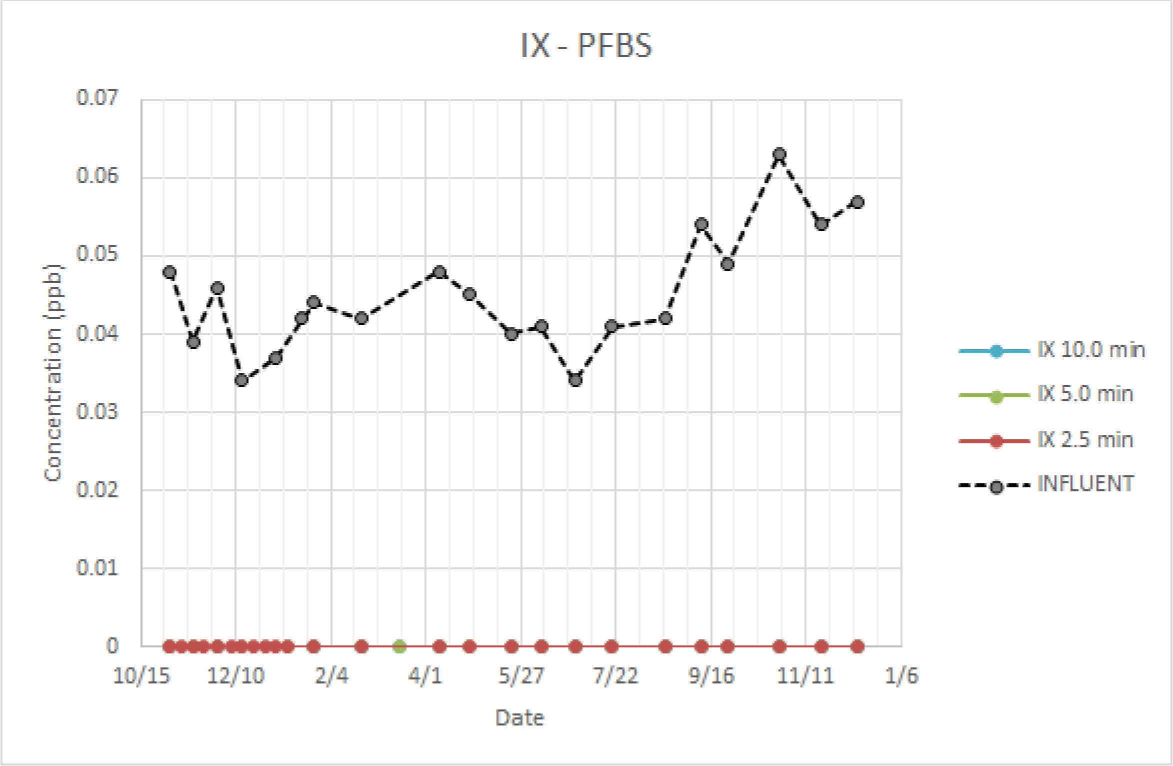


Short-Chain Sulfonic Acid - PFBS

GAC



IX Resin



Lifecycle Cost Comparison

Twenty-Year Present Worth Analysis (USD)
800-gpm Drinking Water Treatment Plant

Treatment Option	Capital Cost	**Annual Operating Cost**	**Present Worth Cost**	**Cost Reduction**
GAC	$2,474,000	$380,000	$7,633,000	-
Resin	$1,990,000	$97,500	$3,315,000	> 50%

Source: Weston & Sampson (independent consultant)

Summary

- There are 4 “proven” technologies for treating PFAS
- 3 are proven at full scale (so far)
  - GAC
  - Single-use IEX resin
  - Regenerable IEX resin
- Not a straightforward exercise to pick the right technology
- Homework should be done to select the most cost effective one

Questions?

Steve Woodard

(207) 210-1551

swoodard@ect2.com