PFAS Treatment Technologies Subgroup
Virginia Department of Health Office of Drinking Water
DRAFT Summary
June 22, 2021
Scheduled for 1.0 hours (10:00 a.m. – 11:00 a.m.)

1. **Opening (10:05 am)**

   ODW Southeast Virginia Field Office (SEVFO) Director, Dan Horne welcomed all Subgroup members and members of the public to the presentation on cost issues and factors. He advised everyone that the presentation would be recorded, so that those who were not present would be able to view it later.

   Dan then introduced the guest speaker, Dr. Erik Rosenfeldt, of Hazen & Sawyer.

2. **Presentation on cost issues**

   (Note: This summary does not attempt to capture all of the material presented, or the questions raised during the presentation. Please refer to slides and recording for additional details.)

   Dr. Rosenfeldt provided an overview of the major treatment processes currently available for PFAS removal – activated carbon (powdered and granular), ion exchange, and high pressure membranes (both reverse osmosis and nanofiltration). He included powdered carbon since it can be used as a short-term solution while a longer-term solution is implemented. He also gave other examples of phased approaches.

   He then moved to discussion of the costs of treatment systems, covering what factors go into the costs, including capital costs and operating costs. He gave examples of how certain design choices will have impacts to costs in other aspects of a project (e.g. – the choice of how tall the filter shell will be affects the building size, which has an impact on floor slab design and HVAC requirements). He also gave examples of how to get better comparisons between technologies (e.g., between ion exchange and granular carbon), and the role of disposal choices and costs in making treatment technology choices.

   The final portion of the presentation featured three case studies. The first case study was a surface water plant in Alabama, looking at both a Phase 1 solution and a future Phase 2 solution for a larger withdrawal. The second case study was a groundwater facility in New Mexico, comparing a larger centralized treatment facility with a smaller "wellhead treatment" approach, featuring a trailer-mounted facility. The final case study was a small (20 to 40 gpm) groundwater facility in New York.

   Dr. Rosenfeldt responded to a number of questions during the presentation. More questions were addressed during an ending Q&A session.

3. Adjournment

Dan adjourned the presentation at 11:18 a.m.

The following people from the Subgroup, public, and ODW attended the presentation:

Henry Bryndza (Dupont)
Wendy Eikenberry (Augusta County Service Authority)
Jamie Bain Hedges (Fairfax Water)
Mark Estes (Halifax County Service Authority)
Mike Hotaling (Newport News Water Works)
Russ Navratil (VA AWWA)
Kelly Ryan (Virginia American Water)
Dan Horne (ODW)

Nelson Daniel (ODW)
Robert Edelman (ODW)

Ellen Egen
Erik Rosenfeldt

Hazen

Experiences in PFAS Cost of Treatment

Erik Rosenfeldt, PE, PhD

Director of Drinking Water Process Technologies

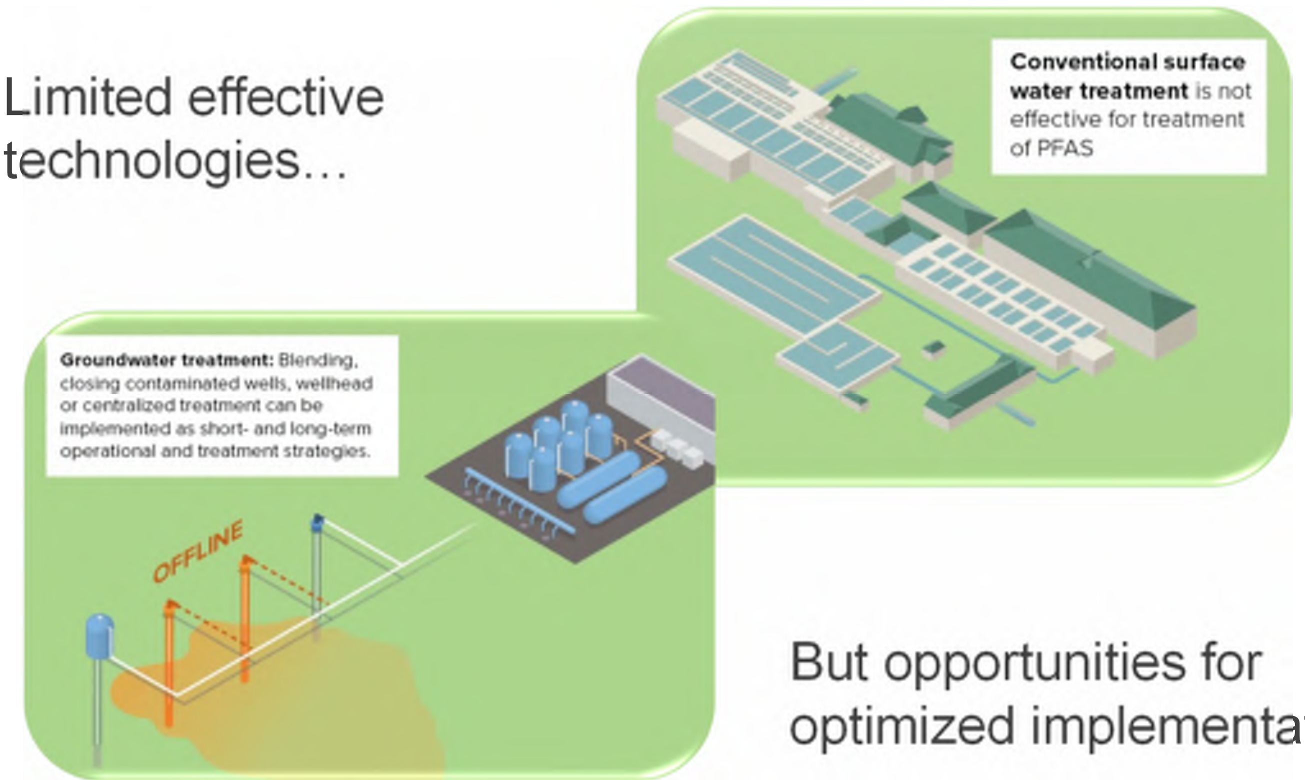
Agenda

- Introduction
  - **Treatment Technologies for addressing PFAS – PAC, GAC, RO, IX, alternative media, alternative approaches**
    - *Benefits and challenges to implementation*
  - **Examples of “Phased Approaches”**
    - *Piloting to distribution*
    - *“Shutting Down” groundwater wells to achieve treatment*
    - *Phased Implementation of Carbon – PAC → GAC*
- Cost of PFAS treatment systems?
  - **What goes into costs of treatment**
    - *CapX – Design Elements*
    - *OpX – Pumping, media replacement, hidden costs?*
    - *Size, additional treatment needs*
- Case studies

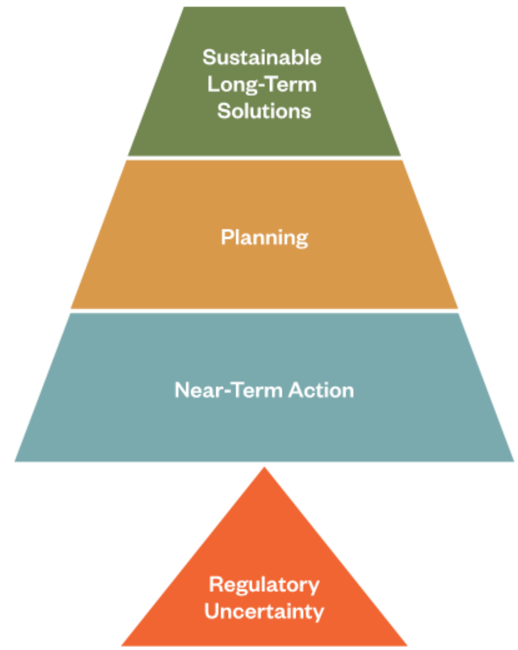
Introduction

PFAS Treatment Options in Drinking Water

Limited effective technologies…



But opportunities for optimized implementation



Summary of PFAS removals for various treatment processes

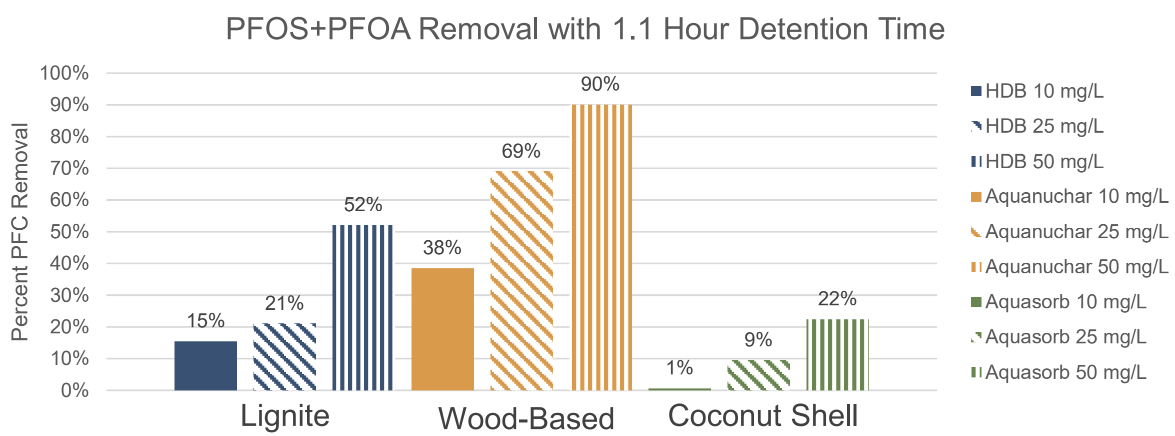
Removal <10%	Removal 10-90%	Removal > 90%

	M.W. (g/mol)	AER	COAG/ DAF	COAG/ FLOC/ SED/ G-or M-FIL	AIX	GAC	NF	RO	MnO4, O3, ClO2, Cl2, CLM, UV, UV-AOP
PFBA	214	Assumed	Assumed						
PFPeA	264								
PFHxA	314								
PFHpA	364								
PFOA	414								
PFNA	464		Unknown		Assumed	Assumed			
PFDA	514		Unknown		Assumed	Assumed			
PFBS	300								
PFHxS	400								
PFOS	500								
FOSA	499	Unknown	Unknown		Unknown	Assumed	Unknown	Assumed	Unknown
N-MeFOSAA	571	Assumed	Unknown		Assumed	Assumed	Assumed		Unknown
N-EtFOSAA	585		Unknown		Assumed	Assumed	Assumed		Unknown

Effective removal of PFAS from source waters depends on target, concentration, raw water quality and other variables (WaterRF 4322)

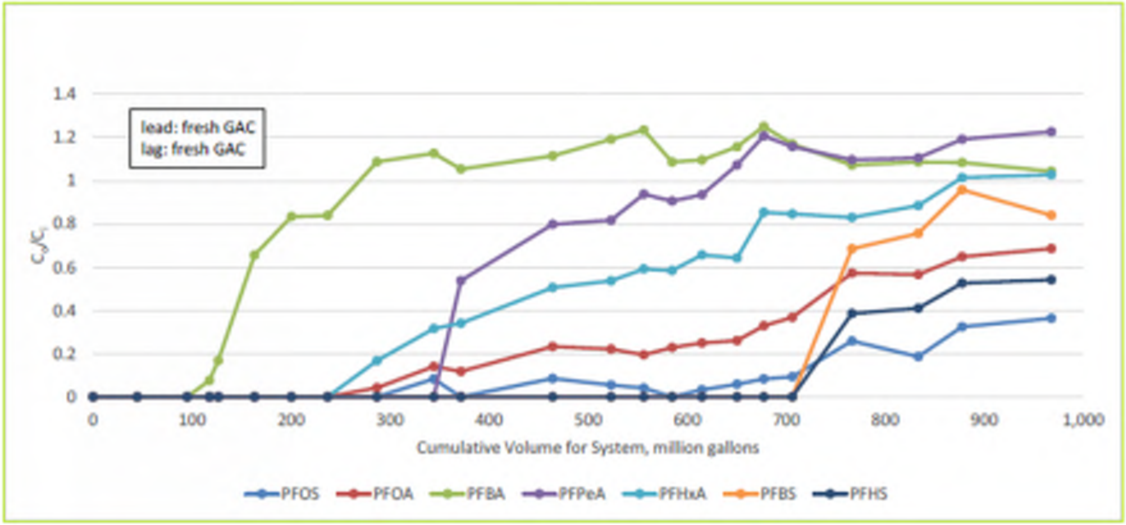
Powdered Activated Carbon Adsorption

- Effective for removal of long chain PFAS (PFOA, PFOS)
- Less effective for short chain PFAS
  - **Less affinity**
- Requires High PAC doses and extended contact times for efficient removal
- Performance impacted by water quality and type of carbon used
- Questions around fate of PFAS in plant residuals



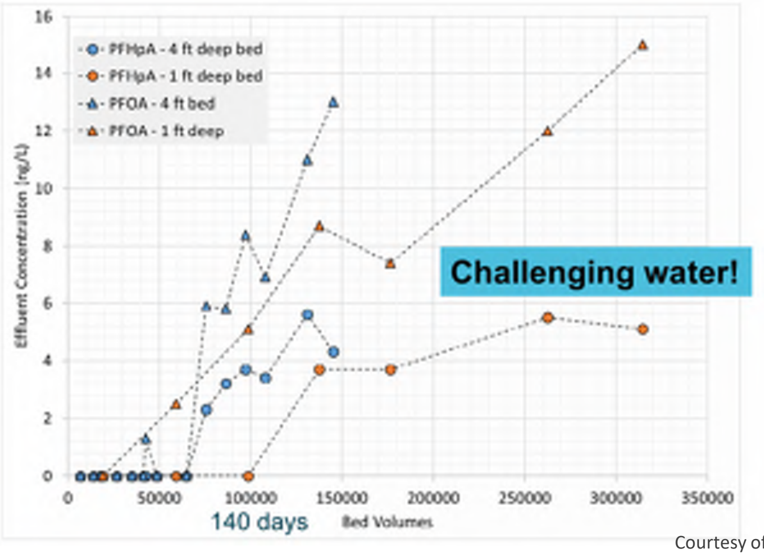
Granular Activated Carbon Adsorption

- Effective for removal of long chain PFAS (PFOA, PFOS)
- Less effective for short chain PFAS
  - Less affinity
  - Breakthrough earlier
  - Carbon usage can be significantly higher
  - Higher O&M costs for GAC regeneration
- Spent Carbon “Reactivation” Possible



Ion Exchange

- PFAS are anions so ion exchange can be effective for removal
- Resin is typically not regenerated at exhaustion due to limitations on discharge
- Typical approach is offsite disposal (incineration)
- Suppliers tout resins selective for PFAS species



Courtesy of Purolite

Reverse Osmosis / Nanofiltration

- High Pressure membranes provide compound exclusion from permeate
- As close to a "complete" PFAS barrier as exists today
- PFAS concentrated in the reject stream, leading to disposal challenges
- "Loose" NF membranes are being examined for short- and long- chain PFAS rejection at reduced O&M

Low Pressure Reverse Osmosis Pilot Data

Parameter	RO Influent (ng/L)	RO Effluent (ng/L)
PFOS +PFOA	18 - 26	ND
PFHxA	19 - 20	ND
PFPeA	16 - 17	ND
PFMOAA	320 - 750	ND – 11
PFO2HxA	12 - 26	ND
GenX	7 - 12	ND
Sum of 45 PFAS tested	423 - 892	ND - 11

(Data provided in-kind to WRF 4913)

RO concentrate at levels 7 – 10x influent

Comparison of PFAS Removal Technologies

PAC

- Effective for removal of long chain PFAS (PFOA, PFOS)
- Less effective for short chain PFAS
- Many facilities may already have PAC
- High doses of PAC required
- Long contact time ideal
- Variable PAC performance (water quality and carbon)
- Impacts to solids handling?

GAC

- Effective for removal of long chain PFAS (PFOA, PFOS)
- Less effective for short chain PFAS
- Effective Removal of many CECs
- Media can be reactivated and put back into service
- EBCT required ~ 10 – 15 minutes

Ion Exchange

- Effective for removal of long chain PFAS (PFOA, PFOS)
- More effective for short chain PFAS
- PFAS Specificity a blessing and a curse
- No media regeneration process
- EBCT ~ 2 – 4 minutes

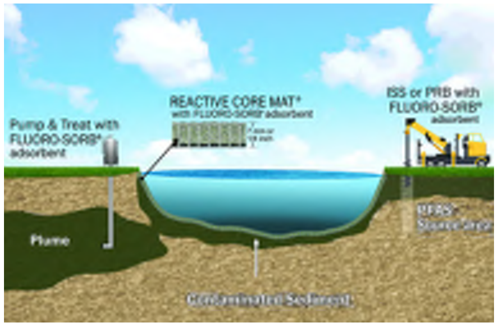
Reverse Osmosis / Nanofiltration

- Effective barrier to PFAS and *almost all* additional CECs
- High energy use
- Disposal challenges of highly concentrated PFAS reject stream

Novel / Alternative Media

Benefits

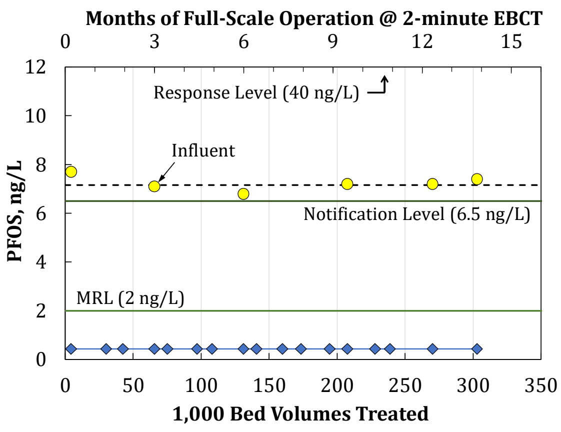
- Similar EBCT as IX but potentially lower cost
- NSF Certified

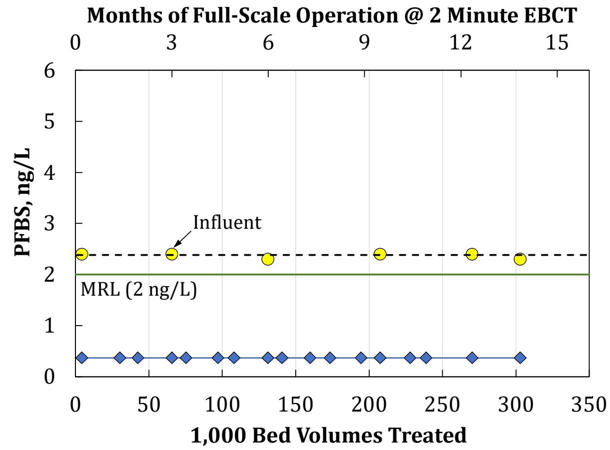


Drawbacks

- Limited industry track record
- Testing necessary

https://www.mineralstech.com/business-segments/performance-materials/cetco/environmental-products/products/fluoro-sorb

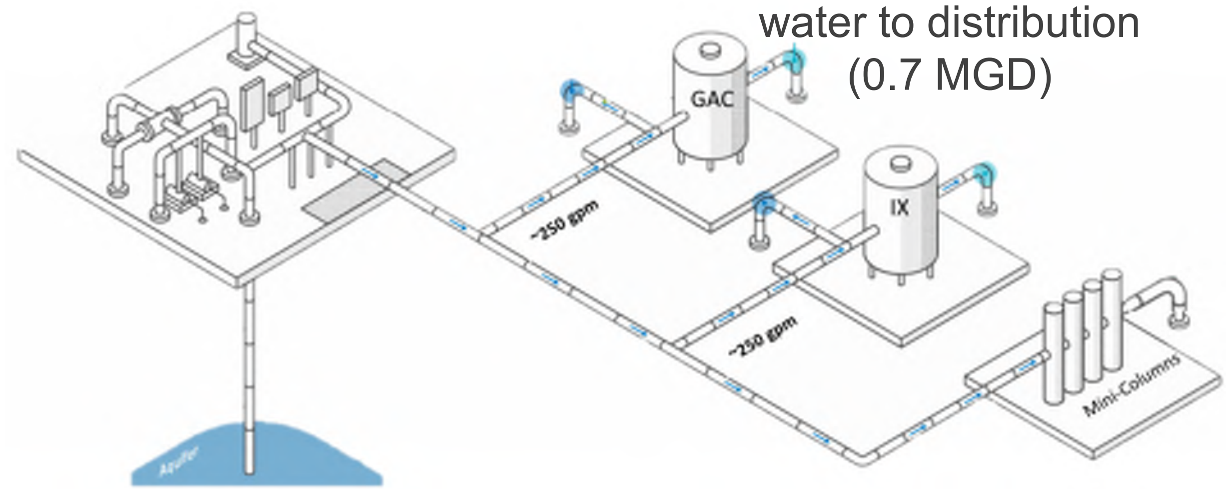


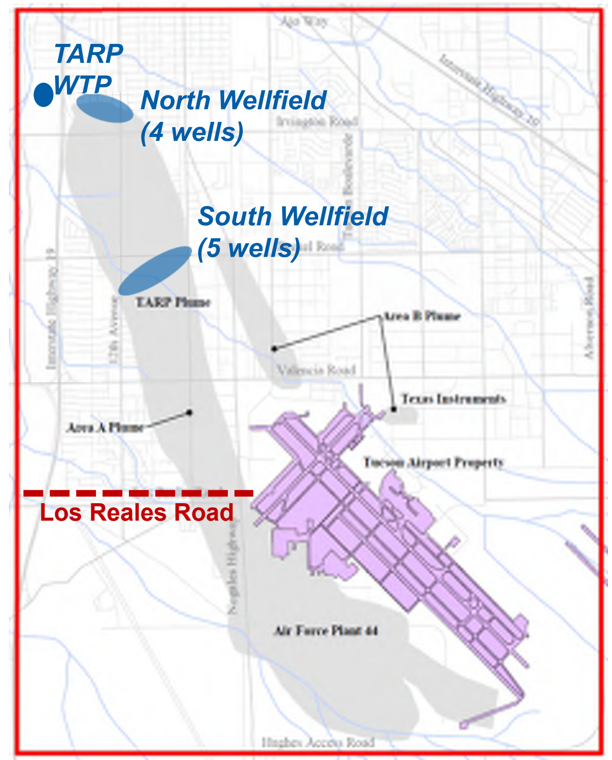


Examples of Phased Approach

“Piloting” Groundwater Technology while meeting demands

Both “pilots” can provide water to distribution (0.7 MGD)





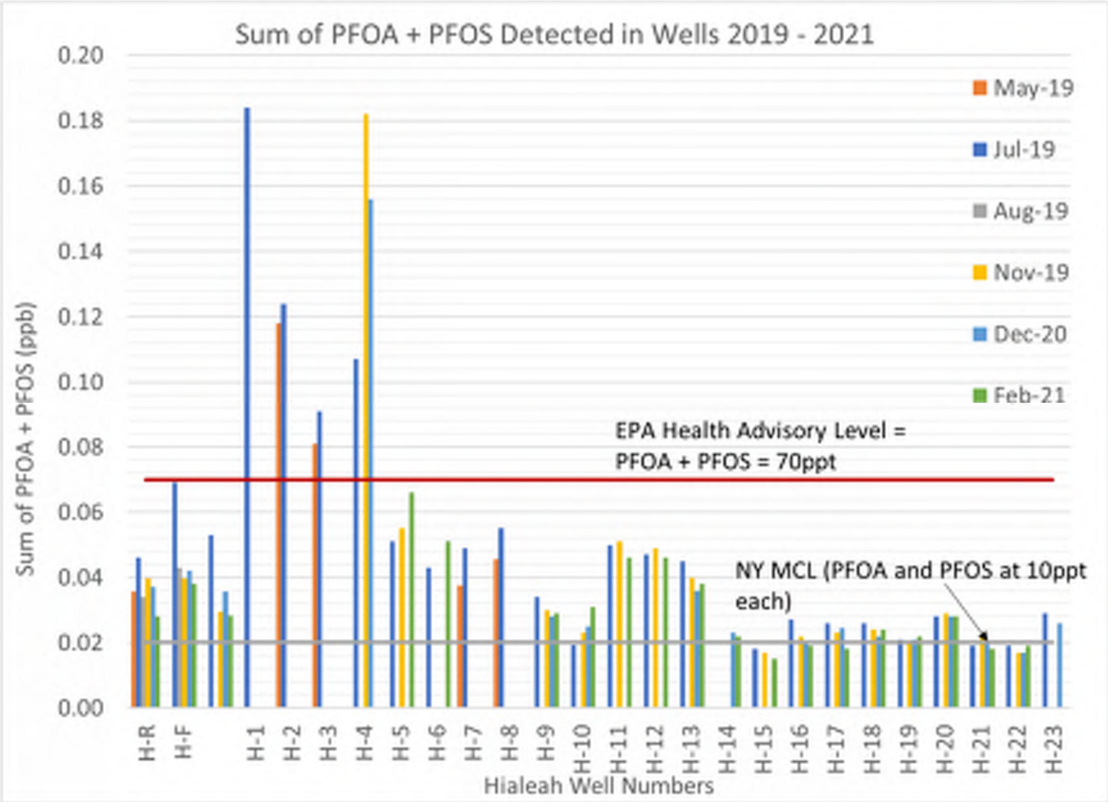
TARP =
Tucson International Airport Area Groundwater Remediation

Examples of Phased Approach

Short-term blending or removing wells from service to achieve PFAS limits

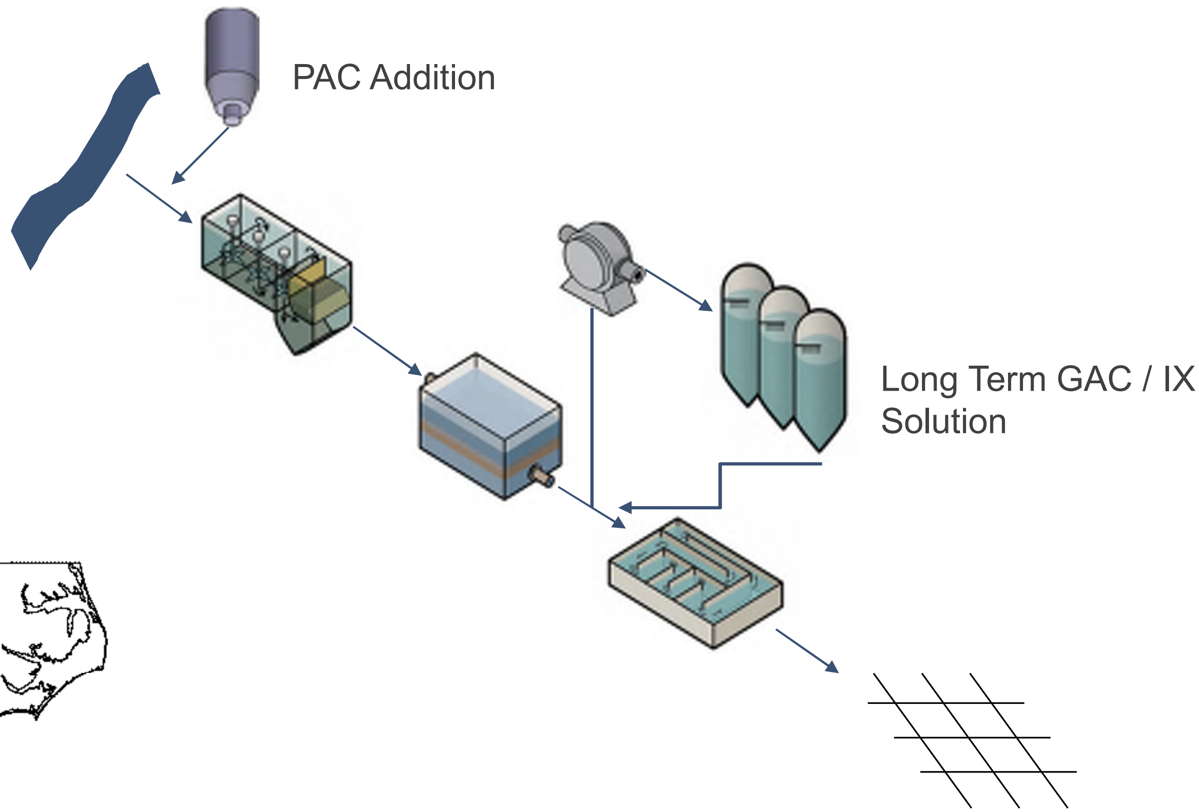
- 60 – mgd groundwater plant
- Served by 23 large wells (> 3 mgd each)
- H-1 – H-4 largely impacted by PFAS
- H-14 – H-23 are highest water quality

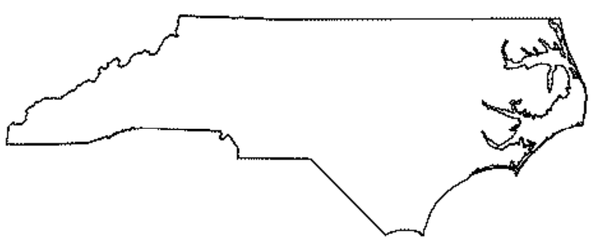
- *Upon observing this trend, utility removed wells H-1 – H-3 from service, dramatically reducing finished water PFOA + PFOS from 68ppt - ~40ppt*



Examples of Phased Approach

- Conventional Treatment Plant
- Detected Elevated PFAS
- Install more PAC capacity and more effective delivery
- Within 5 years, implement GAC or IX technology for PFAS removal





Cost Factors

What goes in to cost of treatment evaluations

Capital Cost

- Cost of Equipment
- Cost of Pumping Facilities!
- Cost of Facility – concrete pad, building?
- Cost of supporting facilities
  - **Chemical systems**
  - **Yard piping**
  - **Site Work**
  - **Electrical, I&C**
- Cost of residuals / concentrate handling
- How to handle potential cost of lost infrastructure?

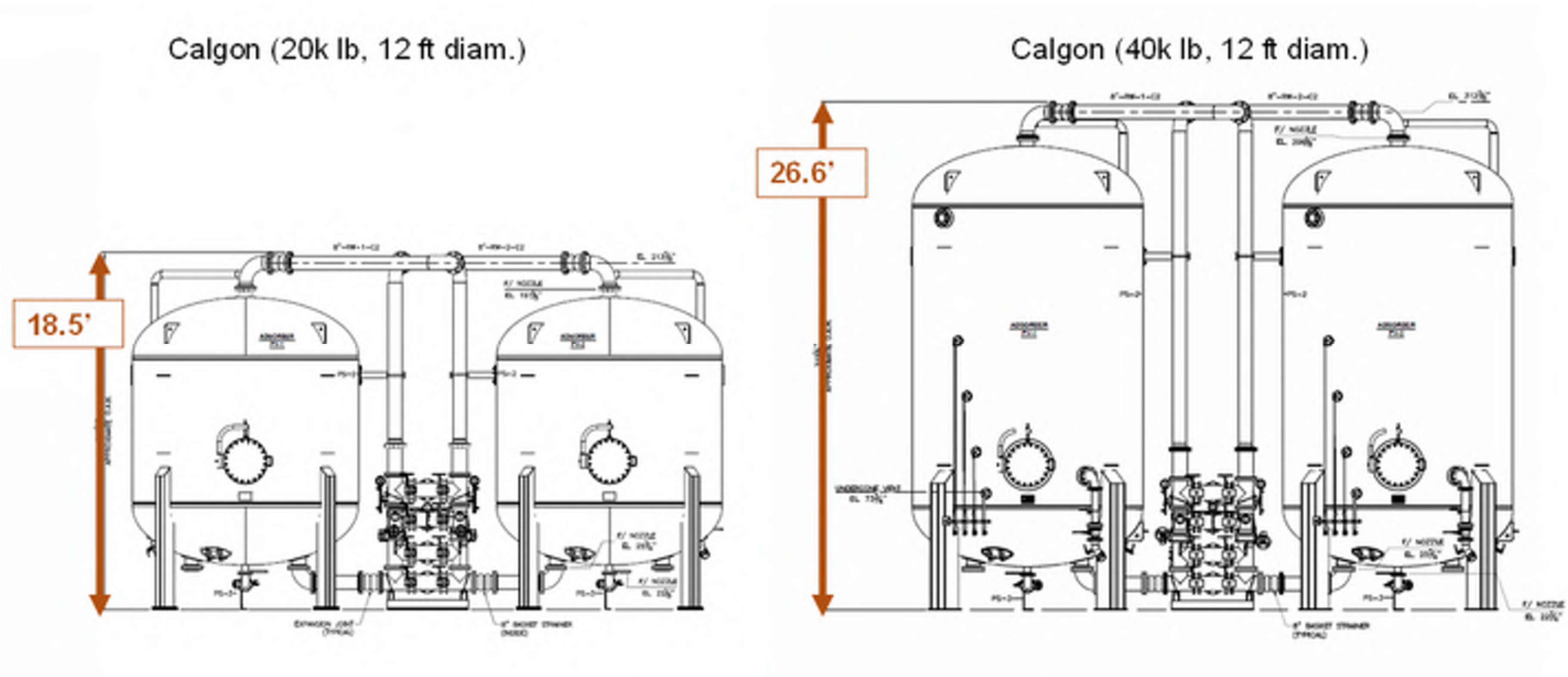
Operating Cost

- Cost of media / element replacement
  - **Water quality**
- Cost of pumping
- Cost of sampling
  - **Ex 1: Small System with 1 impacted wells**
    - *3 PFAS samples every 2 weeks (raw, after lead, finished).*
    - *At $250/sample this is $19,500/year*
  - **Ex 2: Larger System with 8 trains**
    - *1 "raw", 1 "finished" and 8 "intermediate"" (after lead) samples. Sample every 2 weeks.*
    - *At $250/sample this is $65,000 / year*
- Cost of media disposal (if necessary)
- Cost of residuals or concentrate handling

Vessel Configuration – GAC or IX

	Lead-Lag	Parallel
Pros	• Allows for longer EBCT • Full media utilization • No down time • Potential to reduce sampling frequency	• Less vessels needed • Lower capital cost • Lower footprint
Cons	• More vessels needed • Higher pressure loss • Higher capital cost • Higher footprint	• Special permitting • Risk of contaminant breakthrough • Down time (media replacement)

System Heights



What goes in to cost of treatment evaluations

Capital Cost	Operating Cost

Capital Cost

- Cost of Equipment
- Cost of Pumping Facilities!
- Cost of Facility – concrete pad, building?
- Cost of supporting facilities
  - Chemical systems
  - Yard piping
  - Site Work
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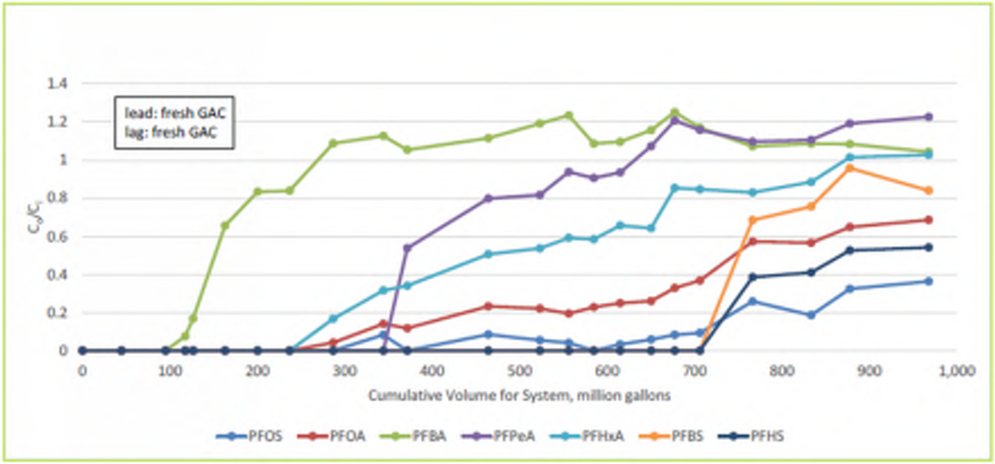
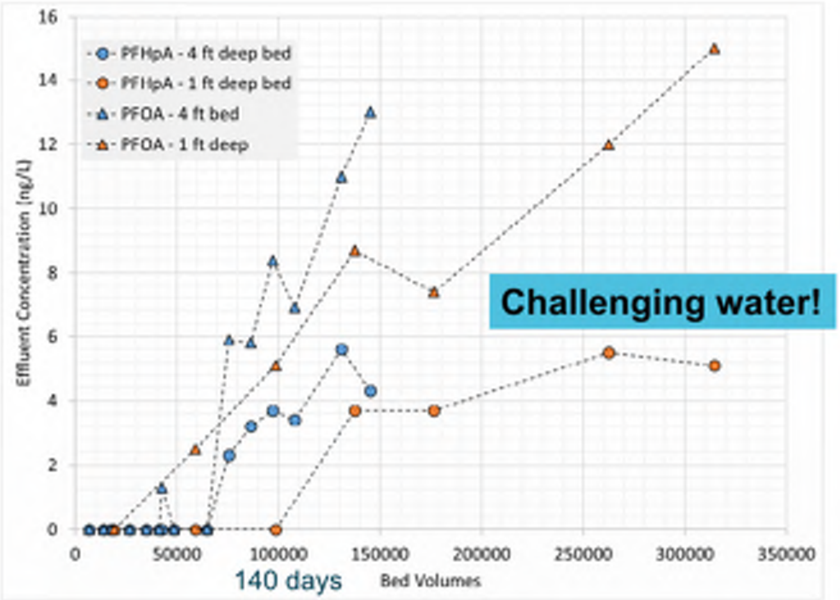
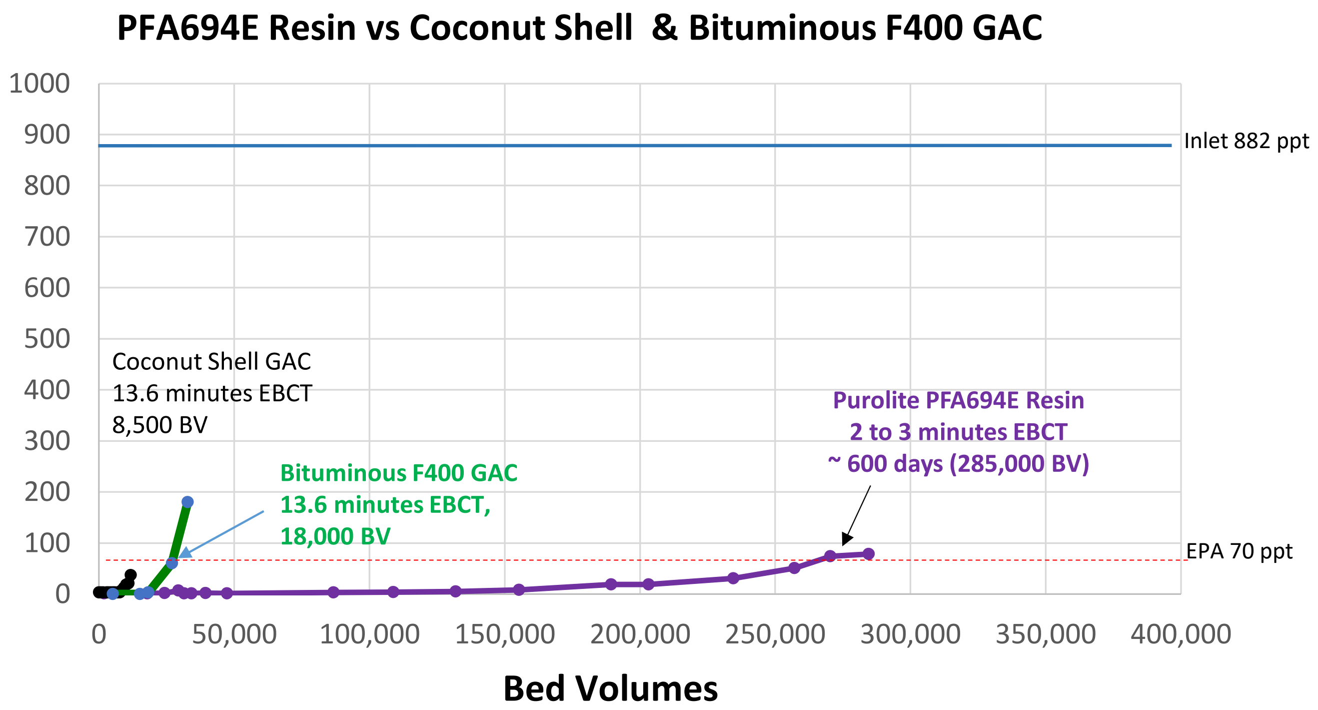
GAC or IX? Media selection is a big challenge





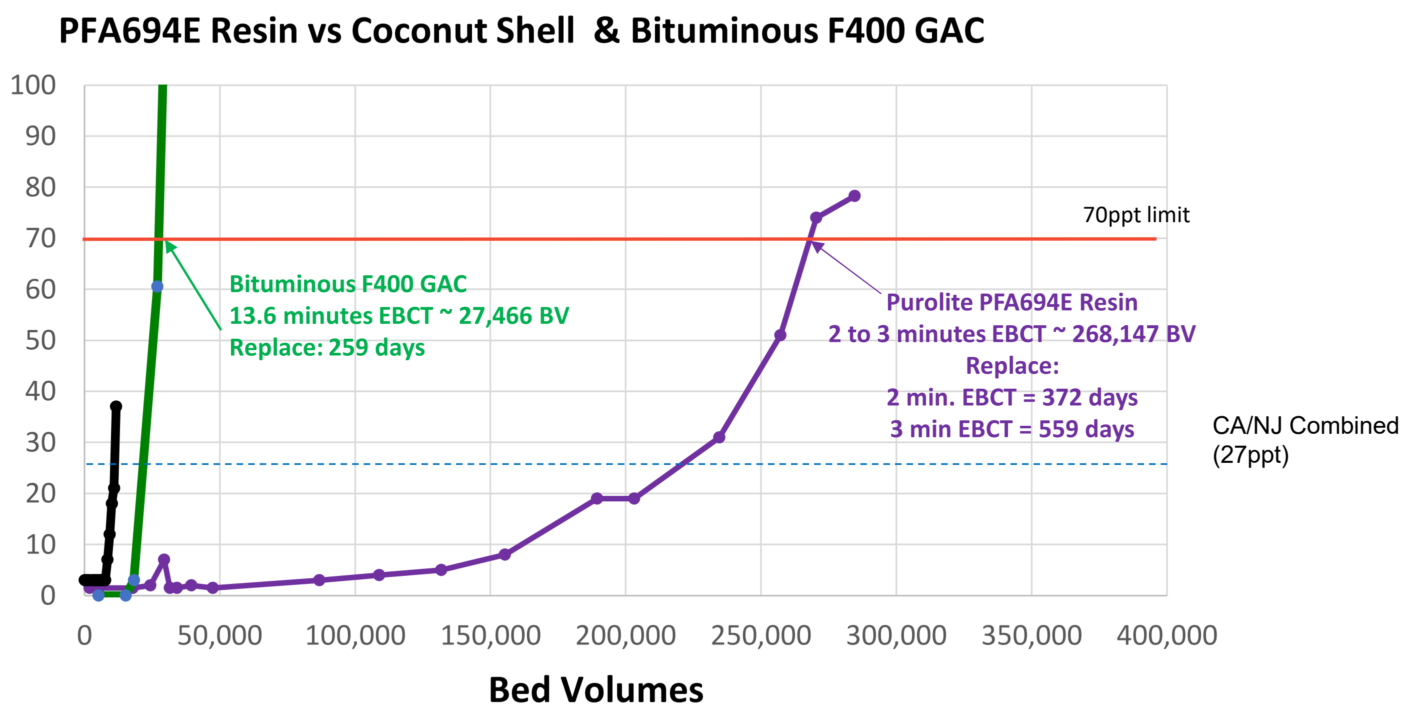
Comparing IX and GAC not straight forward

Here's what their data shows when they describe it…



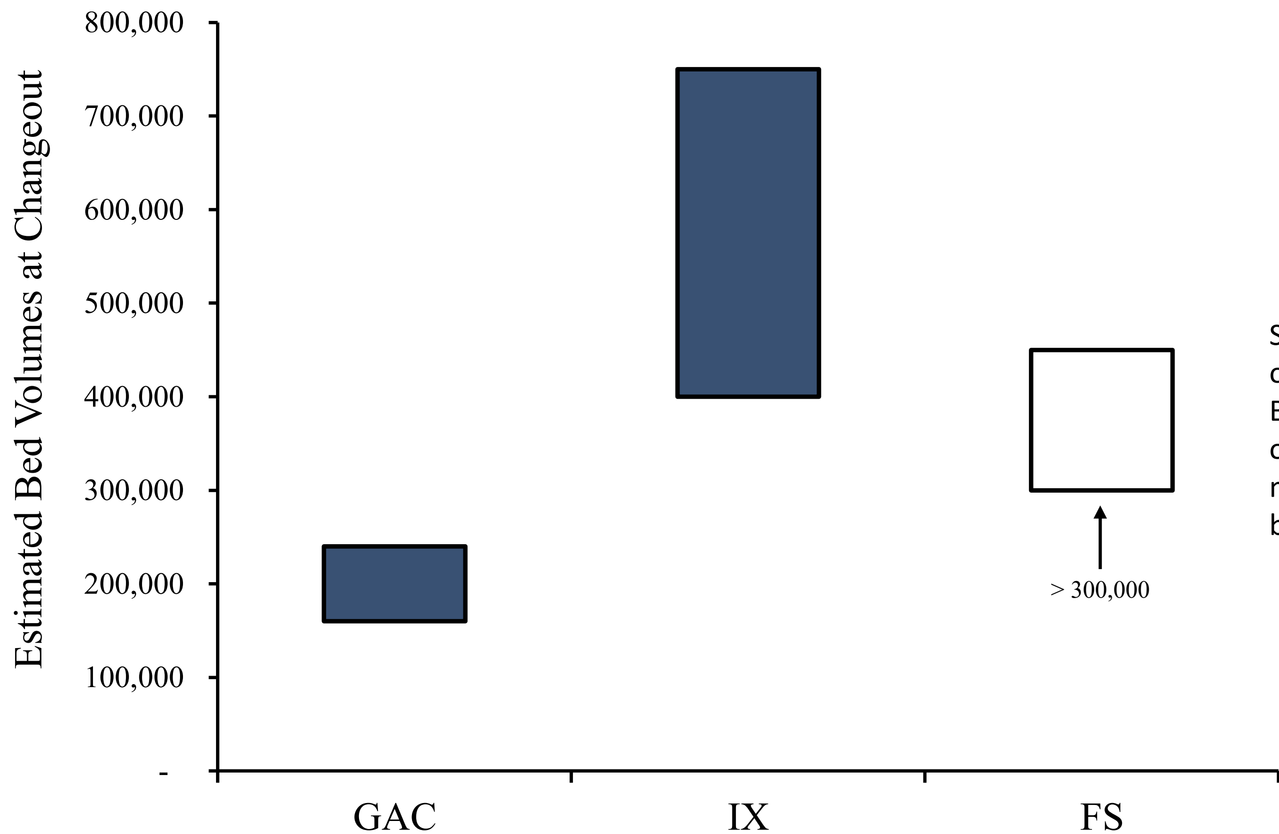
Comparing IX and GAC not straight forward

Here's the same data as I see it…



Water Quality can significantly impact performance of each

Example Comparison of Media Performance (based on PFOS)



Solid bars represent error bars obtained from bench testing (GAC, IX). Because breakthrough was not observed for FS, lower bound is the maximum BV tested with an upper bound of +50% BV.

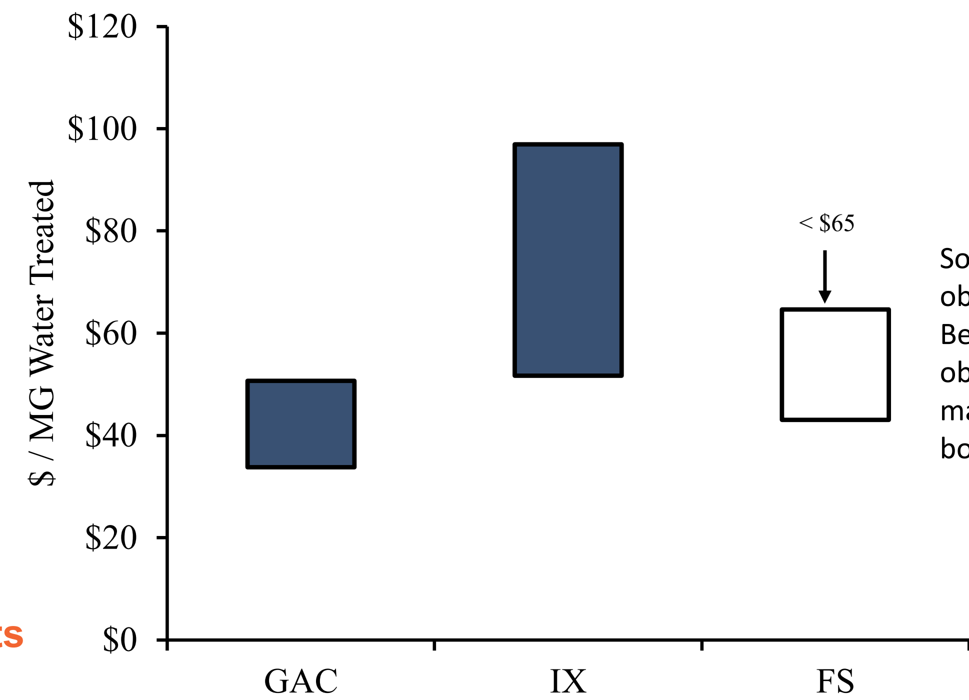
Translating Bed Volumes to O&M Costs

- Although GAC would have much shorter BV, the media has a lower cost than IX or FS

Media Replacement Cost

	$ per cubic foot
GAC	$61
IX	$290
FS	$145

Disposal Costs are also important factors in O&M costs



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Cost of sampling

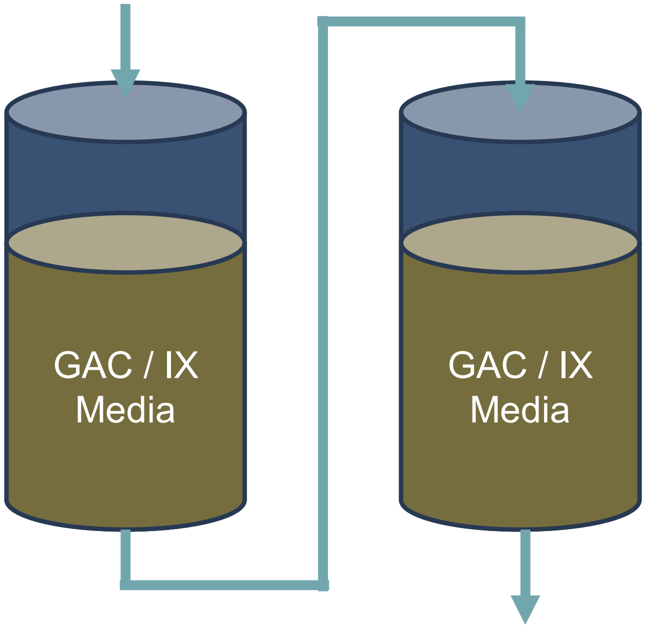
- Why monitor breakthrough?
  - **Regulatory Requirement**
  - **Optimize media replacement / regeneration**

- In order to effectively monitor breakthrough, best to monitor at least 3 locations in each lead/lag train
  - **Inlet**
  - **After the lead vessel**
  - **After the lag vessel**

- PFAS monitoring takes time (often 2 – 3 week sample turnaround) and can be expensive

- Example Cost of sampling
  - **Ex 1: Small System with 1 impacted wells**
    - *3 PFAS samples every 2 weeks (raw, after lead, finished).*
    - ***At $250/sample this is $19,500/year***
  - **Ex 2: Larger System with 8 trains**
    - *1 “combined raw”, 1 “ combined finished” and 8 “intermediate”’ (after lead) samples. Sample every 2 weeks.*
    - ***At $250/sample this is $65,000 / year***

Lead-Lag (Series) Vessels



Cost of Media Disposal

EPA moves to regulate PFAS as "hazardous waste" has created a challenge for media disposal for utilities

Alabama GAC Example

2018 Information

Original quotes from 2 incinerators

- **Vendor A: $200/ton**
- **Vendor B could match**

2021 Information

Updated quotes from 2 incinerators

- **Vendor A: $800/ton**
- **Vendor : No longer accepting GAC**

Client had to rethink entire GAC procurement strategy and entered into a Custom Reactivation agreement with Calgon Carbon including a "Swing Load" for improved speed of replacement

California Media Challenges

- **GAC reactivation not allowed**
- **Incinerators have modified their waste IX media acceptance practices**
  - *Calgon – prices have increased significantly*
  - *Covanta – stopped accepting IX due to concerns about transfer of PFAS to air*
  - *Clean Harbors – will accept IX media so far and appreciates the relatively high heaving value (IX > GAC > Alternate Media)*

Costing Case Studies

Case Study Cost Summary

Project Location	GAC		IX		RO/NF	
	CapX ($M)	O&M ($K)	CapX ($M)	O&M ($K)	CapX ($M)	O&M ($K)
Alabama (10 mgd)	9.0	650	13.0	400	33	2,700
Alabama (6 mgd partial)	4.2					
New Mexico (2 mgd)	4.5	88	3.3	126		
New Mexico (200 gpm)	2.7	76	1.0	72		
New York (40 gpm)	1.0	25				
California (6.2 mgd)	15.0	100	11.1	200		
Massachusetts (2 mgd)	2.5 – 3.4	45	2.0 – 2.5	85		

Case Study Cost Summary

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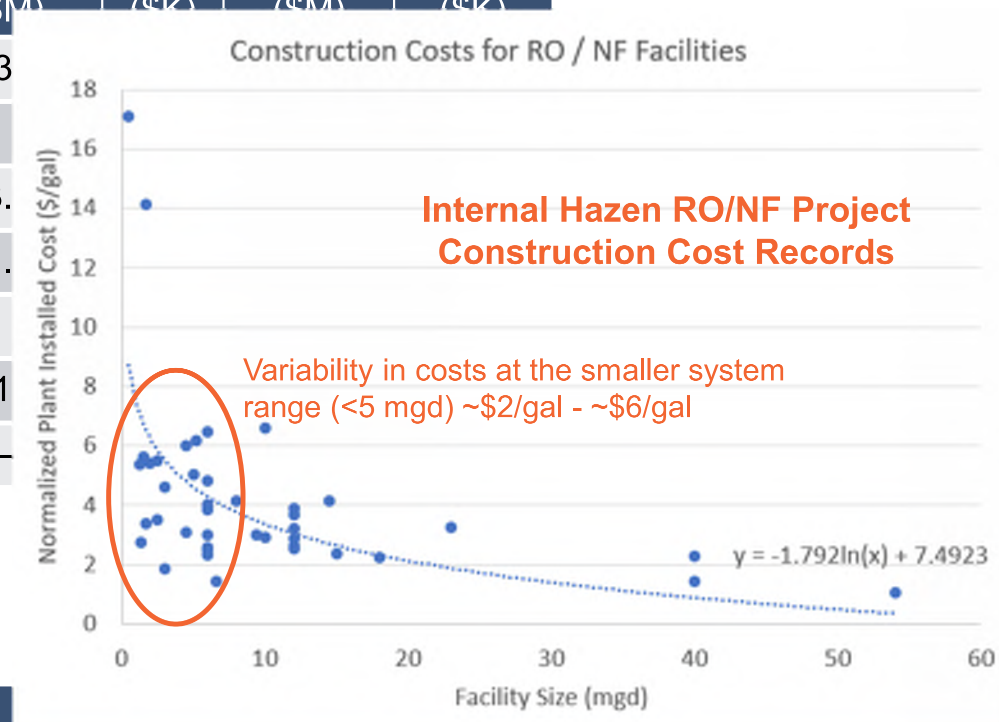
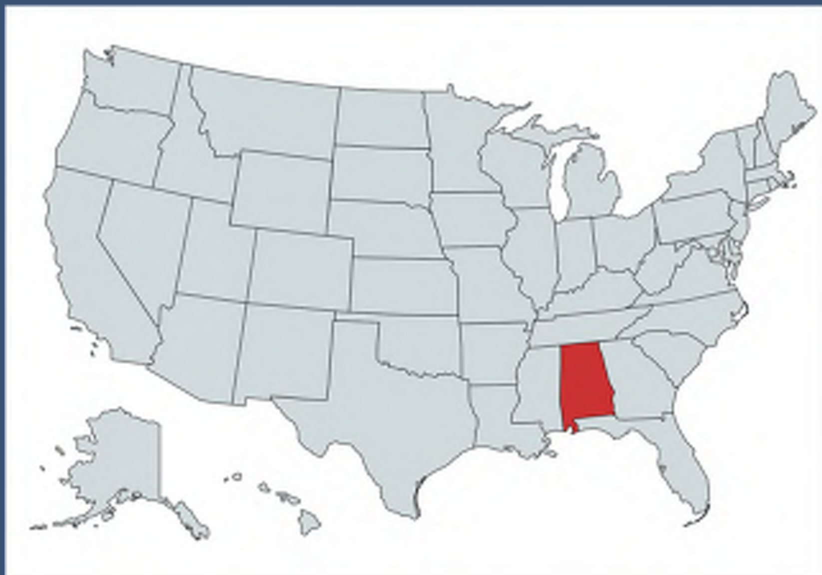
	CapX ($M)	O&M ($K)	CapX ($M)	O&M ($K)	CapX ($M)	O&M ($K)
Alabama (10 mgd)	9.0	650	13			
Alabama (6 mgd partial)	4.2					
New Mexico (2 mgd)	4.5	88	3.			
New Mexico (200 gpm)	2.7	76	1.			
New York (40 gpm)	1.0	25				
California (6.2 mgd)	15.0	100	11			
Massachusetts (2 mgd)	2.5 – 3.4	45	2.0 –			



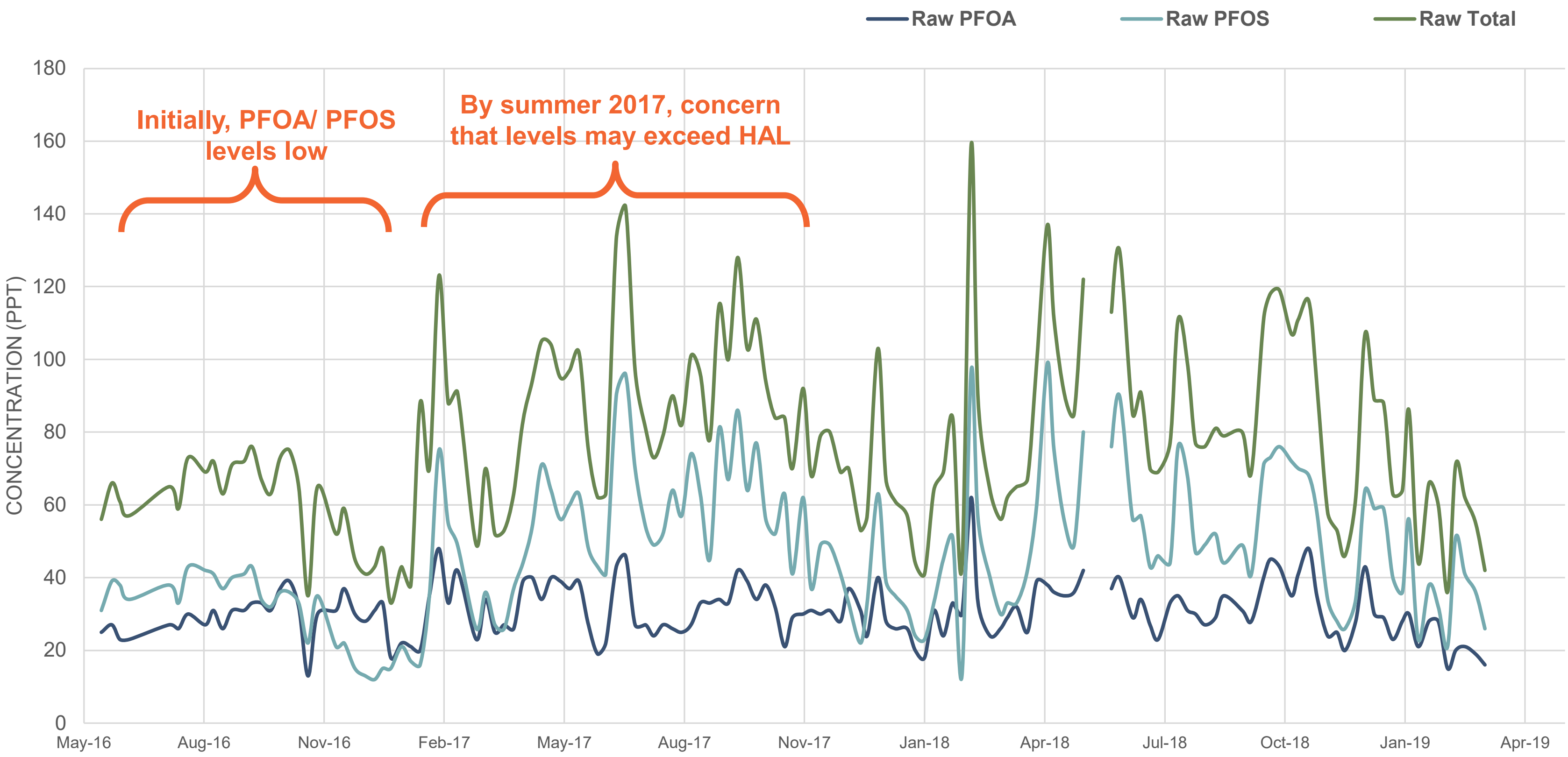


Alabama

Case Study 1

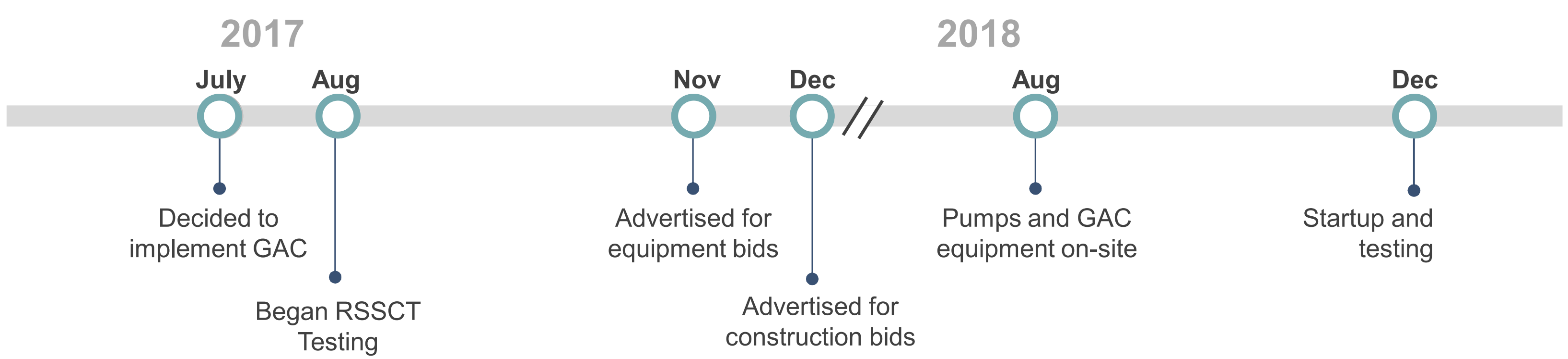
- 24 MGD Plant
- River water source
- River contamination from upstream carpet manufacturers
- Target Treatment:
  - **Achieve Running Average of Less than Federal HAL – 70 ppt**
  - **“Partial Treatment” and Blend to achieve PFAS targets**

Source Water PFOA and PFOS Levels



Project Schedule

- ✓Detailed Design completed in 4 months
- ✓On-line in 18-months



GAC Adsorption Basis of Design

Design Criteria	Value
GAC System Capacity	6 mgd
Total Number of Contactors	8
Number of Lead-Lag Pairs	4
Flow per Pair of Contactors	1.33 mgd
Empty Bed Contact Time (minutes)	20
Minimum GAC Capacity per Contactor	40,000 lbs

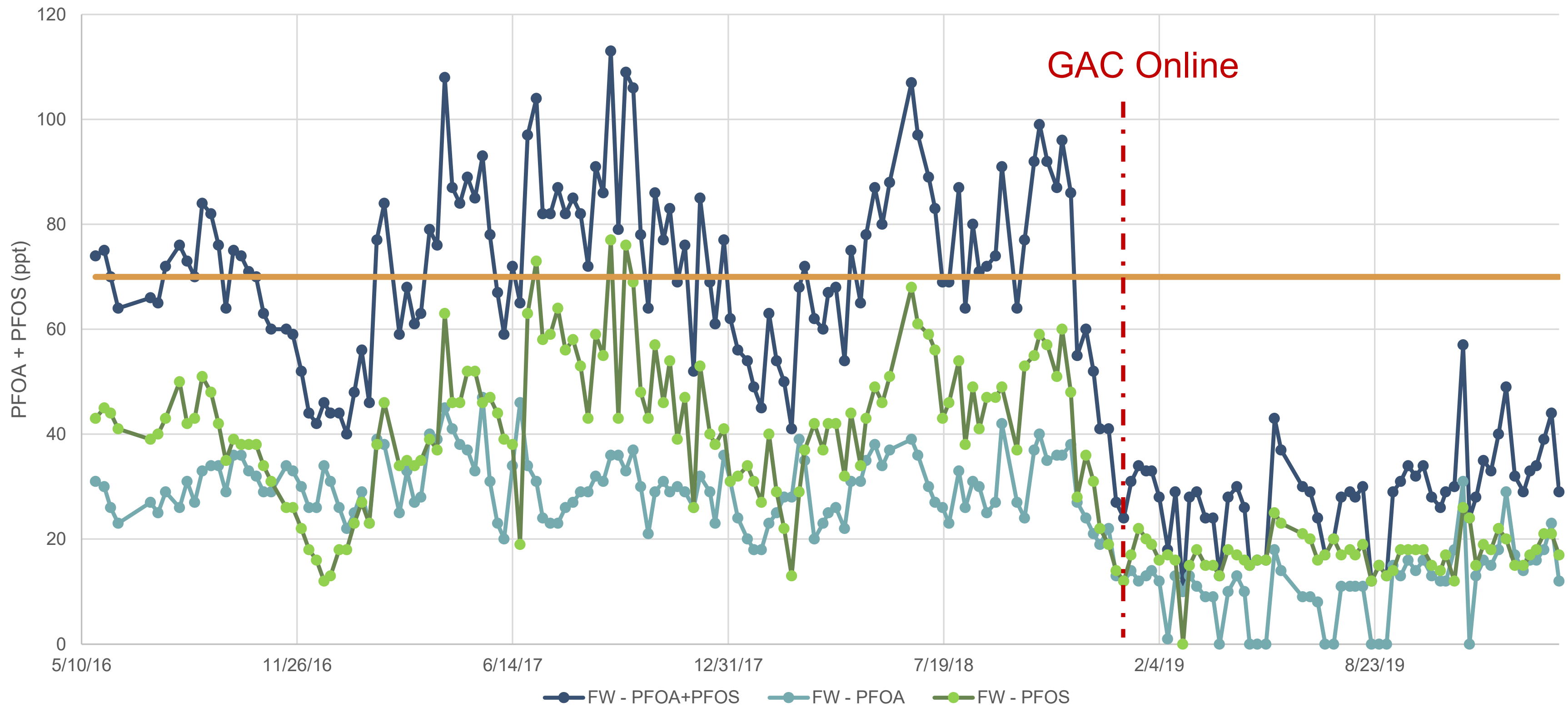
Phase 1 GAC Facility Project Costs

6 mgd capacity

GAC Facility Construction	$2,713,500
GAC Contactors and Media	$1,228,900
Intermediate Pumps and VFDs	$205,200
Total Construction Cost	**$4,147,600**
Engineering and Design	$705,600
Total Project Cost	**$4,853,200**
Unit Cost (per gpd)	**$0.81/ gpd**

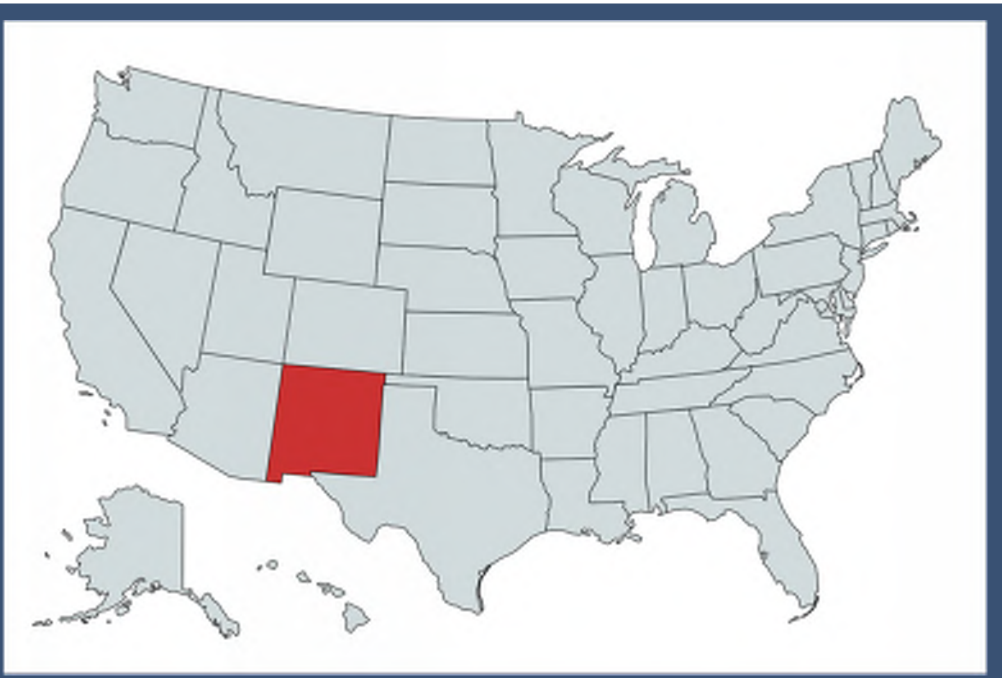
GAC Adsorption for PFOA and PFOS Control

Full-Scale Data from WTP in Alabama, Partial Treatment



“Long-term” Technology Comparison

	Benefits	Drawbacks	Cost
GAC	• Removal of most PFASs • Removal of other chemical constituents • DBP precursor reduction	• Carbon replacement costs can be costly • Need to consider breakthrough time and regeneration cycles	$9M for 10 MGD $0.7 M/year O&M
Ion Exchange	• Proven PFOA/PFAS removal • Potential for removal of short chain PFASs	• Single use of resin • More costly per unit than GAC • Competing ions may affect performance • Limited removal of other contaminants • Resin disposal	$13M for 10 MGD $0.4 M/year O&M
Reverse Osmosis	• Proven PFOA/PFAS removal • Removal of other chemical constituents • DBP precursor reduction	• Most costly option • RO recovery – lose portion of WTP capacity • Biofouling with surface water is key concern • RO concentrate disposal/permitting	$33M for 10 MGD $2.7 M/year O&M



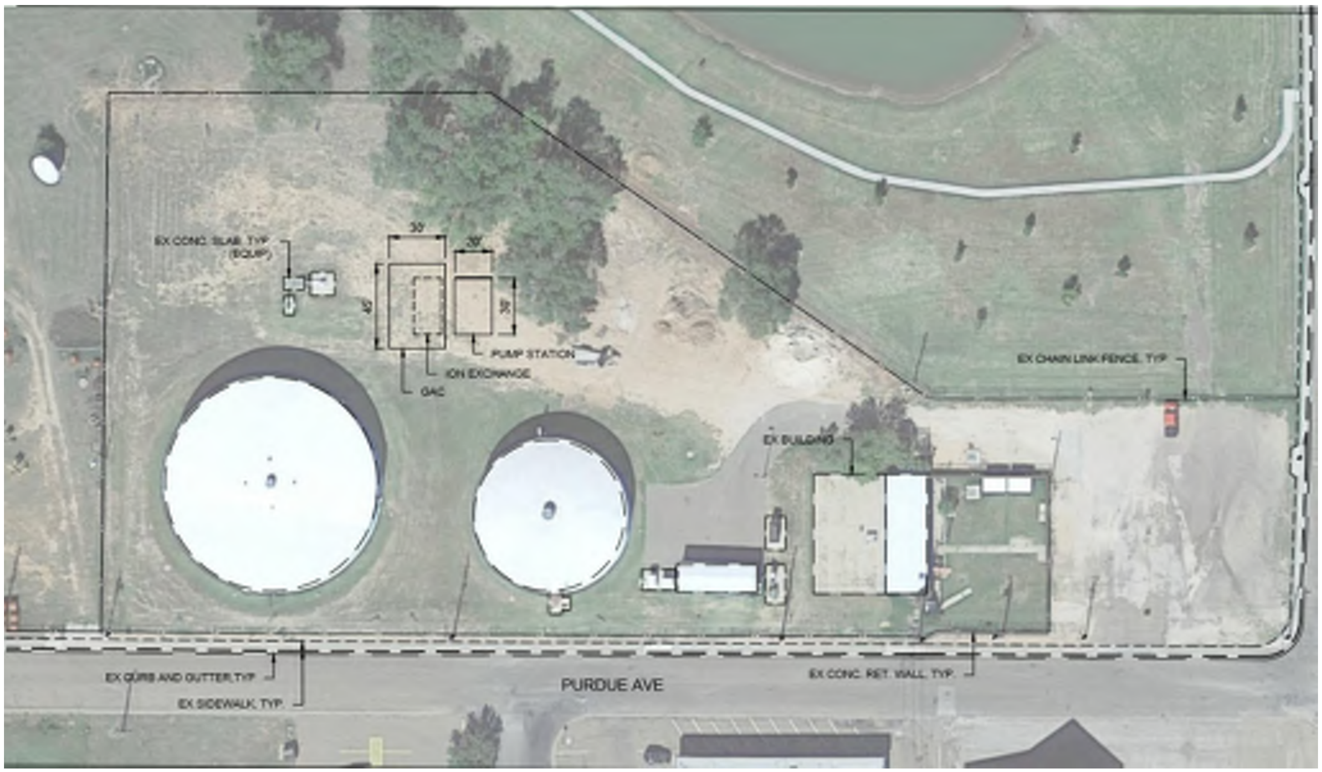
New Mexico

Case Study 2

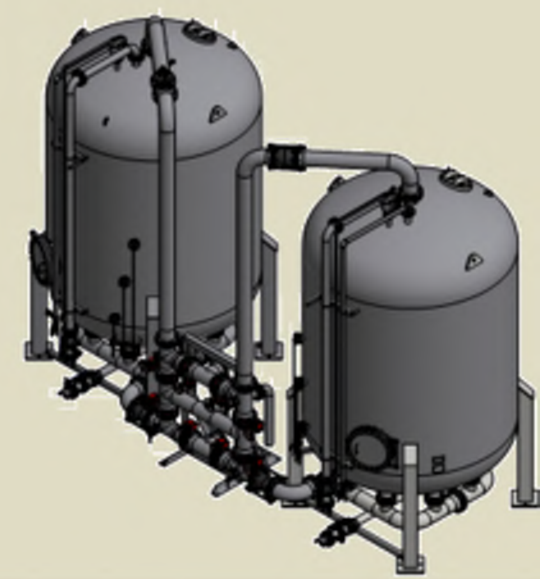
- 2 MGD Treatment Plant
- Groundwater source
  - **> 70 wells ranging in size from 40 gpm – 200 gpm**
- Contamination from upgradient airforce base
- Target Treatment:
  - **Achieve PFAS concentration less than 5 ppt**
- Questions to answer
  - **Technology Selection**
  - **Effective Treatment Approach (Centralized vs. Wellhead)**

Centralized versus Wellhead Treatment Approach

Single 2-MGD Centralized System

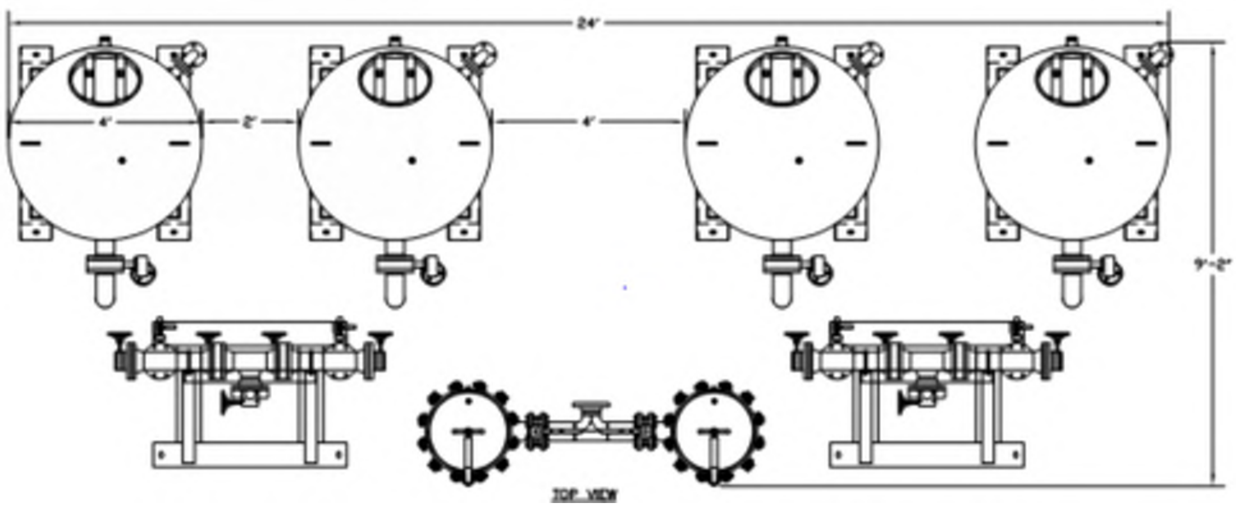


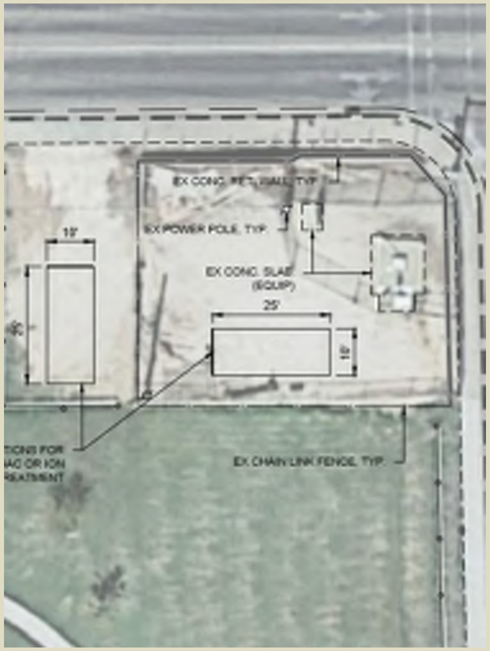
Led Lag GAC or IX
GAC 2 Trains (4 vessels) 12’ Diam.
IX – 3 Trains (6 vessels) 10’ Diam.



Centralized versus Wellhead Treatment Approach

Individual Wellhead Treatment





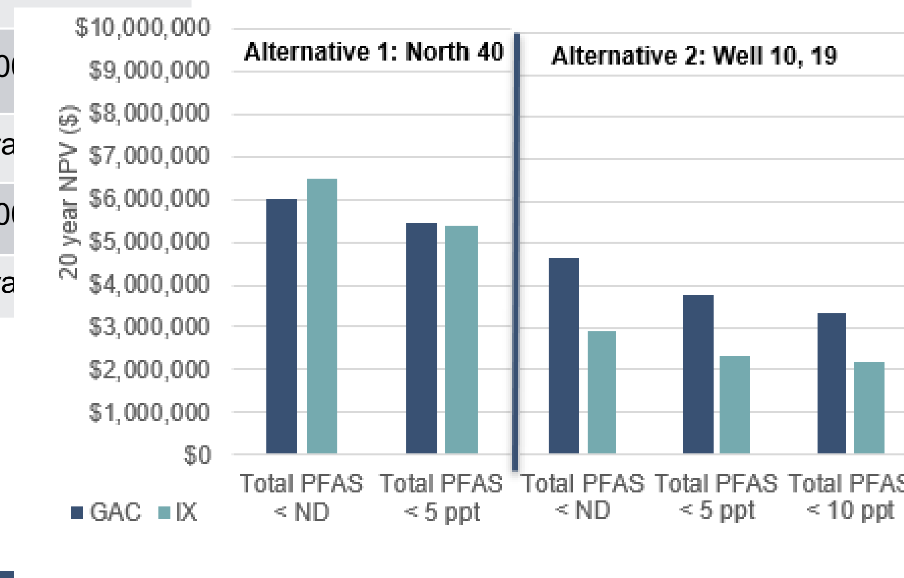
Cost Comparison for the approaches

Alternative	Treatment Strategy[1,2]		ΣPFAS < 5 ng/L
Alternative 1: 2 mgd	GAC	Construction Cost	$4,540,000
		Annual O&M	$88,000
	IX	Construction Cost	$3,286,000
		Annual O&M	$126,000
Alternative 2: 200 gpm	GAC	Construction Cost	$2,668,000
		Annual O&M	$76,000 + operating rules
	IX	Construction Cost	$1,017,000
		Annual O&M	$72,000 + operating rules

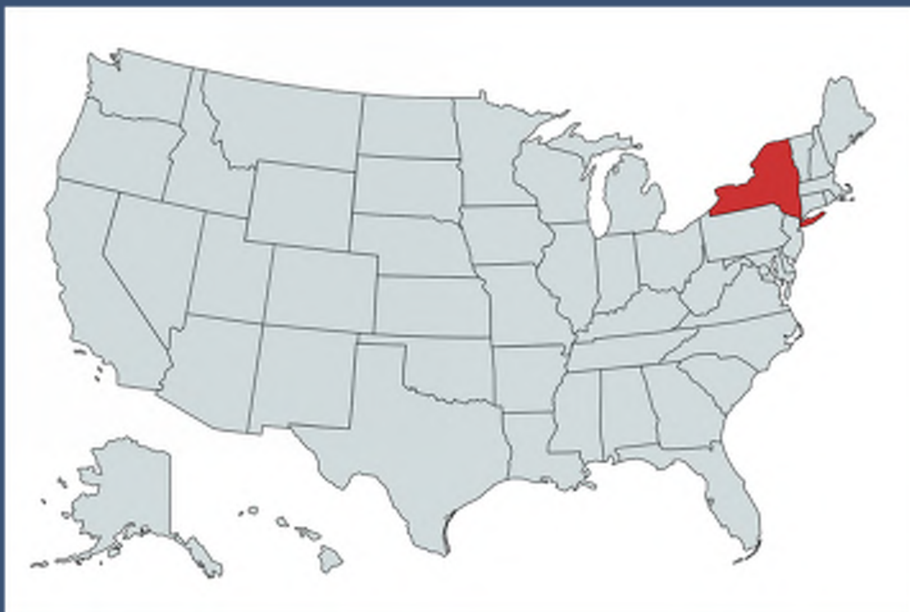
Big difference in appropriate technology selection at 200 gpm scale compared to 2 mgd scale

Cost Comparison for the approaches

Alternative	Treatment Strategy[1,2]		ΣPFAS < 5 ng/L
Alternative 1: 2 mgd	GAC	Construction Cost	$4,540,000
		Annual O&M	$88,000
	IX	Construction Cost	$3,286,000
		Annual O&M	$126,000
Alternative 2: 200 gpm	GAC	Construction Cost	$2,668,0
		Annual O&M	$76,000 + opera
	IX	Construction Cost	$1,017,0
		Annual O&M	$72,000 + opera



Big difference in appropriate technology selection at 200 gpm scale compared to 2 mgd scale



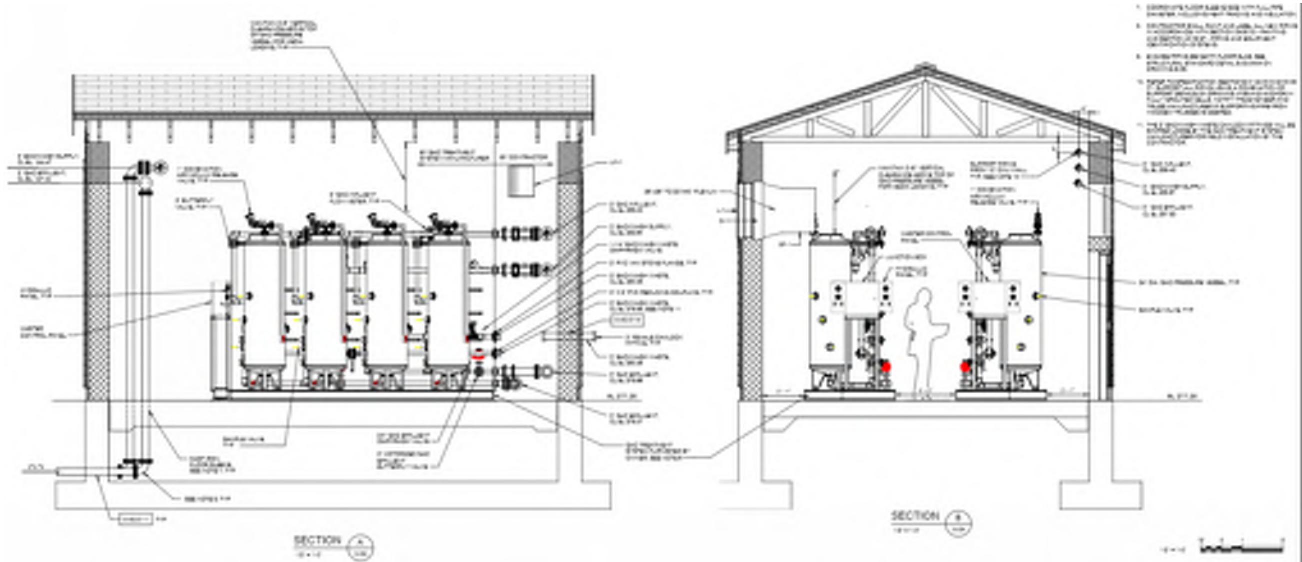
New York

Case Study 3

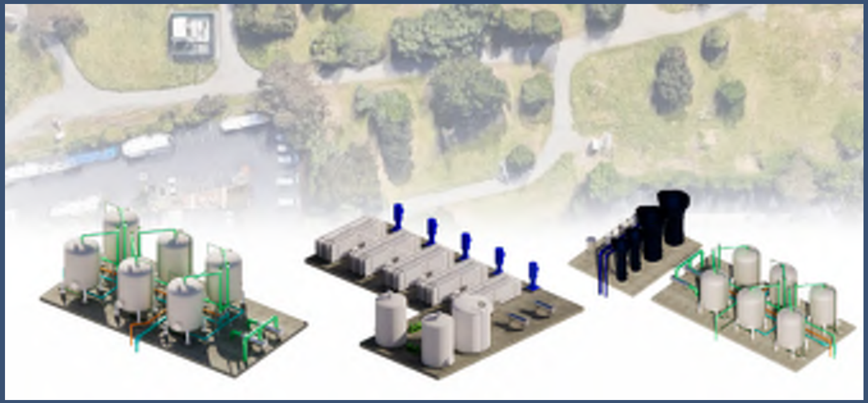
- 40 gpm Treatment Plant Upgrade
- Groundwater source
  - Combined wells sum to 40 gpm
  - Typically operated at 21 gpm
- Contamination from regional industrial contamination
- Target Treatment:
  - Achieve PFOA and PFOS concentration less than 10 ppt each

Case Studies

40 gpm GAC – NY GW



Unit	Quantity	Engineer's Base Estimate		Construction Company A			Construction Company B			Construction Company C			Construction Company D		
		Unit Price	Total Price	Unit Price Bid	Total Bid Price	Deviation from Engineer's Base Estimate	Unit Price Bid	Total Bid Price	Deviation from Engineer's Base Estimate	Unit Price Bid	Total Bid Price	Deviation from Engineer's Base Estimate	Unit Price Bid	Total Bid Price	Deviation from Engineer's Base Estimate
LS	1	$996,120.00	$996,120.00			9%			12%			20%			19%
ALLOW	1	$6,075.00	$6,075.00			0%			0%			0%			0%
ALLOW	1	$3,925.00	$3,925.00			0%			0%			0%			0%
			$1,006,100.00			9%			12%			20%			19%
LS	1	N/A	N/A			N/A			N/A			N/A			N/A
LS	1	N/A	N/A			N/A			N/A			N/A			N/A
			$1,006,100.00		$1,128,413.00	12%		$1,135,000.00	13%		$1,229,890.00	22%		$1,232,878.00	23%
			$1,006,100.00		$1,128,413.00	12%		$1,135,000.00	13%		$1,229,890.00	22%		$1,319,629.00	31%



California

Case Study 4

- 6 mgd Treatment System
- Groundwater source
  - **Needs to meet multiple treatment criteria (PFAS, Iron, etc.)**
- Contamination from airport / industry
- Target Treatment:
  - **Achieve PFOA, PFOS, PFBS concentration less than Notification Limits**
    - *PFOA = 5.1 ppt*
    - *PFOS = 6.5 ppt*
    - *PFBS = 500 ppt*

GAC vs IX/FS Footprint per 5,000 gpm (~ 7 mgd)

GAC TREAMENT
(10: 12ft vessels)

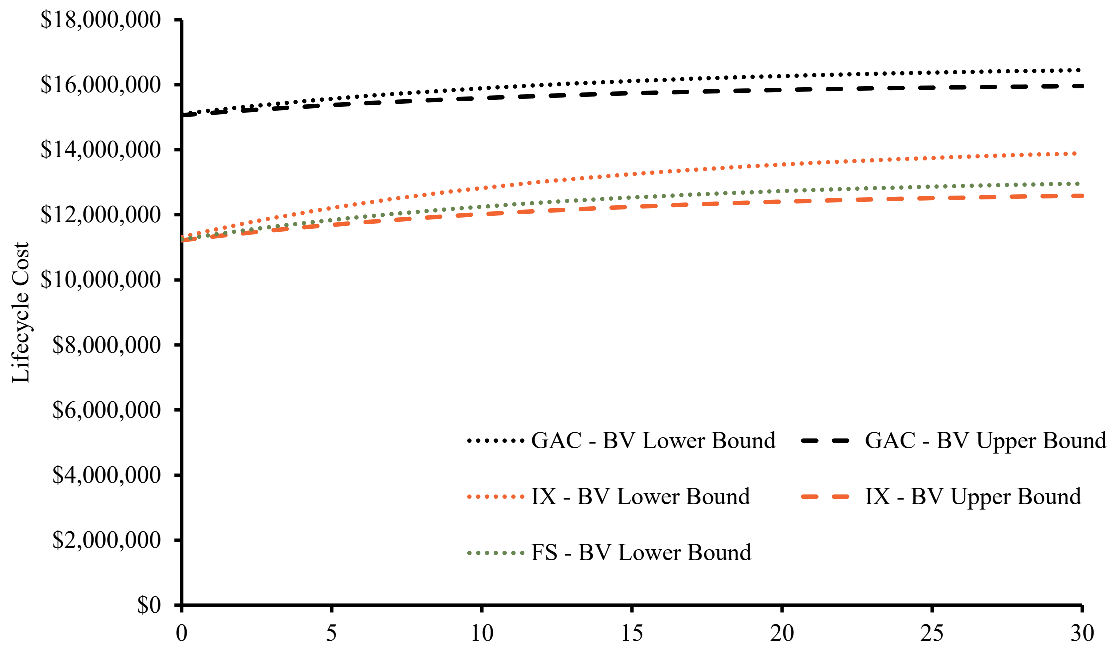
IX/FS TREAMENT
(6: 12ft vessels)

Lifecycle Cost Comparison (7.2 MGD)

- Capital:

	Equipment	Project
GAC	$5.55M	$15.0M
IX / FS	$4.11M	$11.1M

- Asset Life: 30 years
- Discount Rate: 7.64%

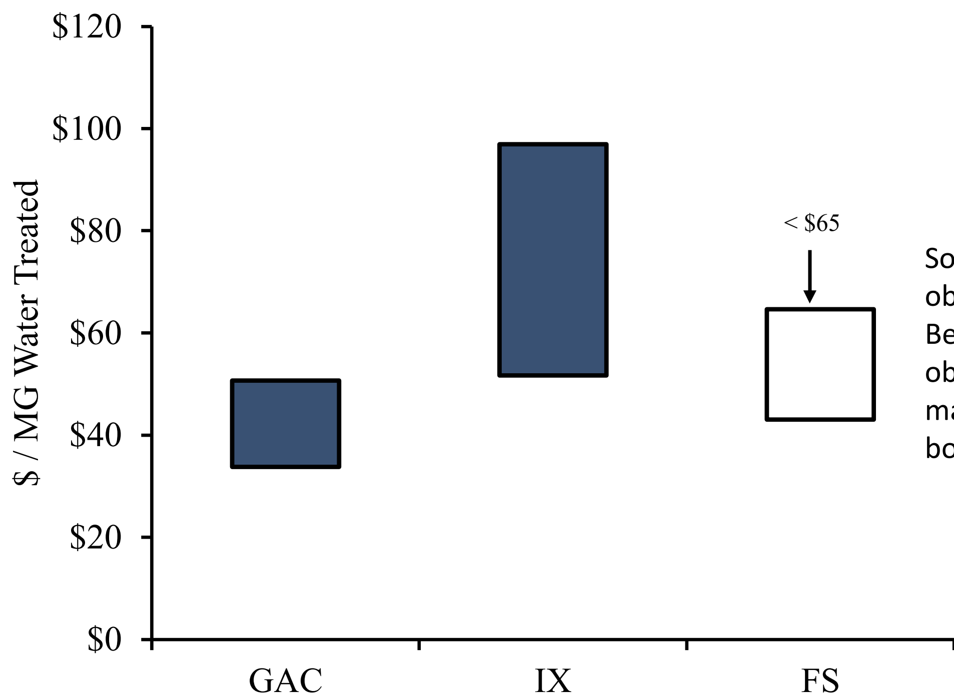


Lower capital and lifecycle cost for IX and FS compared to GAC

Translating Bed Volumes to O&M Costs

- Although GAC would have much shorter BV, the media has a lower cost than IX or FS

	$ per cubic foot
GAC	$61
IX	$290
FS	$145



Solid bars represent error bars obtained from bench testing (GAC, IX). Because breakthrough was not observed for FS, upper bound is the maximum BV tested with a lower bound of +50% BV.

Cost Estimate

PFAS treatment accounts for ~33% of the project's construction costs

Description	No Greensand	With Greensand
Demolition	$200,000	$200,000
Booster Pump	$1,300,000	$1,300,000
Break Tank	$1,800,000	$1,800,000
Greensand Filters	$0	$3,900,000
Cartridge Filters	$1,400,000	$900,000
Ion Exchange/FS	$11,100,000	$11,100,000
IX/FS Feed Pump Station	$300,000	$300,000
Weak Acid Cation IX	$13,000,000	$13,000,000
Decarbonator	$1,900,000	$1,900,000
Electrical Building	$500,000	$500,000
Site Work	$700,000	$700,000
Yard Piping	$3,300,000	$3,300,000
Electrical and Instrumentation	$3,000,000	$3,500,000
PROBABLE CONSTRUCTION COST	**$38,500,000**	**$42,400,000**
Project Costs (Design & ESDC, PM, CM, Legal)	$11,600,000	$12,800,000
PROBABLE PROJECT COST	**$50,100,000**	**$55,200,000**

Massachusetts

Case Study 5

- “Supplemental” Well supplies – 1 mgd each
- Treatment of 2 groundwater wells
  - Additional Water Quality Challenges (Fe/Mn)
  - Combine treatment?
  - Well pumping restrictions
- Target Treatment:
  - Achieve Compliance with “Massachusetts 6” < 20 ppt

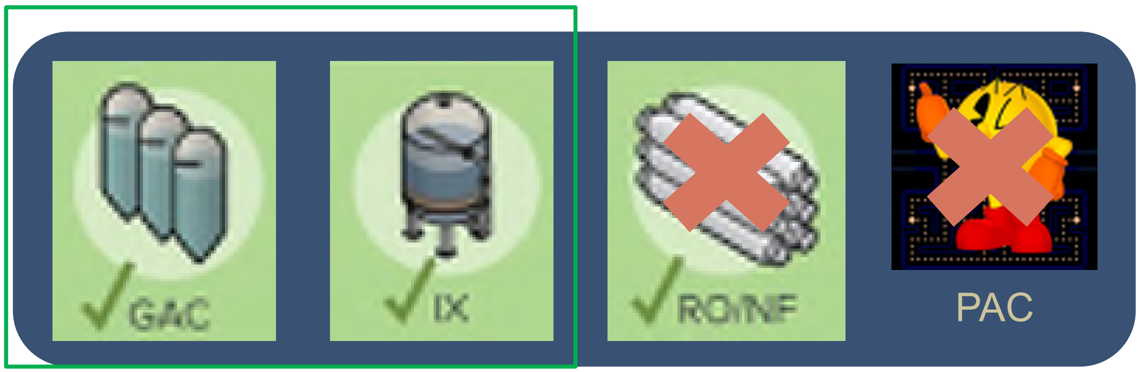
Best Available Technology (BAT) defined by MassDEP

- GAC
- Ion Exchange (IX)
- ~~RO~~
- ~~NF~~
- ~~PAC~~

Most common PFAS treatment strategies in MA

MADEP recognized Concentrate Disposal Challenges

Disposal, Efficiency Challenges – not approved by USEPA

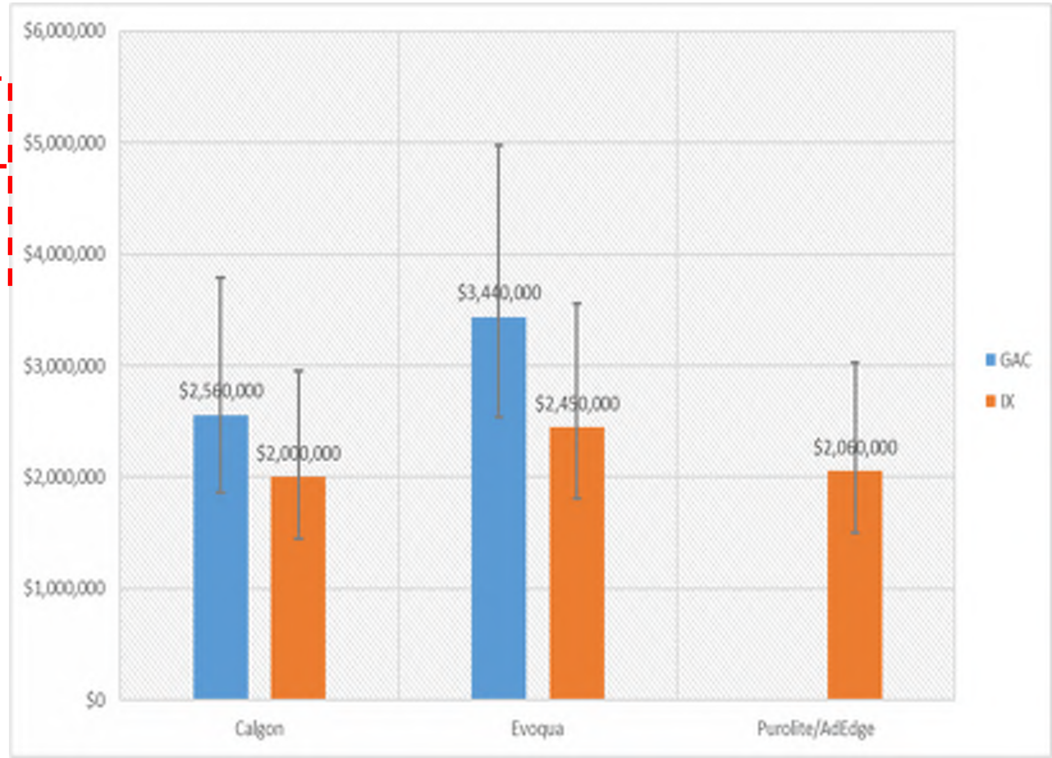


Capital Cost Comparison of Technology

Treatment Technology	Vendor	Estimated Technology Cost[1,2]
GAC	Calgon	$1,860,000 - $3,790,000
	Evoqua	$2,540,000 - $4,980,000
IX	Calgon	$1,450,000 – $2,950,000
	Evoqua	$1,810,000 - $3,560,000
	Purolite/AdEdge	$1,500,000 - $3,030,000

1 Technology costs reflect installed equipment that are specific to the IX and GAC technologies and building, construction, engineering, and 25% design contingency.
2 **Cost does not represent total project cost. Only technology specific equipment and building costs are included.**

- IX less capital cost (1 train vs 2 vs GAC) = smaller building footprint
- Cost is for **Technology (PFAS Equipment + Building)** Only



Media Replacement

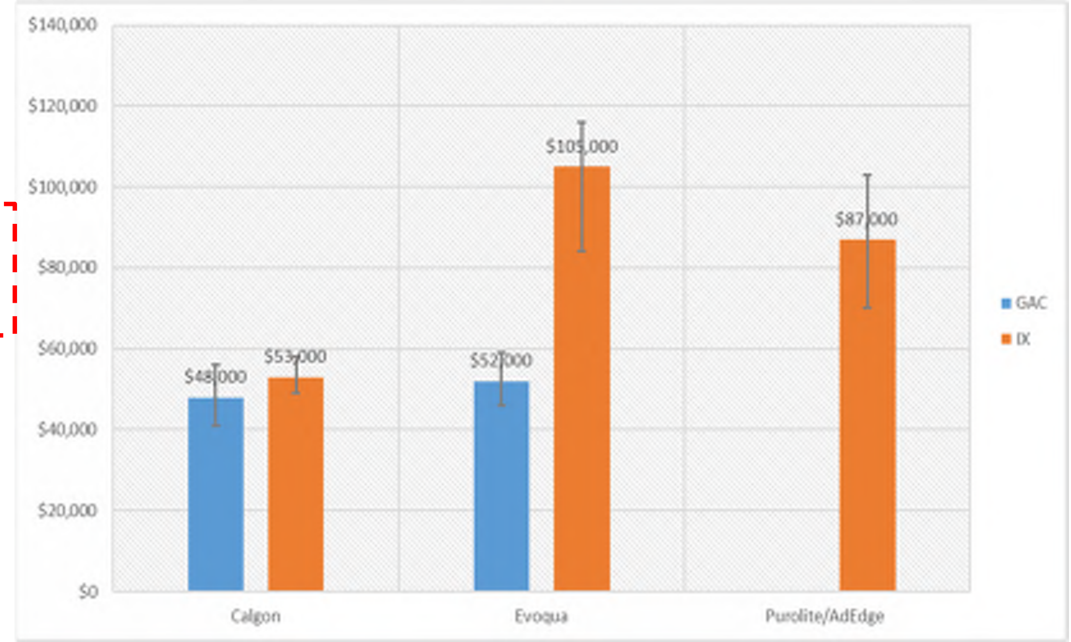
Treatment Technology	Vendor	Lead Vessel Media/Resin Replacement Frequency	Estimated Cost per Replacement
GAC	Calgon	6 - 12 months	$60,000
	Evoqua	6 - 10 months	$65,900
IX	Calgon	18 - 24 months	$226,000
	Evoqua	6 - 9 months	$192,000
	Purelite/AdEdge	6 - 10 months	$166,500

- Comparable media replacement frequency
- Frequencies based on 100% operation of wells – actual replacement will be less frequent
- IX media is more costly to replace (typical)

Annual Operating Cost

Treatment Technology	Vendor	Estimated Annual Operating Cost[1]
GAC	Calgon	$41,000 – $56,000
	Evoqua	$46,000 - $59,000
IX	Calgon	$49,000 - $58,000
	Evoqua	$84,000 - $116,000
	Purolite/AdEdge	$70,000 - $103,000

1 Annual operating cost assumes Well 1 and 2 operate 47% of the year and at a flow of 41% of the rated well capacity based on historical operation of the wells.



- Higher media replacement cost and quoted frequency leads to increase Operating cost for IX

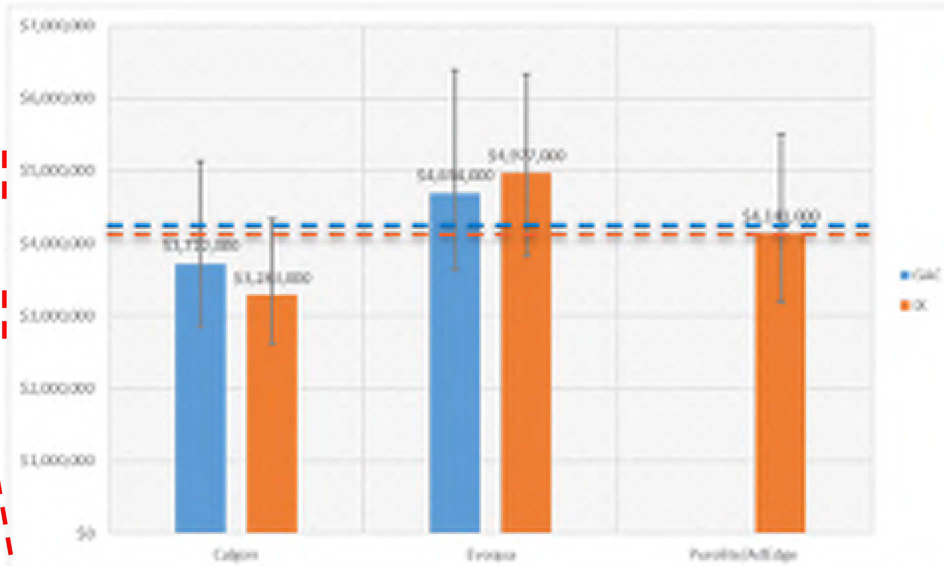
Lifecycle Comparison of Technology Costs

Treatment Technology	Vendor	20-Year NPV[1]
GAC	Calgon	$2,844,000 - $5,130,000
	Evoqua	$3,638,000 - $6,391,000
	Average	$4,208,000
IX	Calgon	$2,621,000 - $4,344,000
	Evoqua	$3,829,000 - $6,338,000
	Purolite/AdEdge	$3,186,000 - $5,506,000
	Average	$4,091,000

1 20-Year NPV assumes Wells 1 and 2 run 47% of the year at 41% of rated capacity.

Treatment Technology	Description	Estimated Technology Cost
GAC	Technology Cost	$3,000,000
	Annual O&M	$50,000
IX	Technology Cost	$2,170,000
	Annual O&M	$80,000

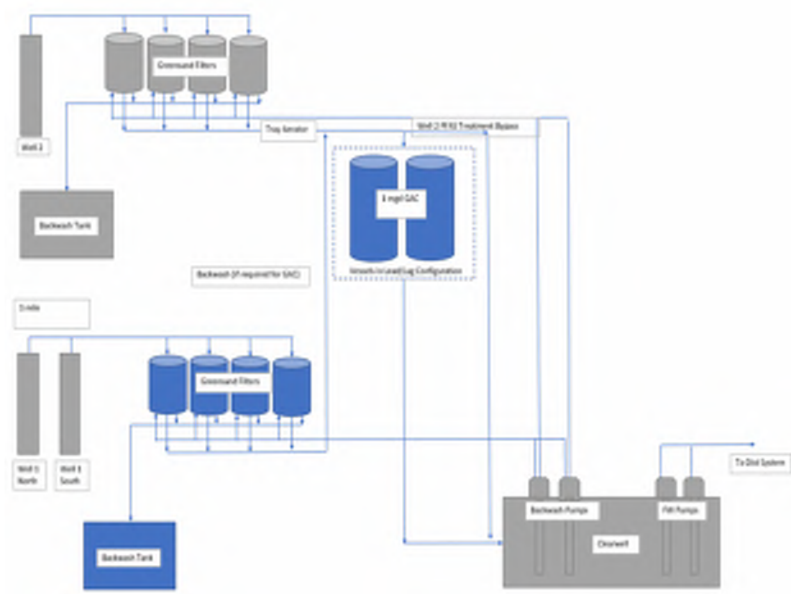
[1]Technology Costs reflect installed equipment and building, yard improvements, construction, engineering, DWD labor, Owner Contingency, and 25% design contingency,
[2] Annual operating cost assumes Wells 1 and 2 run 47% of the year at 41% of rated capacity.



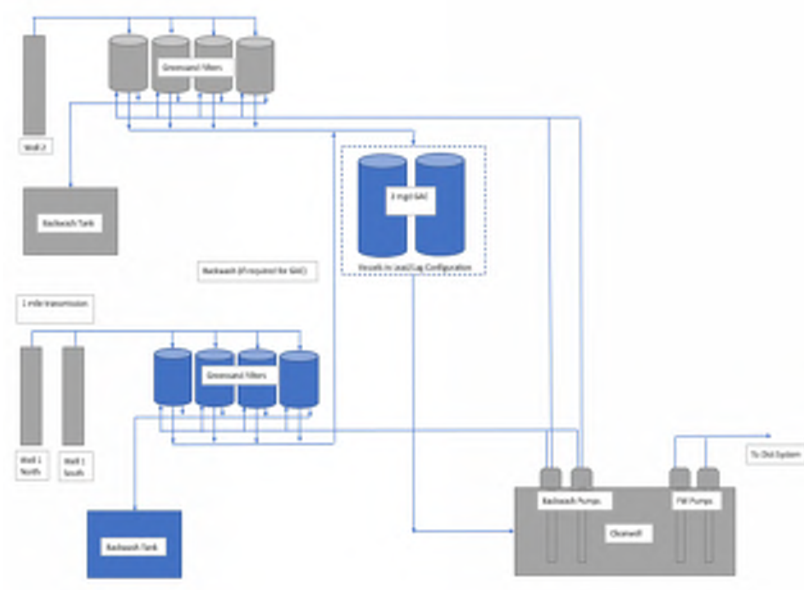
- Comparable lifecycle costs for IX & GAC

Second Question – Best Way to Implement Treatment?

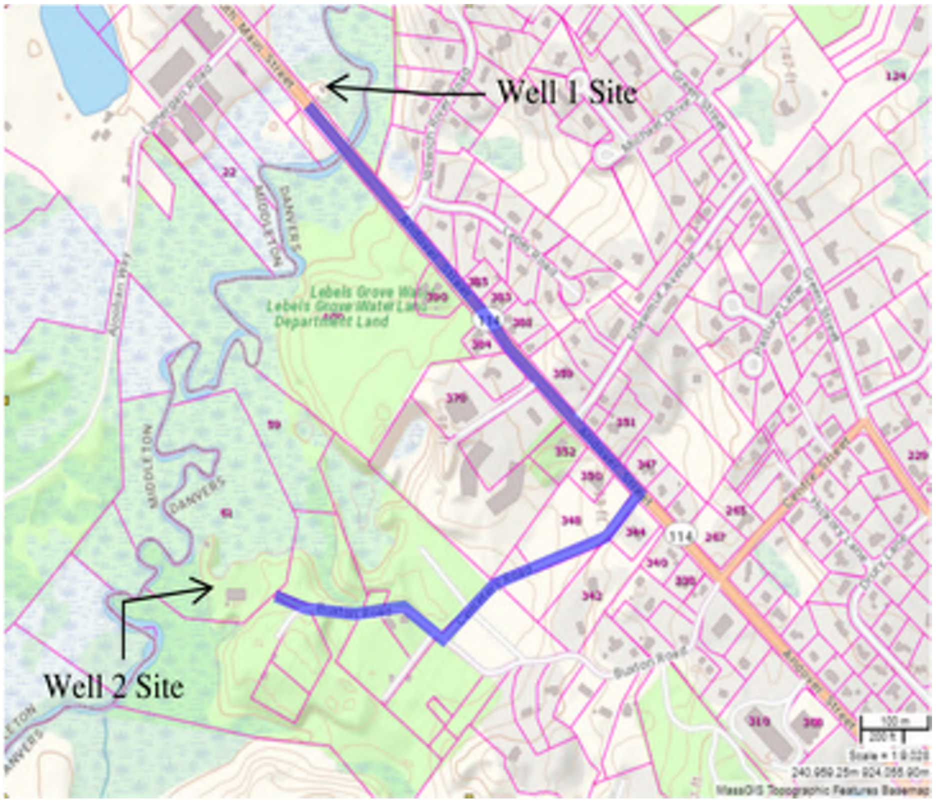
Option #1 – **1 MGD** PFAS facility w/ bypass



Option #2 – **2 MGD** PFAS facility (capability to treat both wells simultaneously for PFAS)



Transmission Main



Item	Low Range Estimate	High Range Estimate
Water Main	$1,600,000	$2,260,000
General Conditions	$240,000	$340,000
Below the Line Adjustments[1]	$520,000	$730,000
Contingency (25%)	$590,000	$830,000
Contract Allowances	$60,000	$80,000
Total	$3,010,000	$4,240,000

1. OH&P, Subcontractor OH&P/markup, Bonds/Insurance, Escalation to 2023.

Option #1 vs Option #2 Cost Comparison

Option #1 – 1 MGD PFAS facility w/ bypass

Item	Low Range Estimate	High Range Estimate
WTP Cost	$2,800,000	$3,960,000
General Conditions	$420,000	$590,000
Below the Line Adjustments[1]	$910,000	$1,280,000
Contingency (25%)	$1,030,000	$1,460,000
Contract Allowances	$100,000	$150,000
Total	$5,260,000	$7,440,000

1. OH&P, Subcontractor OH&P/markup, Bonds/Insurance, Escalation to 2023.

Option #2 – 2 MGD PFAS facility
(capability to treat both wells simultaneously for PFAS)

Item	Low Range Estimate	High Range Estimate
WTP Cost	$3,780,000	$5,330,000
General Conditions	$570,000	$800,000
Below the Line Adjustments[1]	$1,220,000	$1,720,000
Contingency (25%)	$1,390,000	$1,960,000
Contract Allowances	$140,000	$200,000
Total	$7,100,000	$10,010,000

1. OH&P, Subcontractor OH&P/markup, Bonds/Insurance, Escalation to 2023.

Questions?

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