PFAS Treatment with Single-use Ion Exchange Resin

Case Histories and Cost vs GAC

Presented by: Francis Boodoo

Co-authors: Cathy Swanson, Ted Begg, Joe Klimek, Jord Yniguez

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Francis Boodoo

Cathy Swanson

Ted Begg

Authors

Joe Klimek

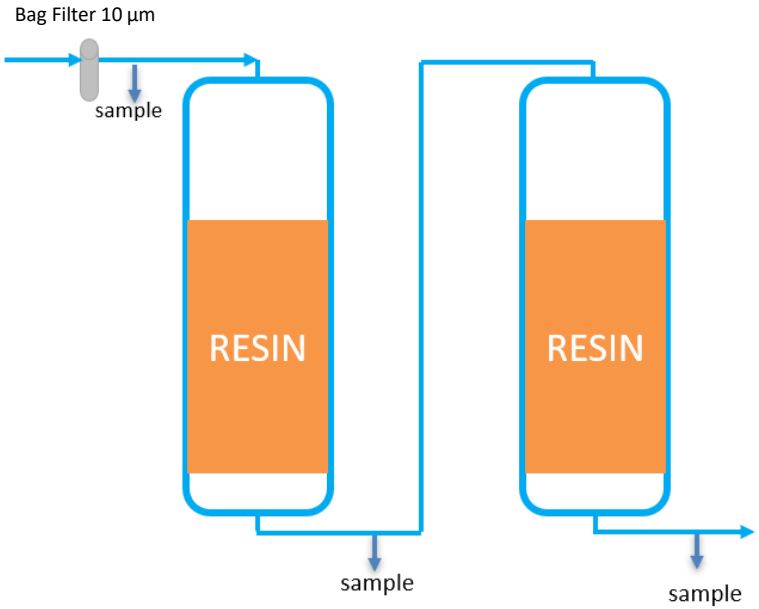
Jord Yniguez

Authors

Topics

- Case Histories – Resin vs GAC
- O&M Cost Estimates
- Modeling vs Accelerated Pilots vs Full Pilots
- Buffered resin

Simple & Easy to Operate Lead-Lag Vessels



- Reduces PFAS to ND
- 1.5 to 3 minutes EBCT
- 20 to 40 BV/h 3 to 4 gpm/ft3 resin
- 36 inches bed depth
- 6 to 12 gpm/ft2 (15 to 30 m/h)
- 8-ft diameter for 500 gpm flowrate
- Minimal operator attention

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Compact Vessels – minimum footprint and overhead space

Courtesy Onion Equipment

- Long resin life ~ 2 to 3 years
- No Backwash Tank or backwashing
- No liquid waste to drain
- No chemicals or regeneration
- Minimal operator attention

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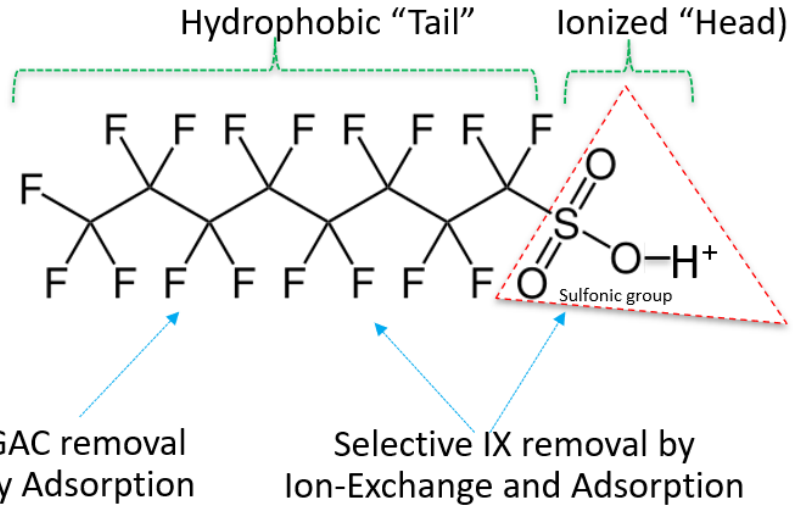
PFAS-selective resin: Dual removal mechanism

PFOS



Adsorption

Ion Exchange
&
Adsorption

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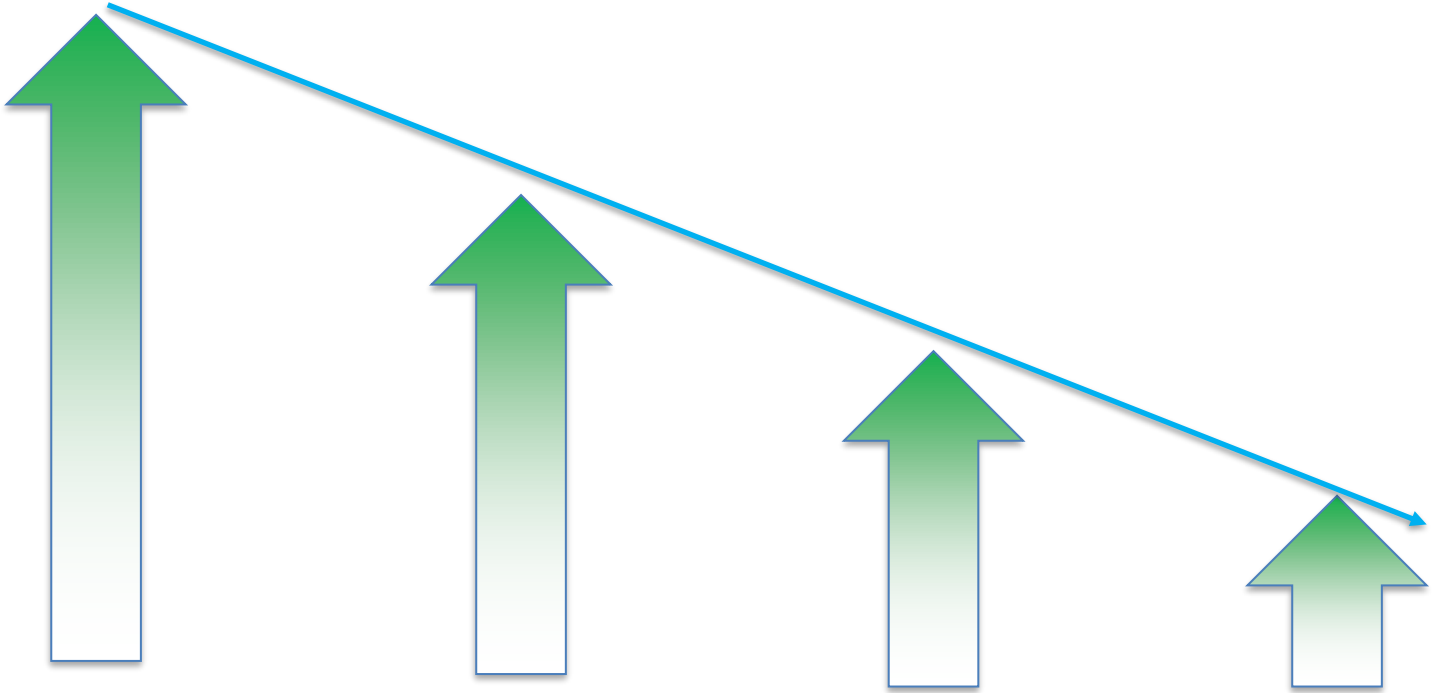
Affinity of PFAS-Selective Resin



All Sulfonates

PFOS > PFHxS > PFPeS > **PFBS**

> C7 Carboxylates

PFDA > PFNA > **PFOA** > PFHpA

C4 – C6 Carboxylates

PFHxA> PFPeA > PFBA

Major Anions

NO3 > SO4 > Cl . HCO3

PFOS
PFHxS
PFBS
PFTrDA
PFTA
PFDoA
PFUnA
PFDA
PFNA
PFOA
ADONA
PFHpA
GenX
PFHxA
PFPeA
PFBA
NO3
SO4
Cl
HCO3

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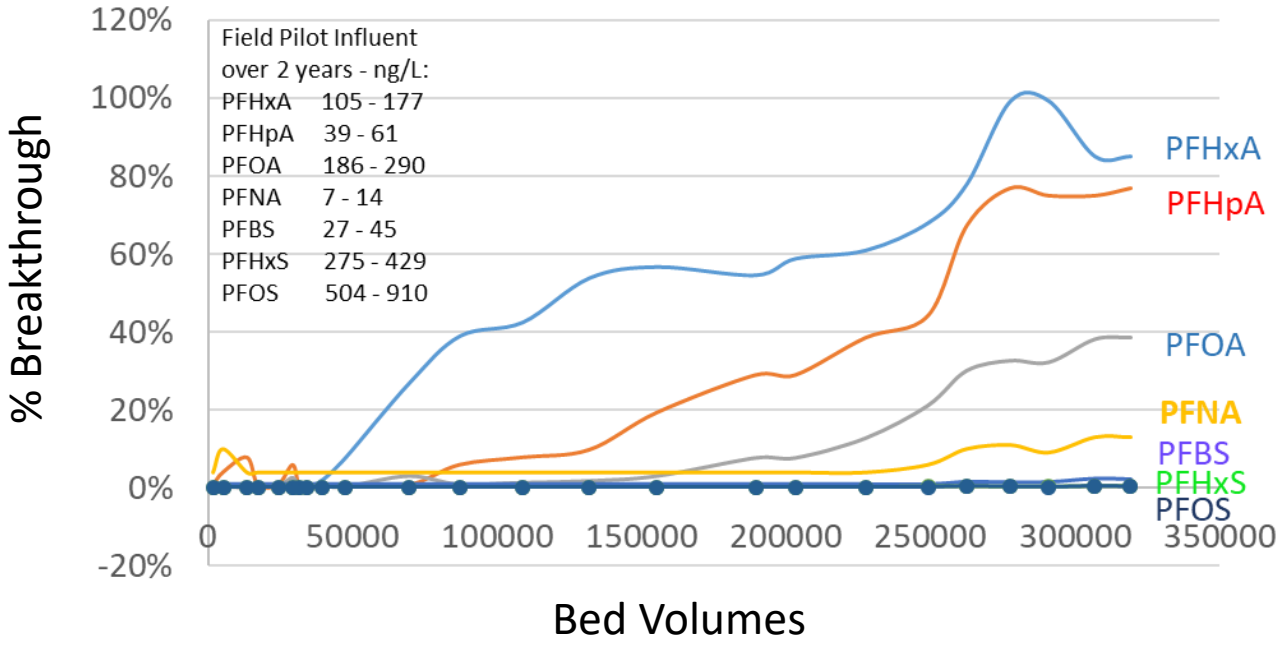
Order of PFAS Breakthrough

PFBA < PFPeA < PFHxA < PFHpA < PFOA < PFNA < PFBS < PFHxS < PFOS



PFBA at inlet of 42 ppt is not shown but will break before all other PFAS

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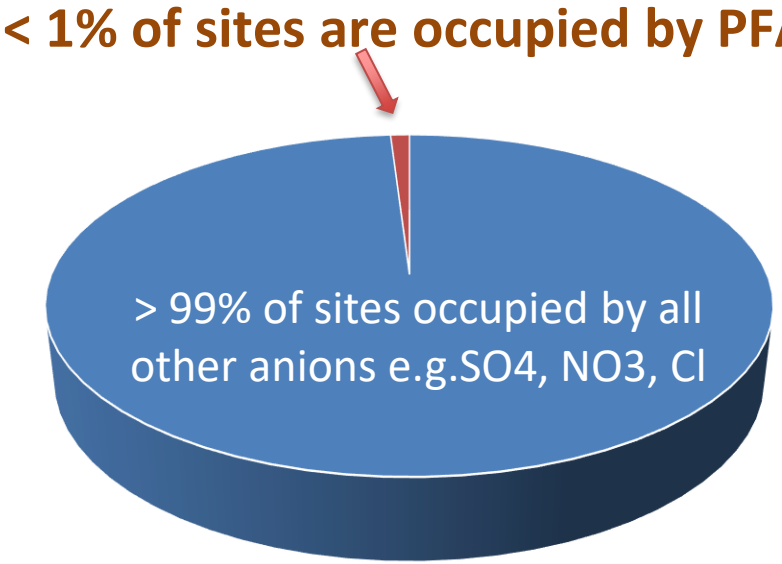
How Selective is Resin?

https://www.aliexpress.com/item/32698329541.html



Concentrations of major anions are ~ 1 million times higher than PFAS

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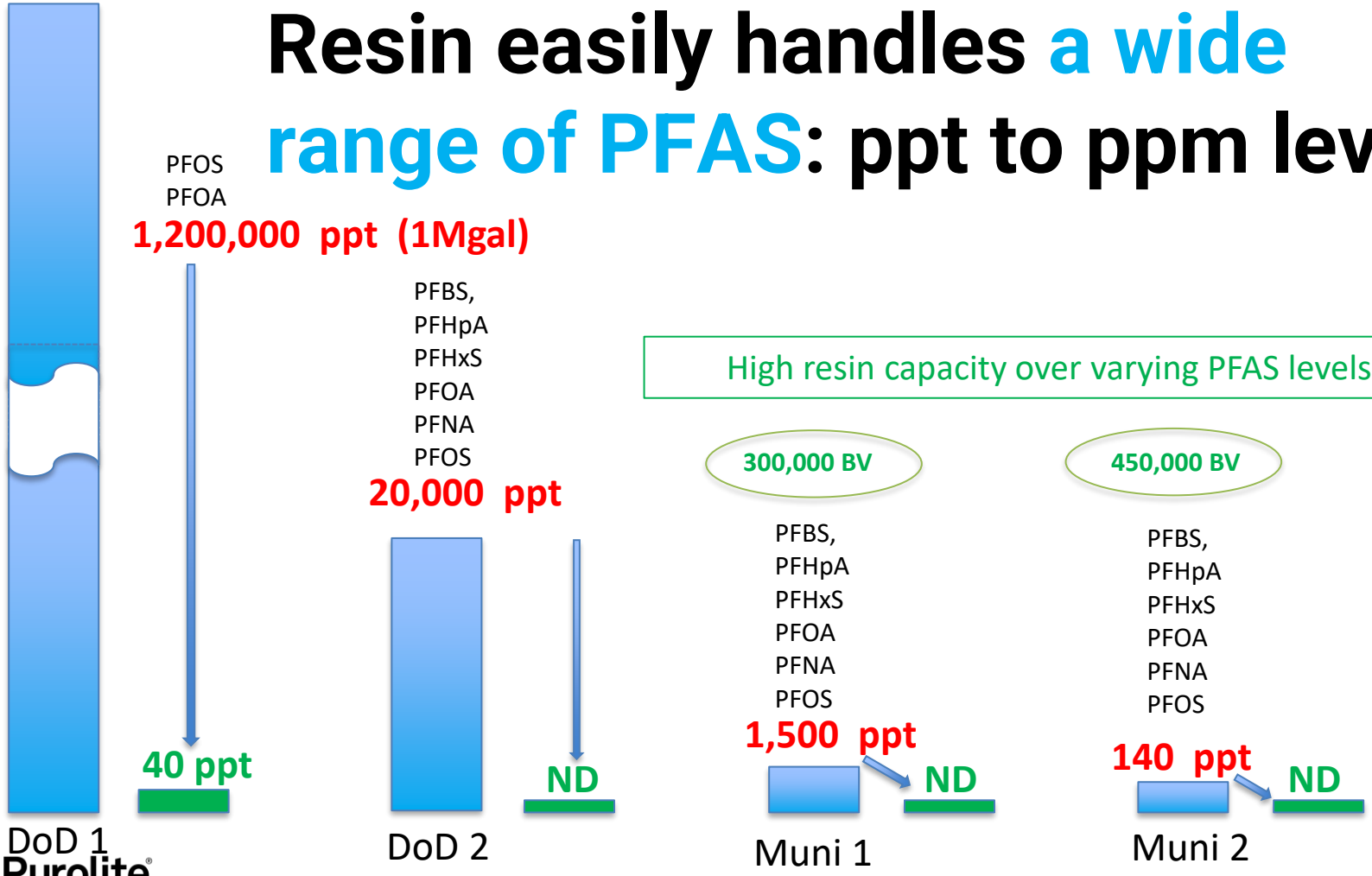
Resin easily handles a wide range of PFAS: ppt to ppm levels



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Case History: Horsham Well 10

140 ppt Total PFAS
PFAS Reduced to Non-Detect using
GAC and PFAS-Selective Resin

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Photo courtesy Altair Equipment

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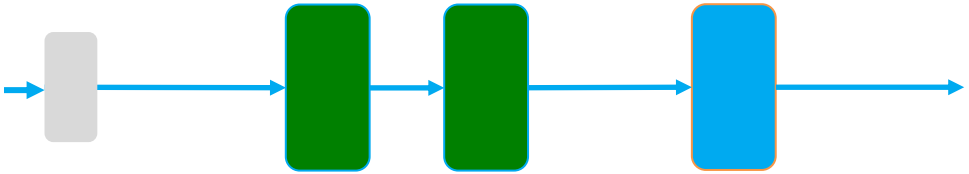
Well 10 - Initial Treatment: GAC > GAC > Single-use Resin

Inlet Water:

PFOS	55 ppt
PFOA	27 ppt
PFBS	8.4 ppt
PFHxA	9.6 ppt
PFHpA	4.7 ppt
PFHxS	36 ppt

Total PFAS 140 ppt

Well Water
50 gpm



2.8ft BD, LV 7 gpm/ft2

Total 5.6 min
For B-GAC

1.8min @ 2/3rd point
2.8 min. Effluent

Solids Filter

Total 40 ft3
Bituminous GAC
3-ft diameter

20 ft3 PFA694E
selective resin
3-ft diameter

No regeneration or other chemicals are used.
Resin is disposed of after a single use

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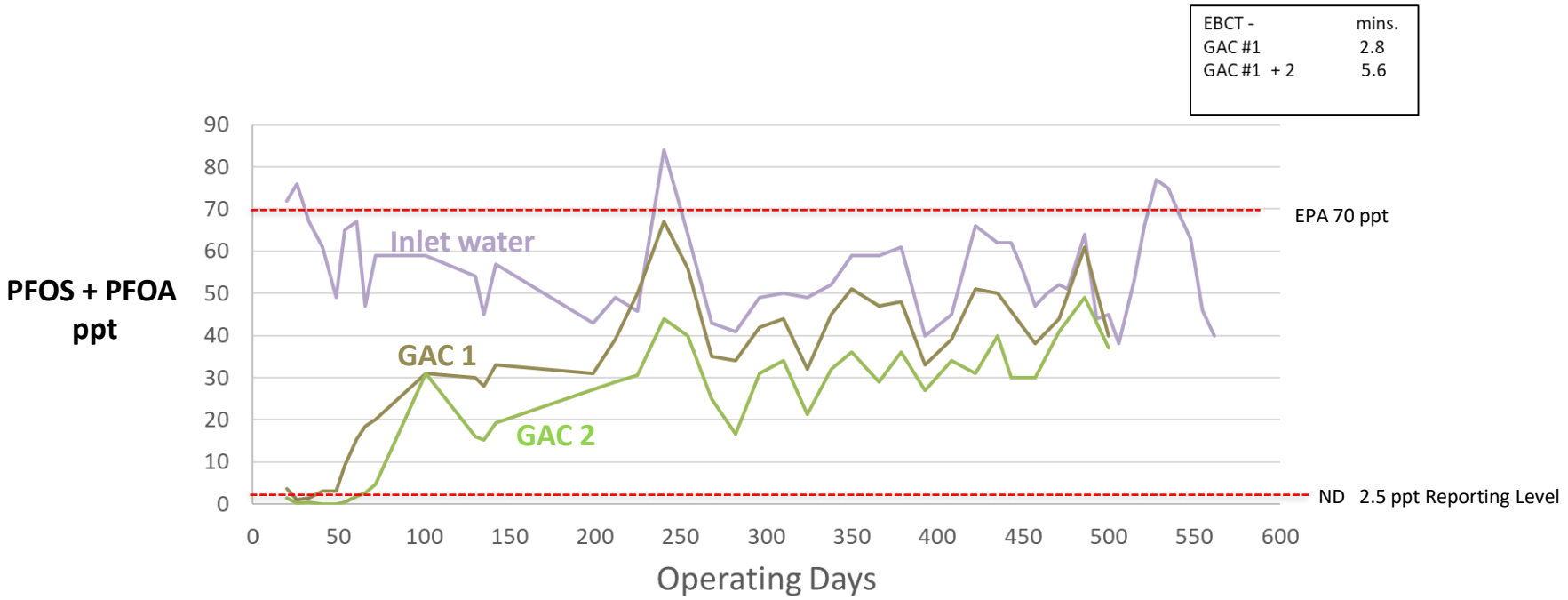
PFOS + PFOA Removal – Bituminous GAC 1 + 2



B-GAC at 17,000 BV to reach MRL of 2.5 ppt at 5.6 mins EBCT

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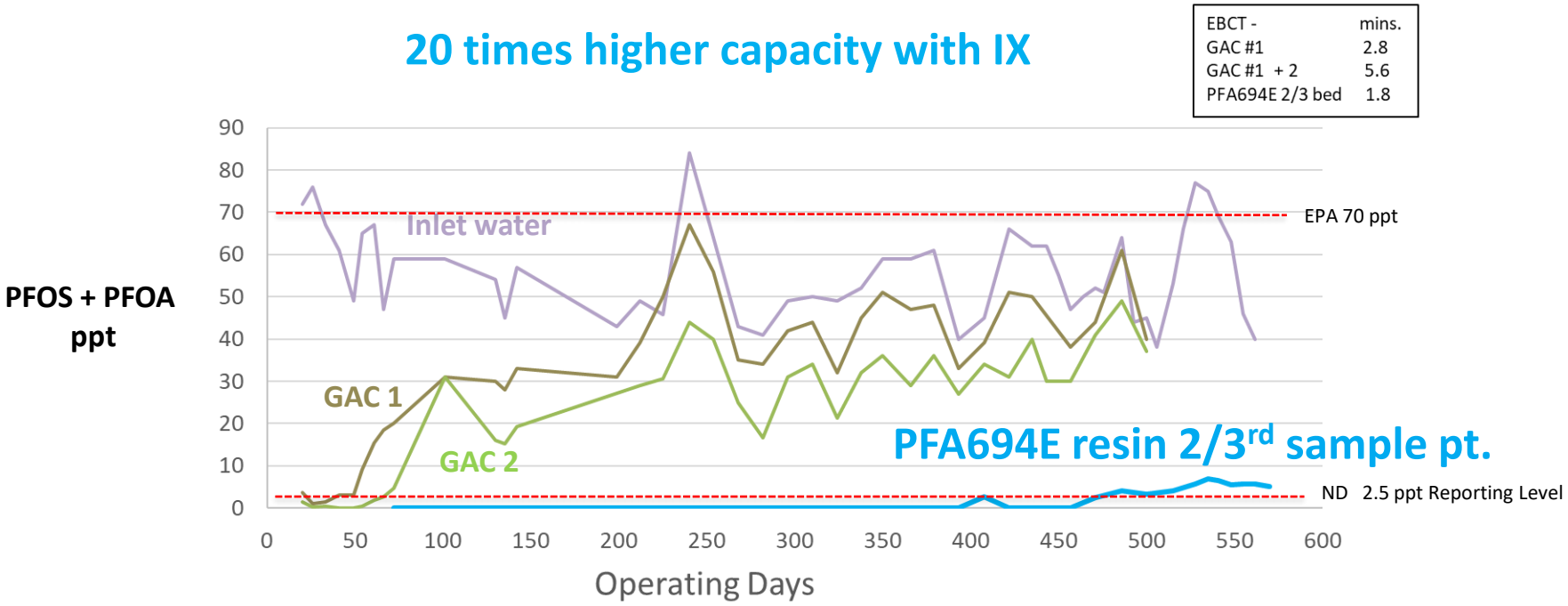
Well 10

PFOS + PFOA Removal – In service for 570 days



1 liter resin treats > 456,000 liters of water to ND

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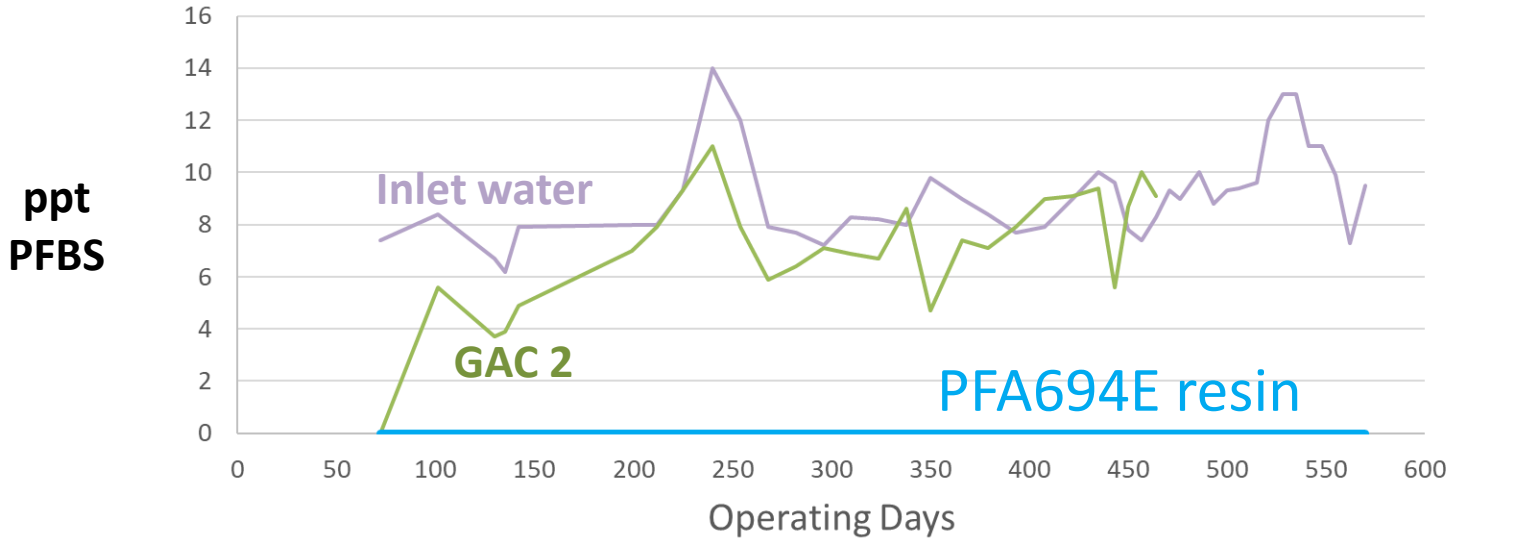
Well 10

PFBS – Short Chain Sulfonic Type PFAS

20 times higher capacity with IX

EBCT -	mins.
GAC #1 + 2	5.6
PFA694E 2/3 bed	1.8



PFBS – Perfluorobutanesulfonate, $C_4F_9.SO_3H$; Mol.Wt. 300

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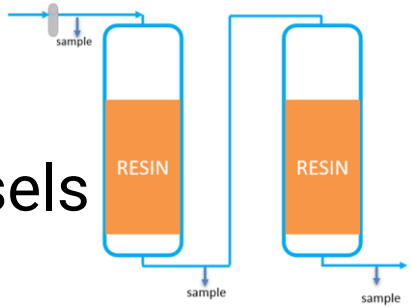
Well 10

Update on Horsham Well 10

- Permanent System handles 100 gpm flow
- GAC is no longer used
- Single-use PFA694E installed in Lead-Lag Vessels
- Now targeting short-chain PFAS removal



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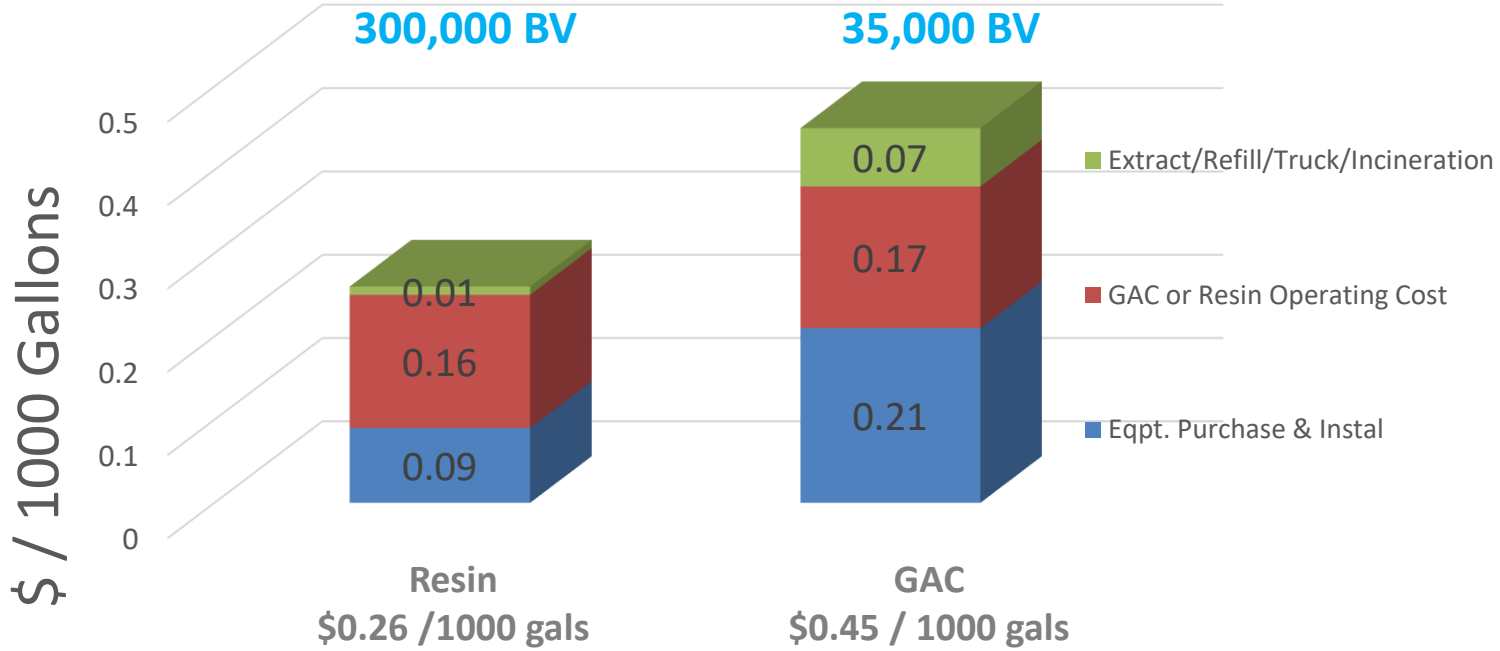
Total Cost $ /1000 gals
Capital + Operating Cost - 500 gpm system



Treatment to < 5 ppt of combined PFOS + PFOA

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Case History: Warminster Well 26

2000 ppt Total PFAS

Compared:

- **Bituminous GAC**
- **Coconut Shell GAC**
- **Single-Use PFAS-Selective Resin**

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Warminster Well 26 - Medium PFAS Levels

	Min.	Avg.	Max.	Eurofins Lab#
	ppt	ppt	ppt	Det. Level ppt
PFBA *	55	55	55	1.8 - 2
PFBS	27	34	45	0.3 - 4
PFPeA *	138	138	138	1.8 - 1
PFHxA	105	141	177	0.4 -2
PFHxS	275	316	429	0.4 -4
PFHpA	39	52	61	0.3 -1
PFOA	**186**	**236**	**290**	0.3 - 1
PFNA	7	10	14	0.4 - 1
PFOS	**504**	**650**	**910**	0.3 - 4
Sum	**1336**	**1632**	**2119**	

- Limited analyses
\# for 2018 to 2016

TOC	**730,000 ppt**
VOCs (TCE, PCE, CCl4)	**230,000 ppt**

Expect < 500 ppt VOC in stripper effluent

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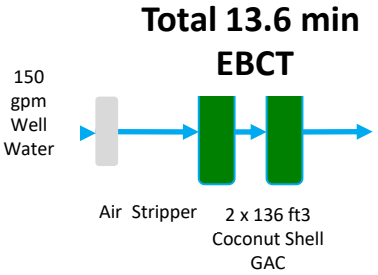
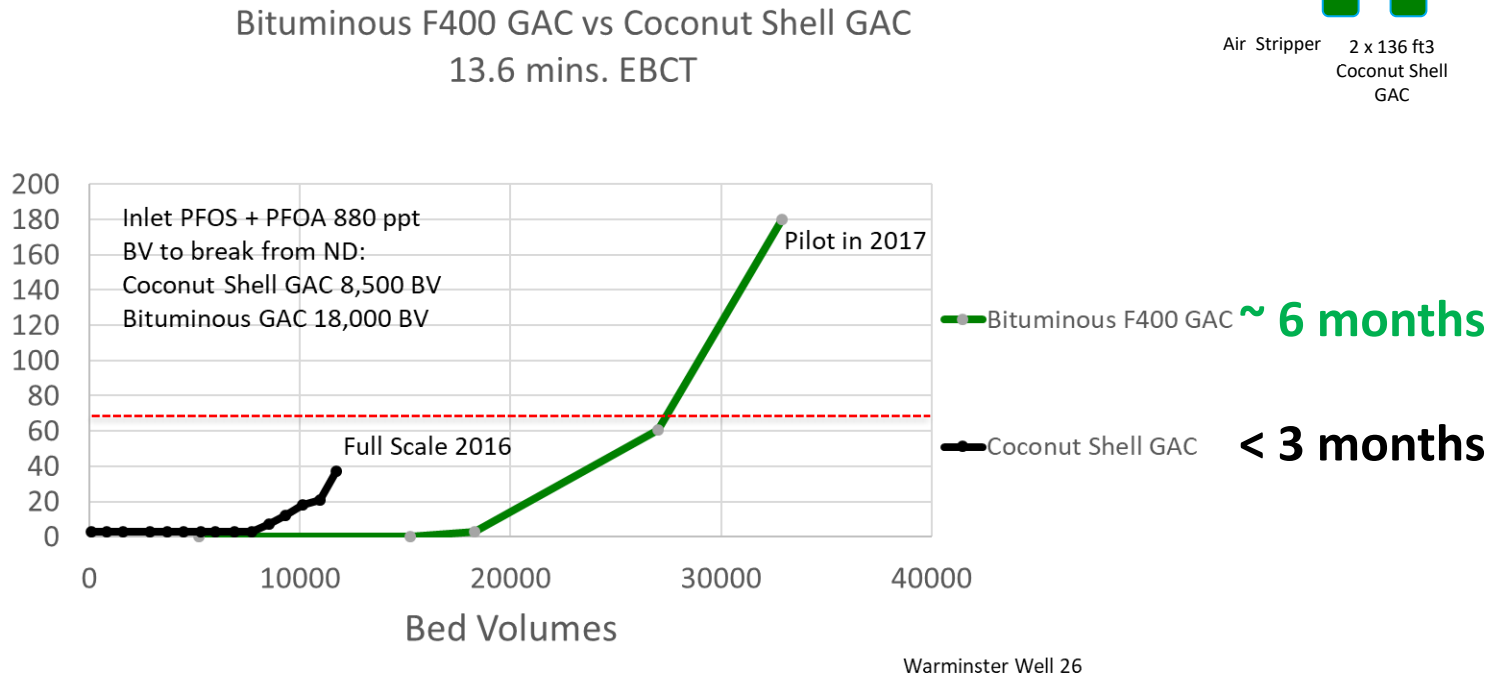
Coconut Shell GAC Full Scale (2016) Bituminous F400 GAC Pilot (2017)





Coconut Shell GAC: 80 days; Bituminous GAC: 170 days

Well 26

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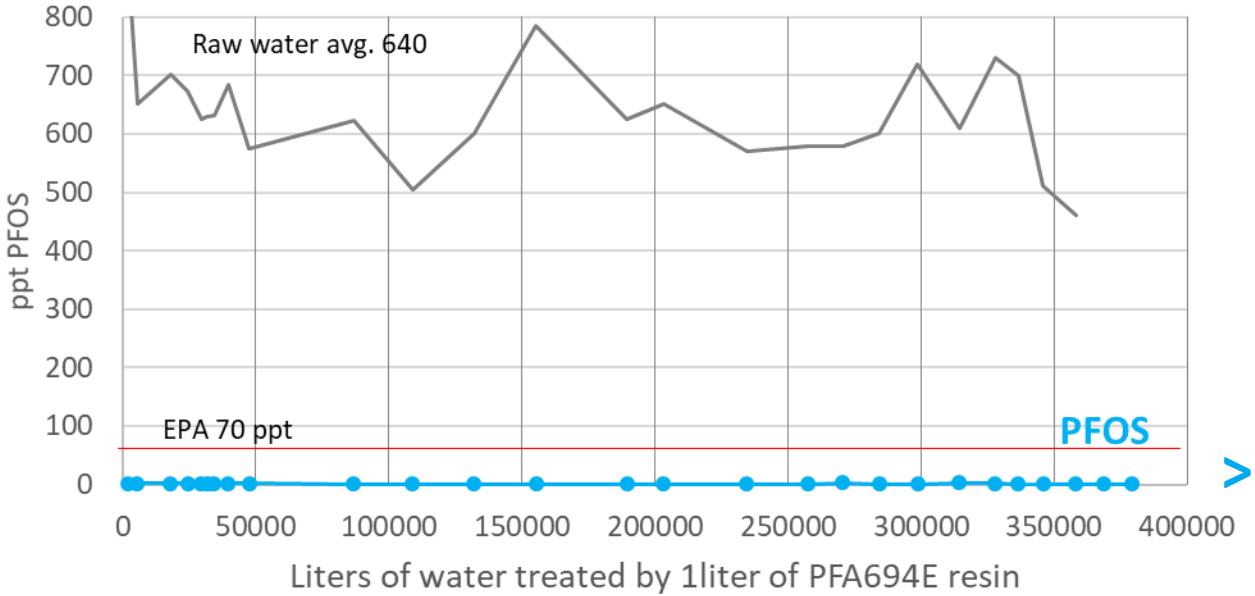
PFA694E Resin: PFOS Removal 967 days

(single vessel 2 to 3 mins. EBCT)



> 32 months

With Lead-Lag Design: ~750,000 BV thru Lead before leakage ex Lag reaches 2 ppt

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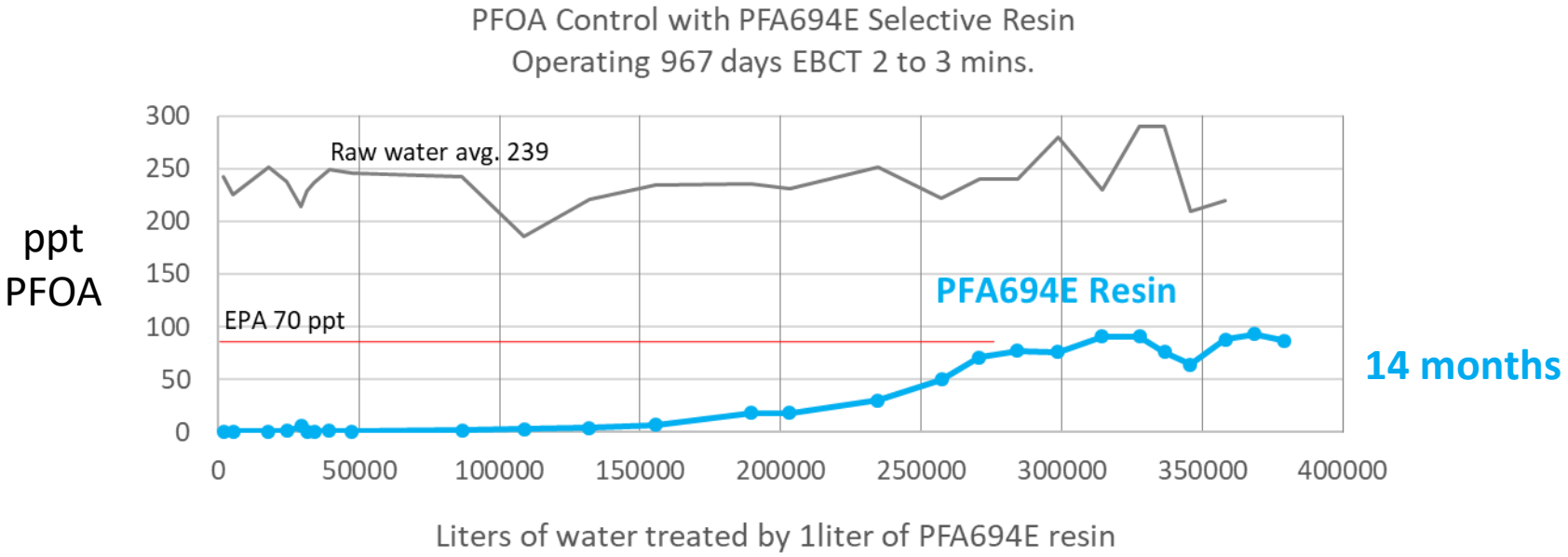
PFA694E Resin: PFOA Removal 967 days

(single vessel 2 to 3 mins. EBCT)



With Lead-Lag Design: ~300,000 BV thru Lead before leakage ex Lag reaches 7 ppt

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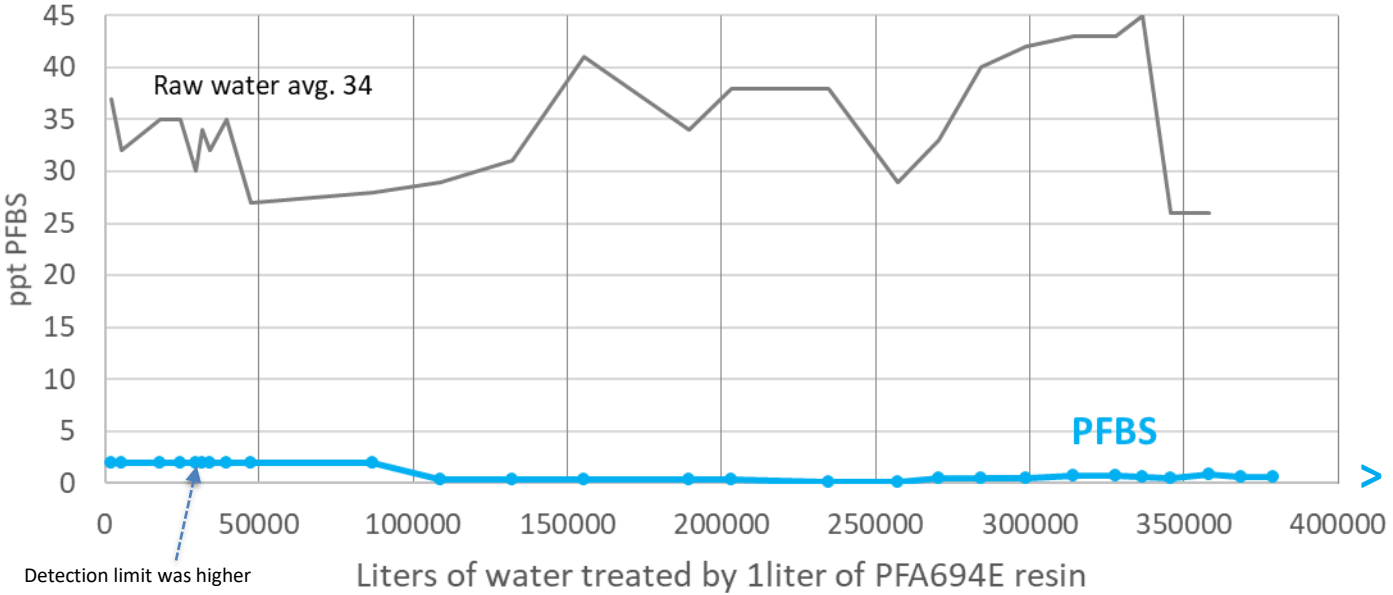
PFA694E Resin: PFBS Removal 967 days

(single vessel 2 to 3 mins. EBCT)



> 32 months

With Lead-Lag Design: ~750,000 BV thru Lead before leakage ex Lag reaches 2 ppt

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Update on Warminster Well 26

- GAC no longer being used due to higher OPEX
- 500 gpm system uses PFA694E resin in Lead-Lag vessels
- PFA694E resin system continues to meet expectations

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Comparing Resin & GAC Designs for Potable Water

Design Comparison	Resin	GAC	
Total System flow - gpm	2000	2000	
Vessel Diameter - feet	12	12	
Number of trains	1	4	4 times more equipment
Flow per train - gpm	2000	500	
Total number of vessels for all trains (lead + lag)	2	8	
Pounds of GAC	[redacted]	20,000	33.6 lb/cu ft density
Media volume per vessel - ft^3	504	595	
EBCT Contact time per vessel - minutes	2	9	> 4 times more EBCT
Estimated BV for lead vessel change out trigger	**280,000**	**35,000**	
Total Water Treated per Year - MMgals/year	1,051	1,051	
Days Between Lead Vessel Change-outs	367	216	
Volume of Media Consumed per Year – ft^3	502	4015	8 X more media consumed

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Comparing Resin & GAC Designs for Potable Water

	IX	GAC
Media consumed per year – Cubic Feet	502	4015
Media Cost per pound		$ 2.00
Media Cost per cubic foot	$ 300.00	$ 67.20
Media Cost per year	$ 150,552	$ 269,790
Operating Cost - $/1000 gallons	$ 0.14	$ 0.26

Resin is ~ half the OPEX for GAC

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Piloting for 2+ years is just too long:

Consider Better / Faster Options:

(1) Predictive Modeling &

(2) Accelerated Piloting

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20-year history of successful modeling

of contaminant removal with Ion Exchange

- Perchlorate
- Arsenic
- Chromate
- Uranium
- Nitrate
- Bromide
- Routine thruput guarantees given

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Everything starts with the water

Provide this:

- Critical items shown in blue
- If not provided, assumed ND in green
- Endpoint target – this is key

Parameter	Units
Operational Flow Rate	gpm
Operational Schedule	hour/day
Daily Volume (average)	Gallons
Sulfate	mg/L
Nitrate	mg/L
Alkalinity (as $CaCO_3$)	mg/L
Chloride	mg/L
Fluoride	mg/L
Perchlorate	ppb
Arsenic	ppb
Hexavalent chromium	ppb
Uranium	ppb
Calcium	mg/L
Magnesium	mg/L
Sodium	mg/L
Potassium	mg/L
Iron	ug/L
Manganese	ug/L
pH	
TDS	mg/L

Parameter	Abrv.	Units
Suspended Solids		mg/L
Oil & Grease		mg/L
Total Organic Carbon		mg/L
Perfluorobutanoic acid	PFBA	ppt
Perfluoropentanoic acid	PFPeA	ppt
Perfluorohexanoic acid	PFHxA	ppt
Perfluoroheptanoic acid	PFHpA	ppt
Perfluorooctanoic acid	PFOA	ppt
Perfluorononanoic acid	PFNA	ppt
Perfluorododecanoic acid	PFDoDA	ppt
Perfluorotetradecanoic acid	PFTeA	ppt
Perfluorobutanesulfonic acid	PFBS	ppt
Perfluorohexanesulfonic acid	PFHxS	ppt
Perfluoroheptanesulfonic acid	PFHpS	ppt
Perfluorooctanesulfonic acid	PFOS	ppt
4:2 FTS (fluorotelomer sulfonate)	4:2 FTS	ppt
6:2 FTS (fluorotelomer sulfonate)	6:2 FTS	ppt
8:2 FTS (fluorotelomer sulfonate)	8:2 FTS	ppt
GenX	GenX	ppt
VOC	VOC	ppb

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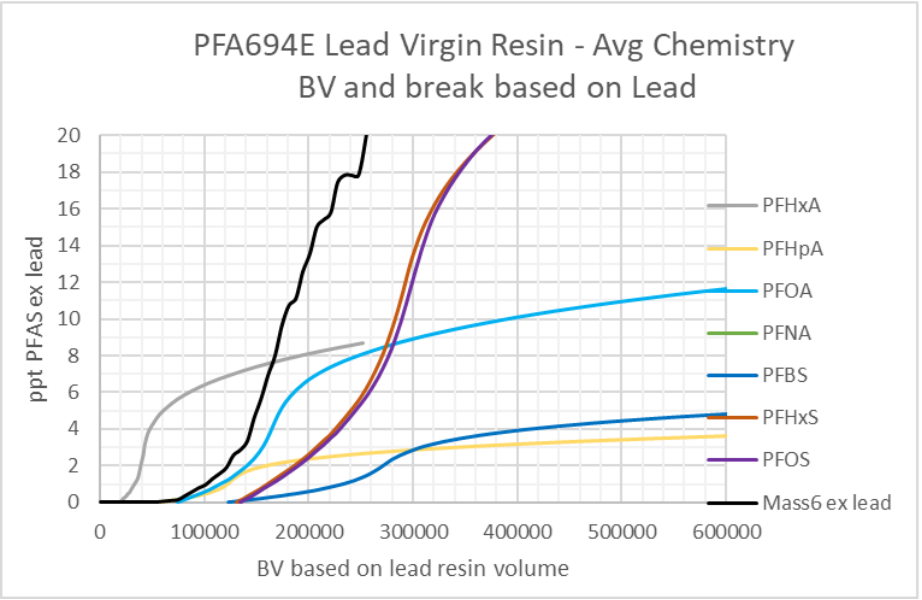
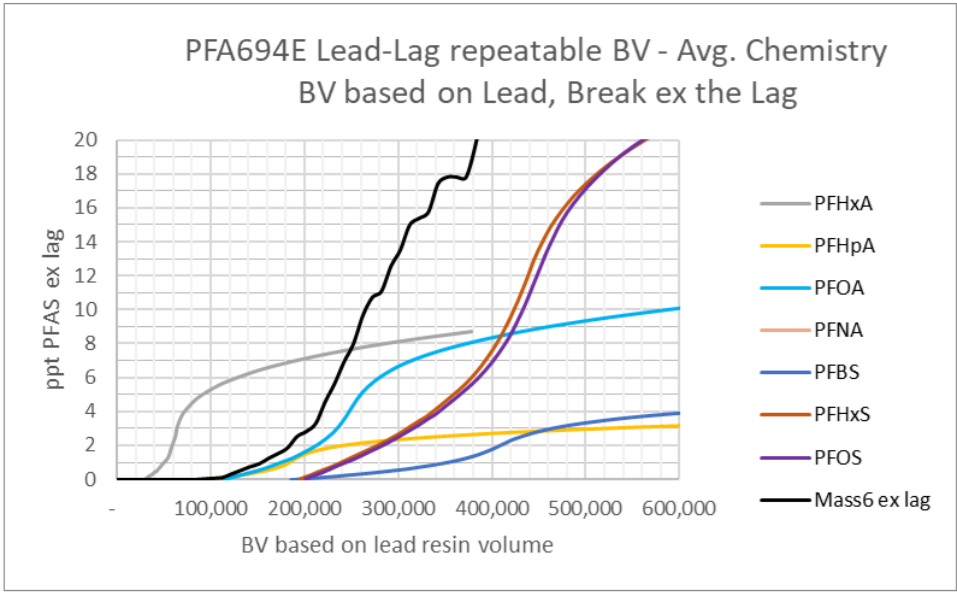
Simulating breakthru can save valuable time





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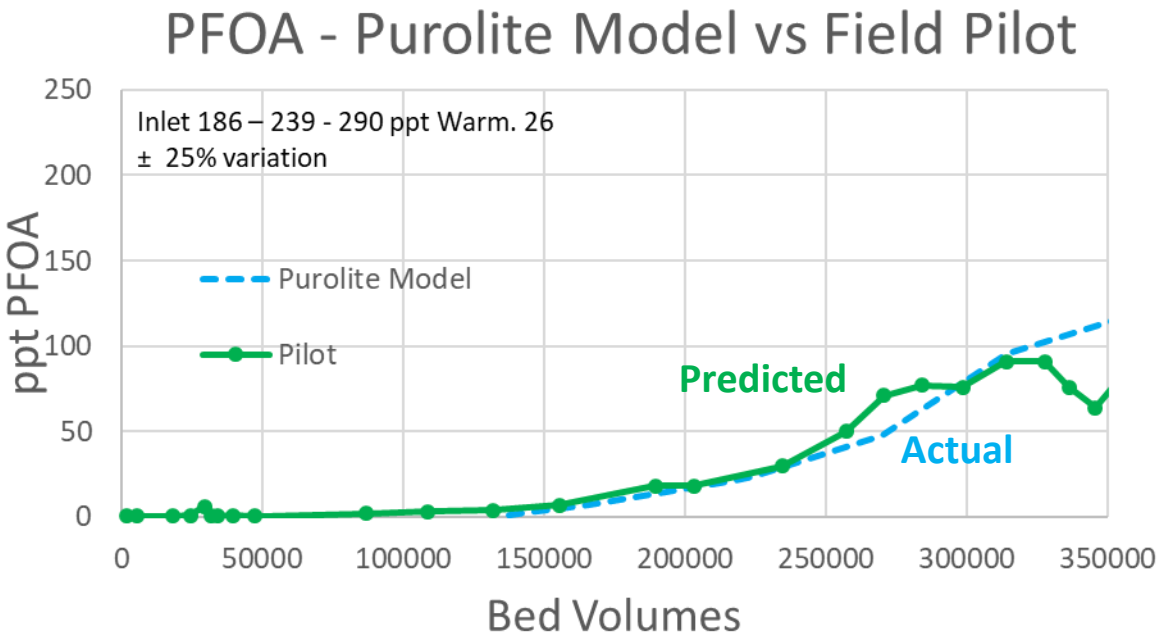
Example Modeling: Warminster Well 26 Pilot
Predicted vs Actual Modeling – Strong Correlation



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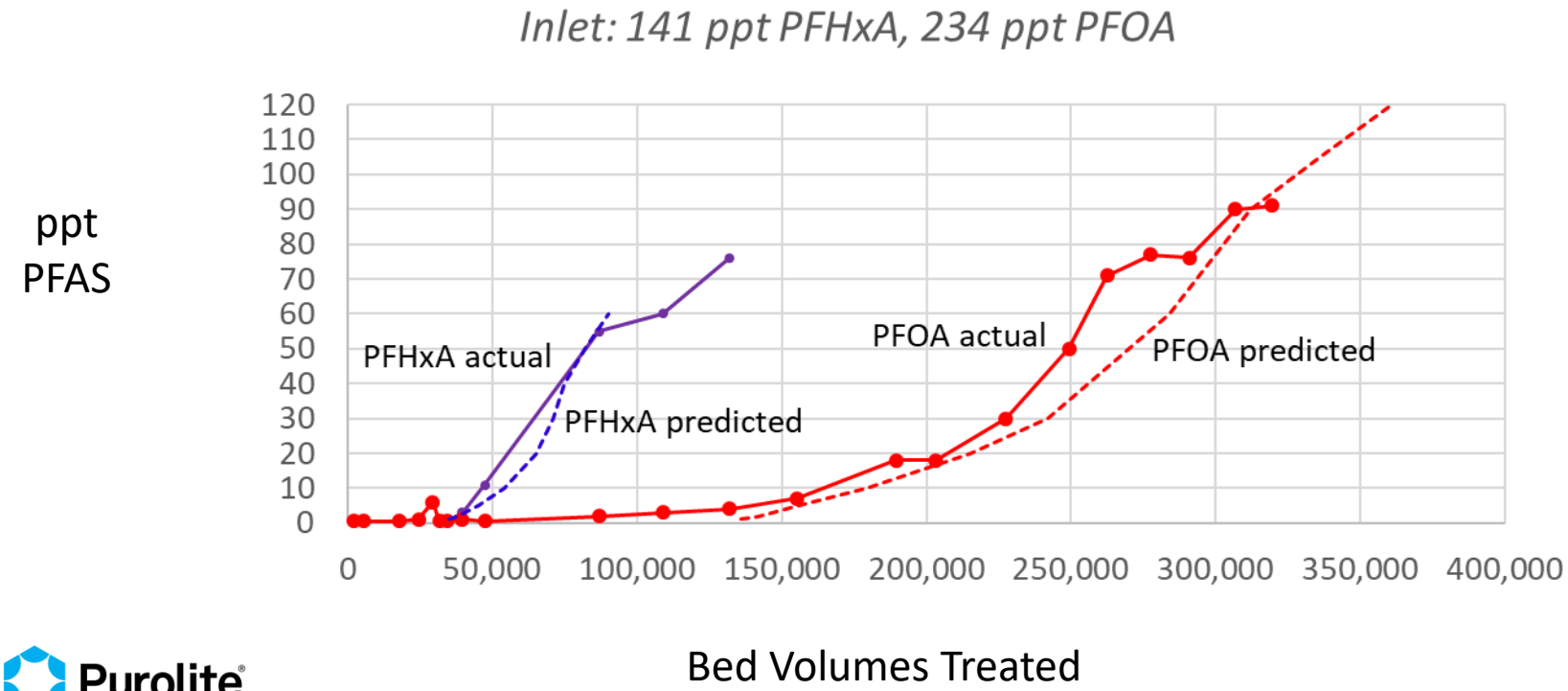
Example Modeling – Warminster Well 26:
Full Scale 2 mins. EBCT
Predicted vs Actual – Very Strong Correlations



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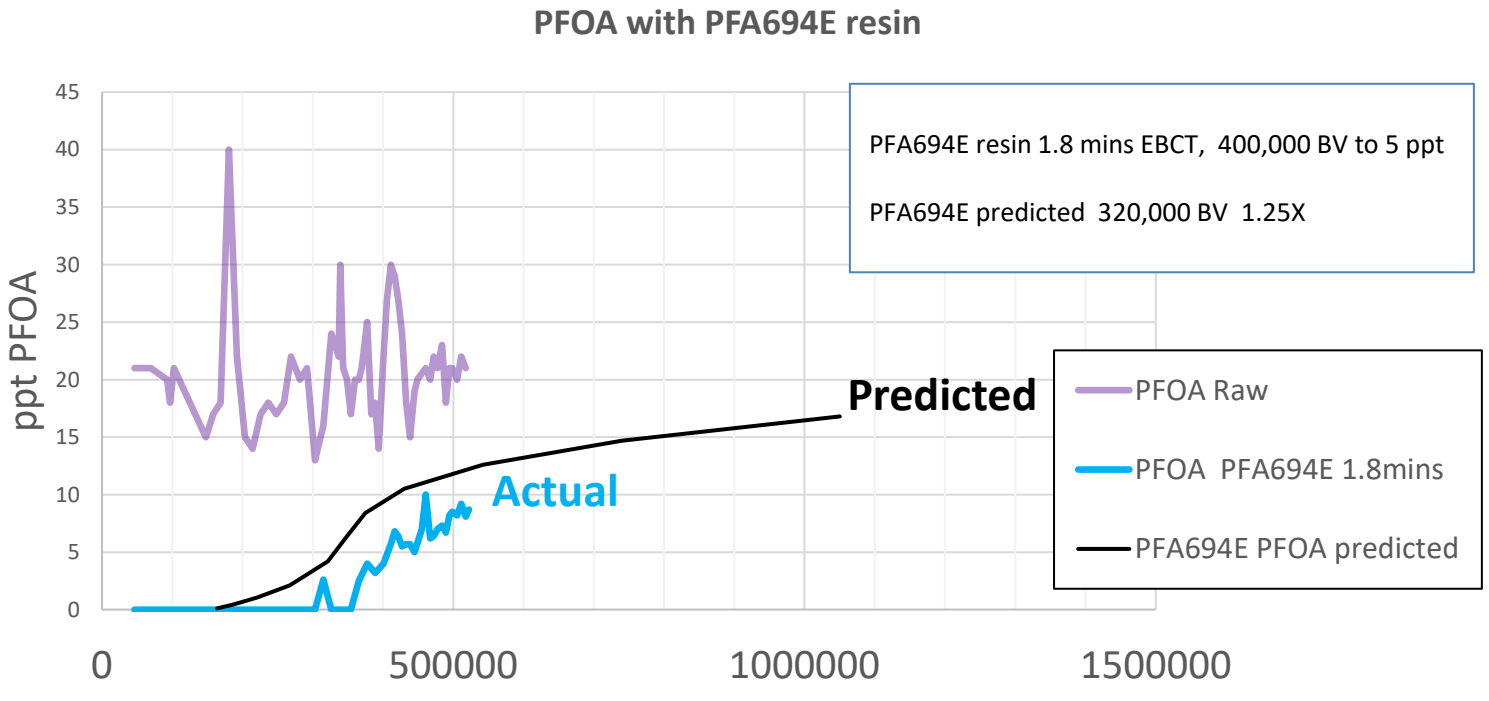
Example Modeling – Horsham Well10:
Full Scale 2 mins. EBCT
Predicted vs Actual - Conservative



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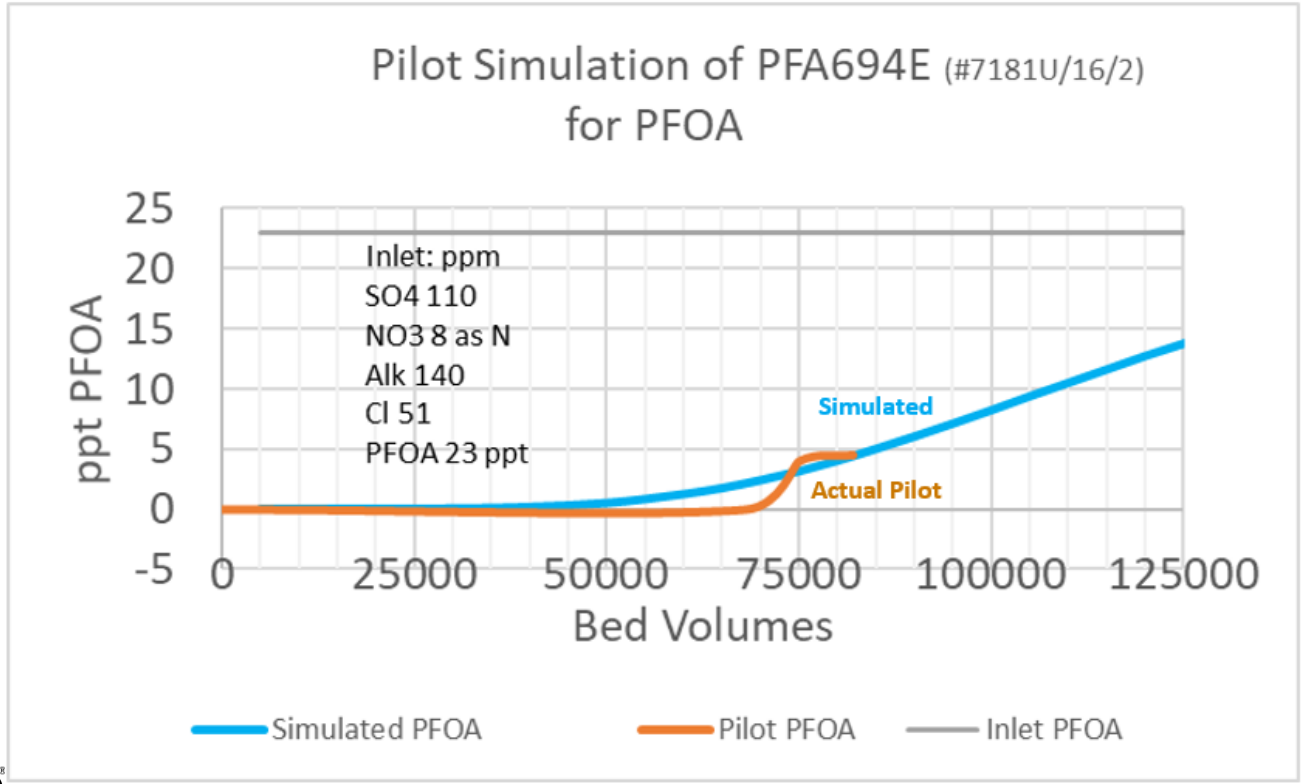
Example Modeling - Colorado Pilot Predicted vs Actual – Strong Correlation



2 min EBCT

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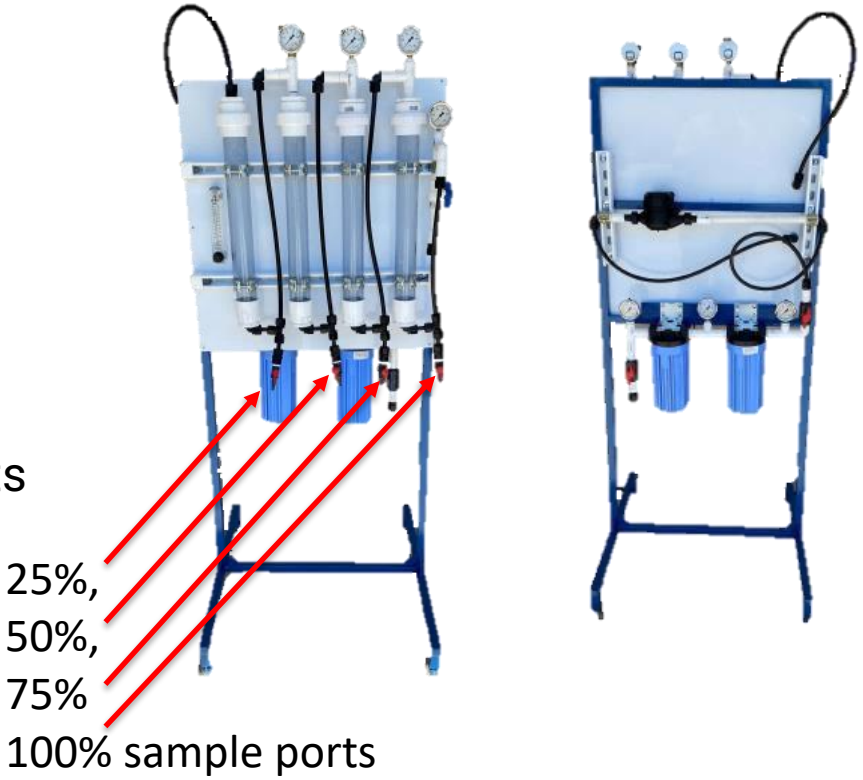
Accelerated Piloting – 4 times faster

- Validates predictive modeling
- Faster decisions
- Quick pilot for uncommon PFAS
- Segmented Columns & sampling

  ports at 25%, 50%, 75% and 100% points
- Get results 4 times faster from 25% port
- EBCT (minutes): 0.5, 1, 1.5 and 2



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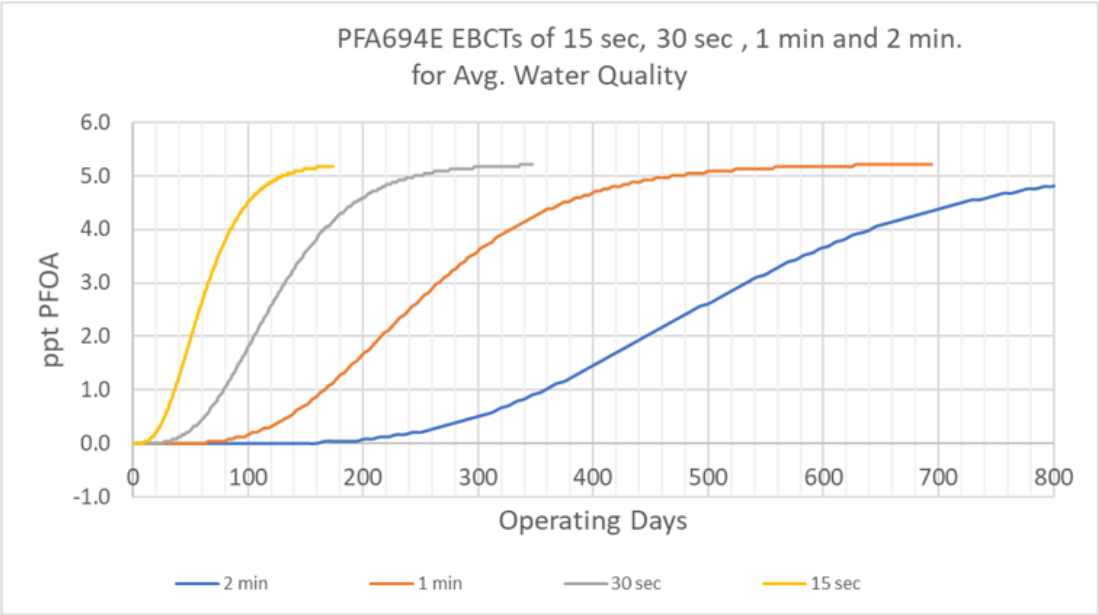
Shorter Bed Depths – Faster Results

Time to breakthrough is not linear to the bed volumes!



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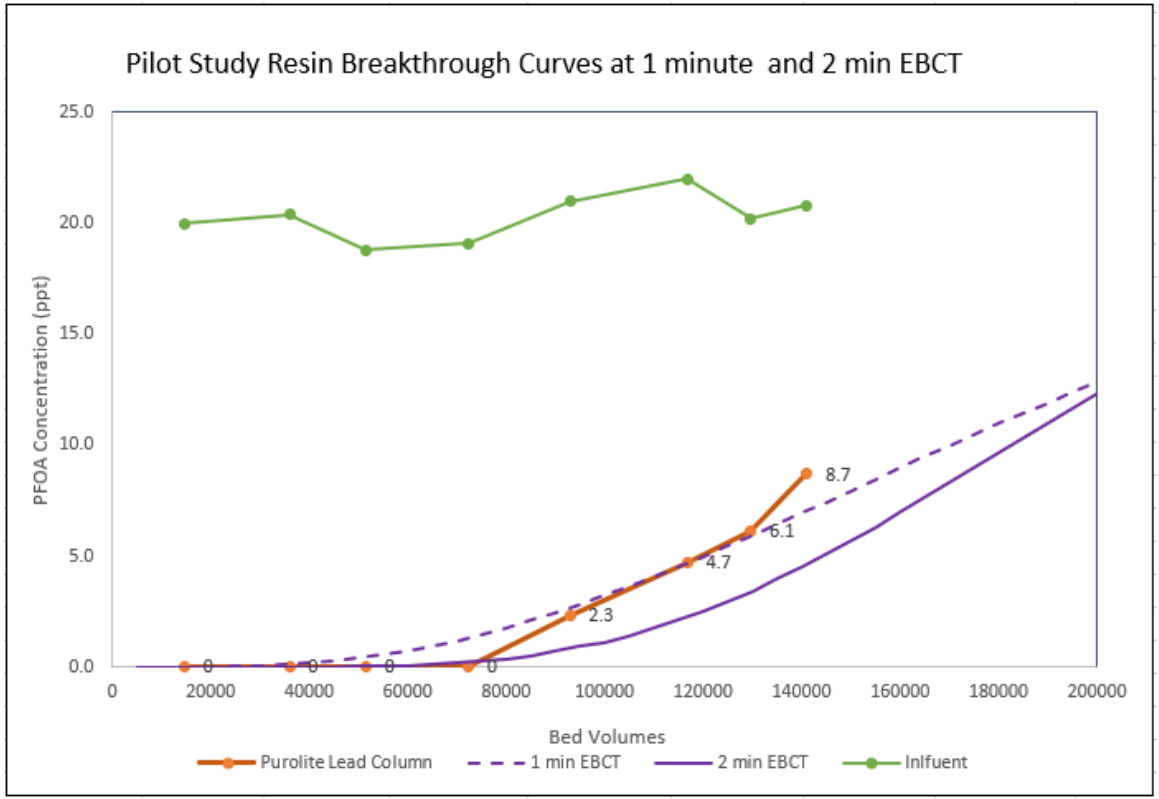
Modeling 1 minute vs 2 minutes EBCT Predicted vs Actual – Strong Correlation

Modeling can account for shorter bed depths



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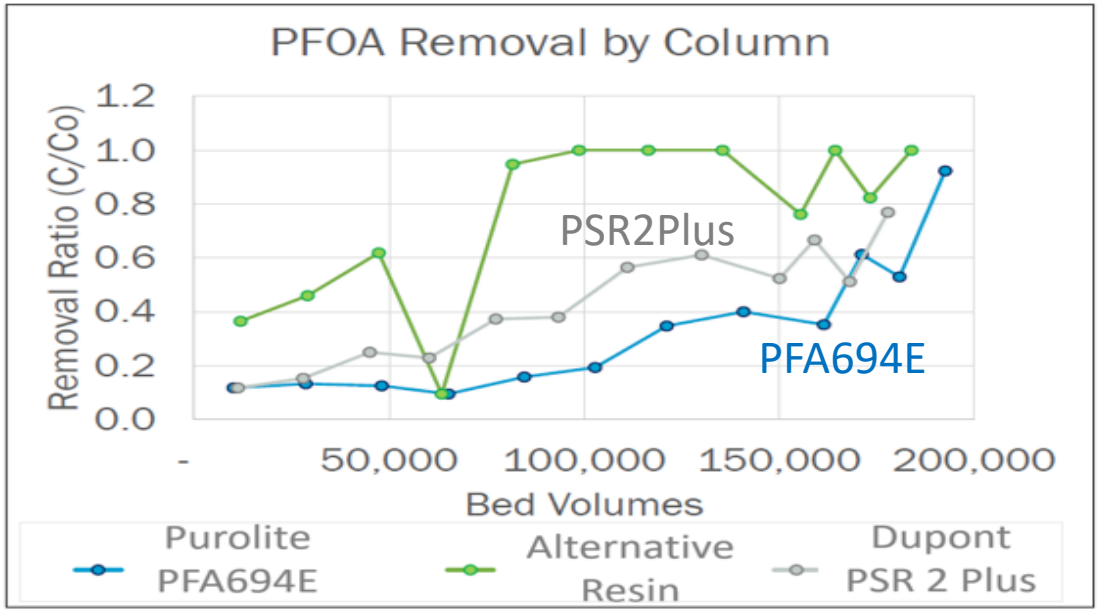
Brown & Caldwell Pilot in Colorado - Published Results

Water Quality
Sulfate: 192 ppm
Nitrate: 7.5 ppm
Alkalinity: 212 ppm
PFOA: ~20 ppt
PFOS: ~140 ppt



Used a short resin bed equal to 20 seconds EBCT

Source: 0-60 in the PFAS Lane – A Colorado Case Study
Jeff Jackson, Erin Mackey, Brown and Caldwell
Presented at the CA NV Section AWWA Conference
San Diego, California, October 22, 2019

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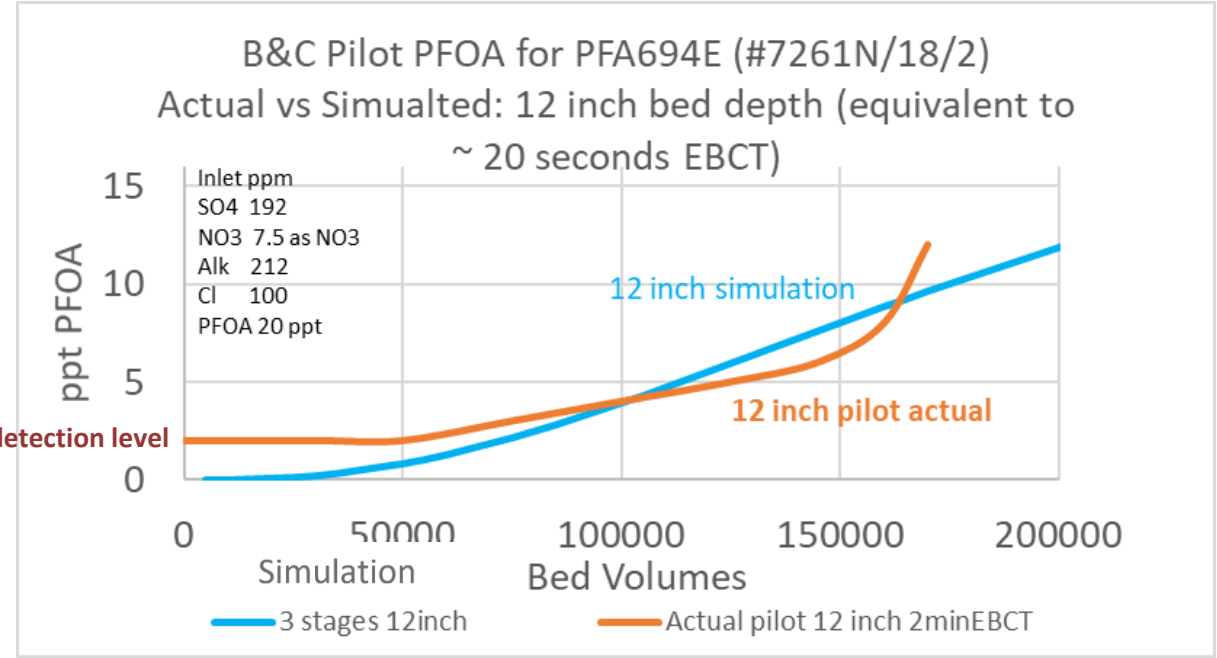
Brown & Caldwell Colorado Pilot – Post modeling Predicted vs Actual

Strong correlation even with a short 12” bed depth



Used 12-inch bed depth equivalent to ~20 seconds EBCT

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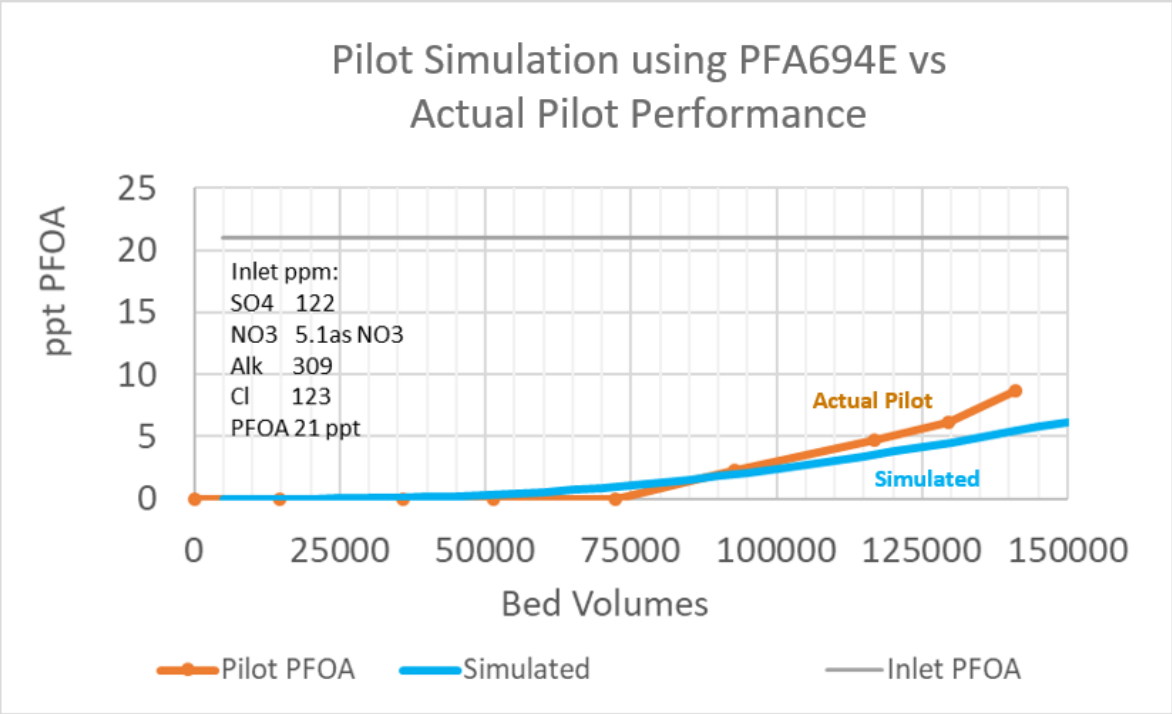
Example Modeling - California Pilot #1 Predicted vs Actual – 1min EBCT



Strong Correlation

1 minute EBCT

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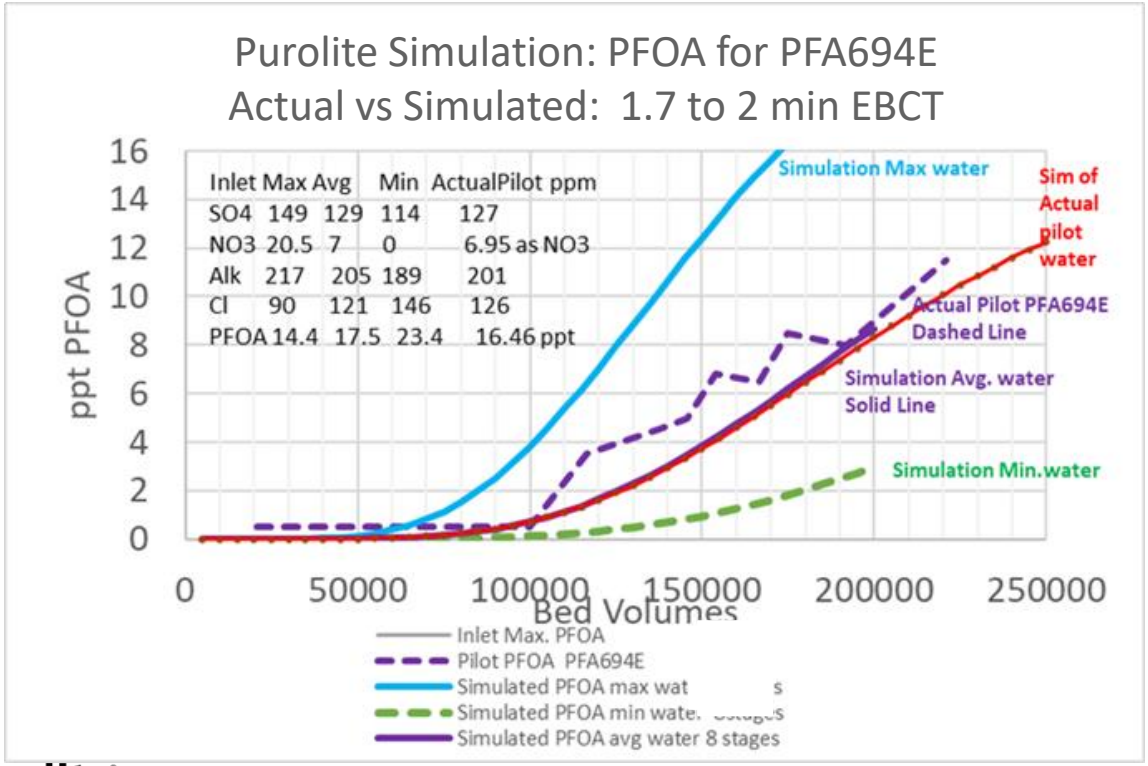
Example Modeling - California Pilot #2
Predicted vs Actual - 95% Correlation



Generating a Prediction Envelope: For Min., Max., Avg.

for variable influent water quality is a major benefit for OPEX planning.

Actual Pilot and Predicted Average were very close!

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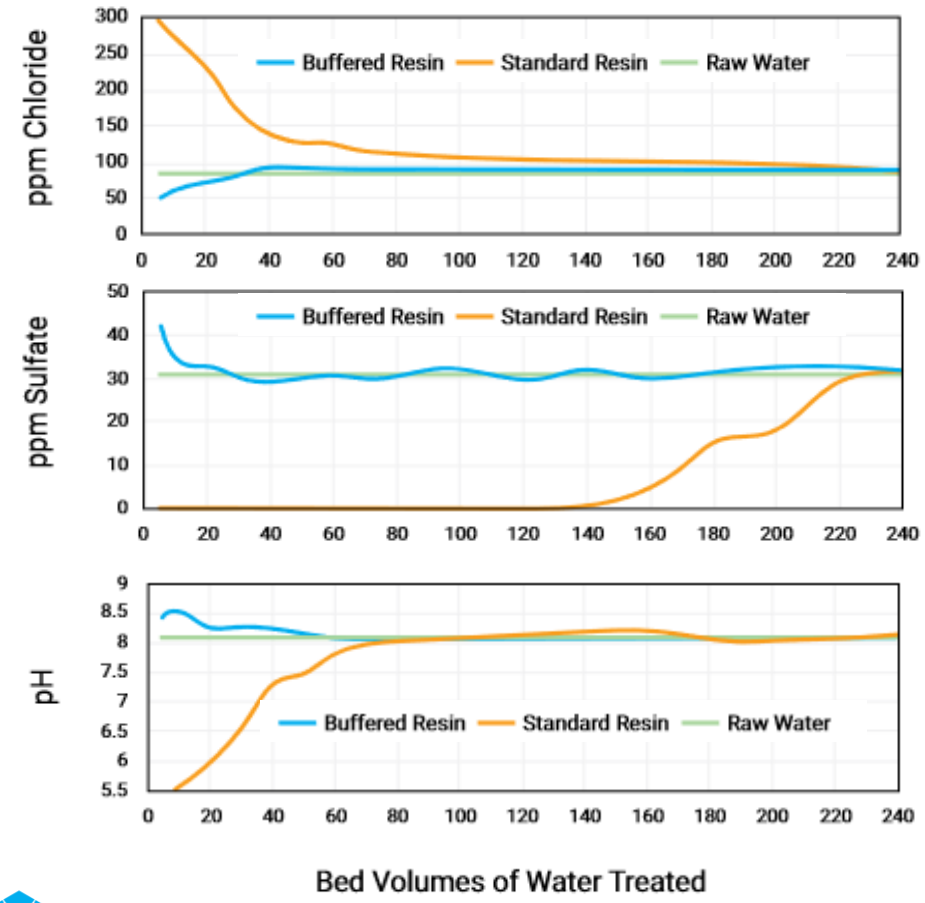
Buffered PFAS Resin

No CSMR issues

- Unbuffered resin starts-up with
  - High Chloride,
  - Low sulfate, pH and alkalinity
  - High CSMR & low pH can cause corrosion
- PFA69EBF buffered resin starts with buffered levels of Cl, SO4 HCO3 & pH
- Better corrosion control at start-up



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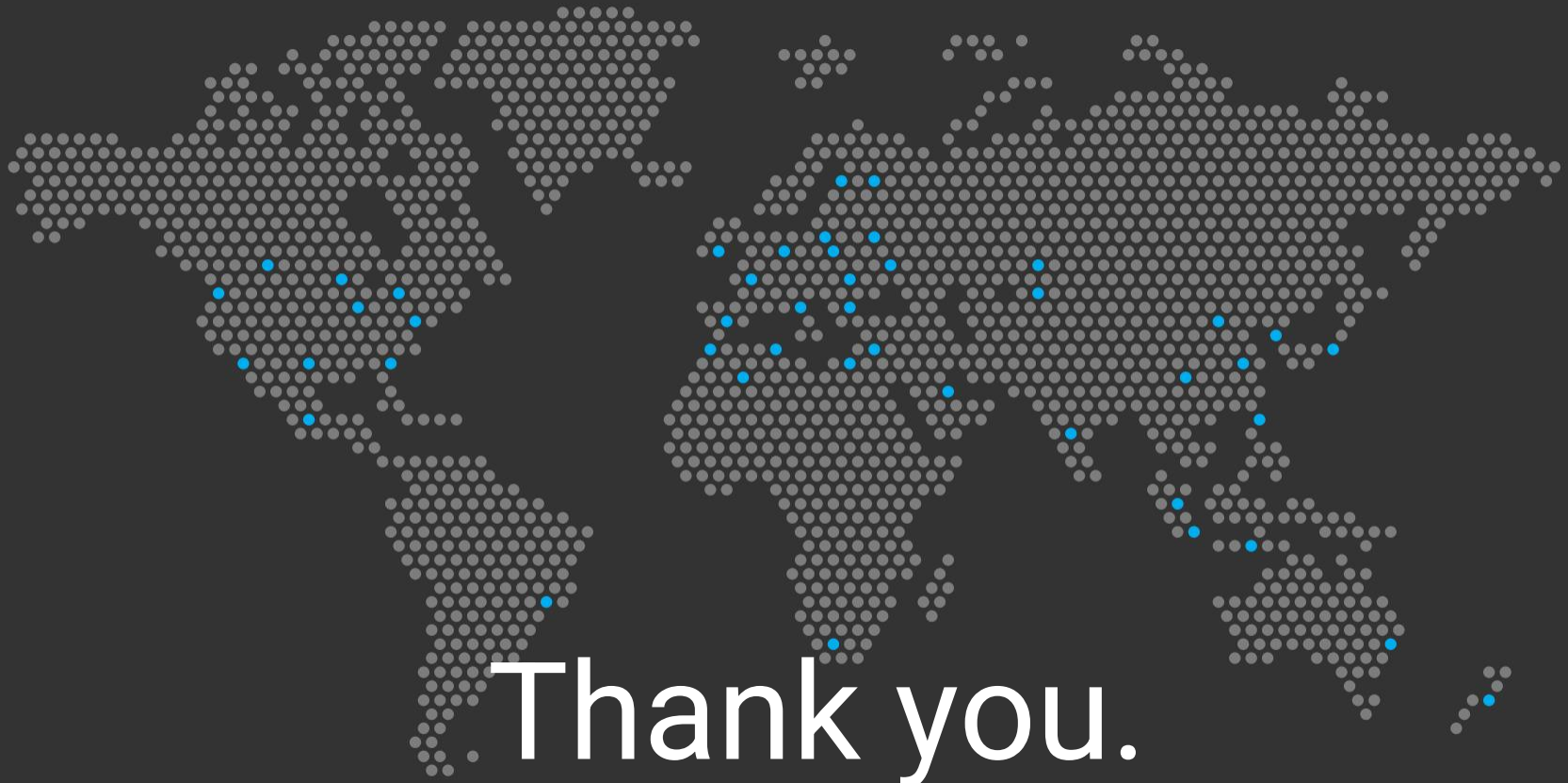
Conclusions

- PFAS-selective resin is cost-effective for PFAS
- Modeling is accurate & conservative allowing reliable O&M cost estimates
- Modeling excels for widely-changing water chemistries
- Accelerated Piloting provides results 4 times faster & is also conservative
- Buffered resin can help with CSMR issues



Thank you.

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