PFAS:
The Treatment Toolbox

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WATER
OUR FOCUS
OUR BUSINESS
OUR PASSION

carollo
Engineers...Working Wonders With Water®

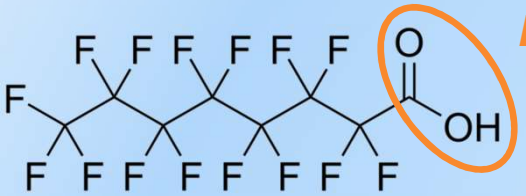
Overview

Physical & chemical properties

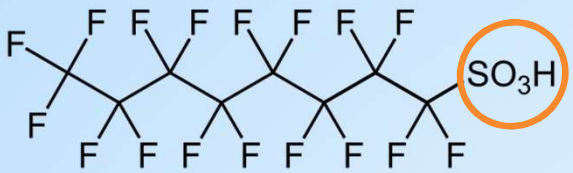
Treatment approaches:

1. What *doesn't* work
2. What we know *does* works
3. Case study
4. Innovative approaches

Unique Chemical Properties Drive Uses



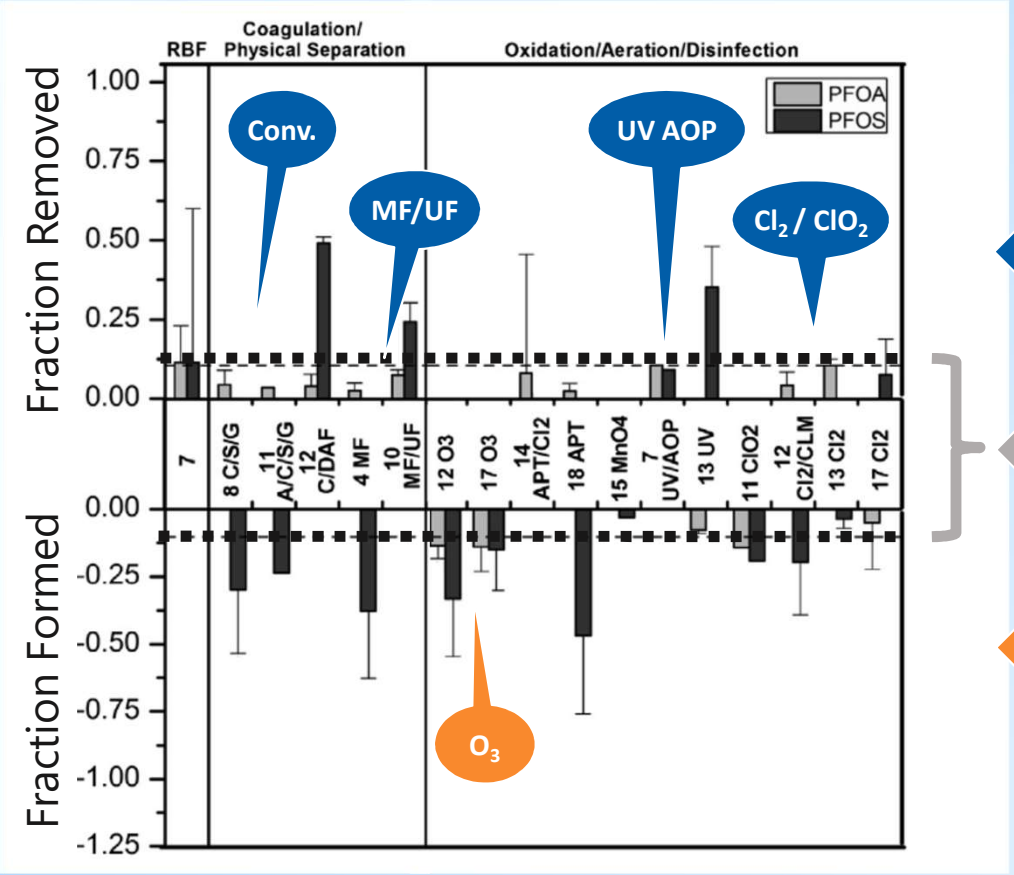
PFOA



PFOS

Properties	Desirable		Less Desirable
Extreme Chemical Inertness	Fire Fighting		Difficult to Destroy
Hydrophobic *and* Lipophobic	Repels Stains & Prevents Wrinkles		Accumulates in Protein Tissues & Blood (not sequestered in fat)
Surface Active	Good Coating Material		Difficult to Measure / Sample Accurately

PFAS Treatment: Conventional Treatment Just Doesn't Cut It



Limited/ no removal

Limits of Detection

Formation??

Edited from Appleman *et al*, 2014. *Water Research, 51, 246-255.*

So….What Treatment Options *Do* We Have for PFAS?

Carbon Adsorption (GAC)

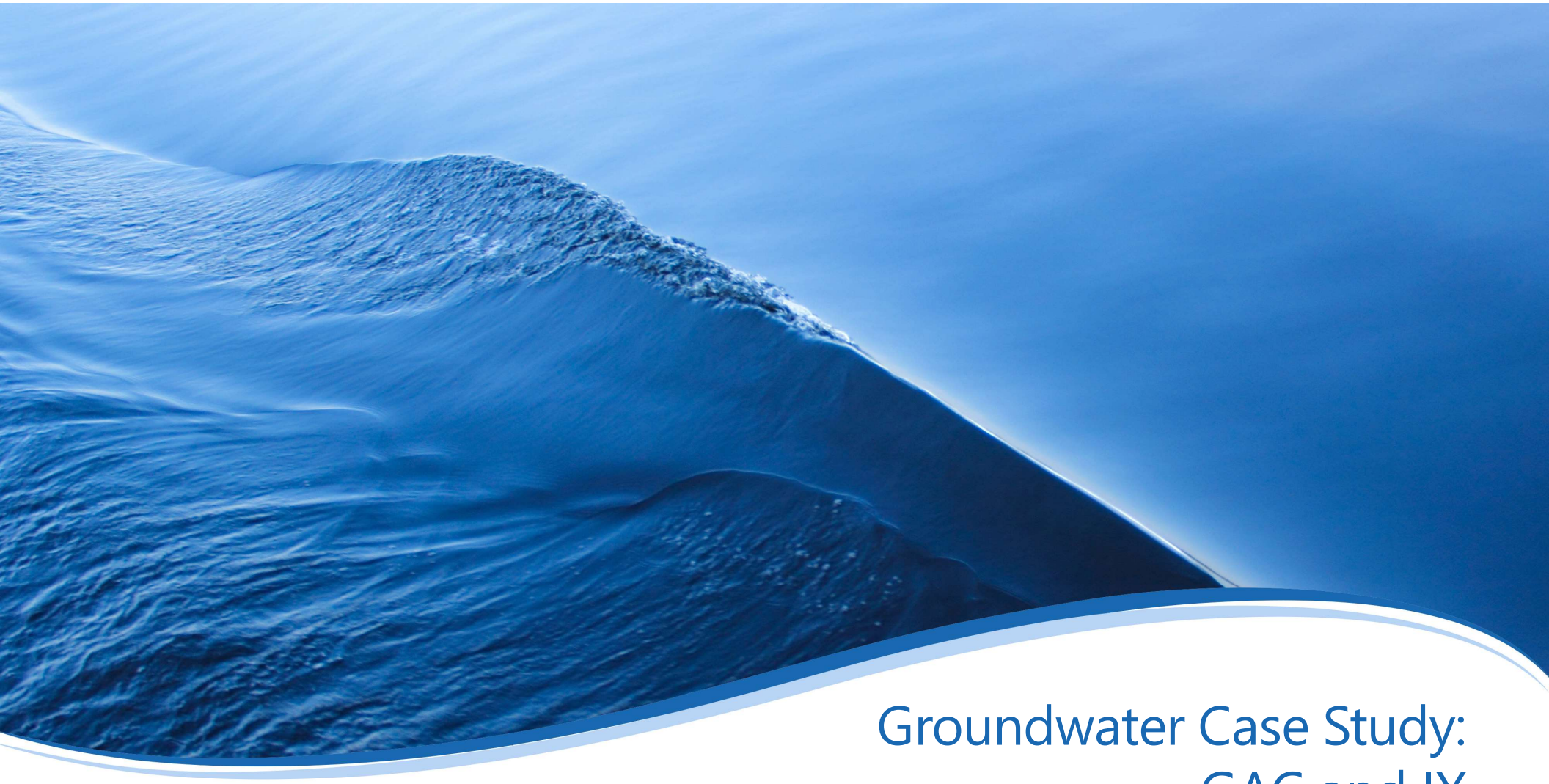
Ion Exchange (IX)

Reverse Osmosis
(RO or NF)

Other Options: Are They
Ready for Prime Time?

Process Selection Depends on Treatment Goals

Process	Effective for…?	Capital Cost	Operation & Maintenance Cost	Residual?
GAC	Long-chained PFAS and some short-chained PFAS	Lower	Low-Med	Spent carbon / regeneration ($)
AIX	Depends on resin	Lower	Low-Med	Spent resin / regeneration ($)
NF / RO	All (RO) Most (NF)	High	Med-High	Liquid concentrate ($$$)



Groundwater Case Study: GAC and IX

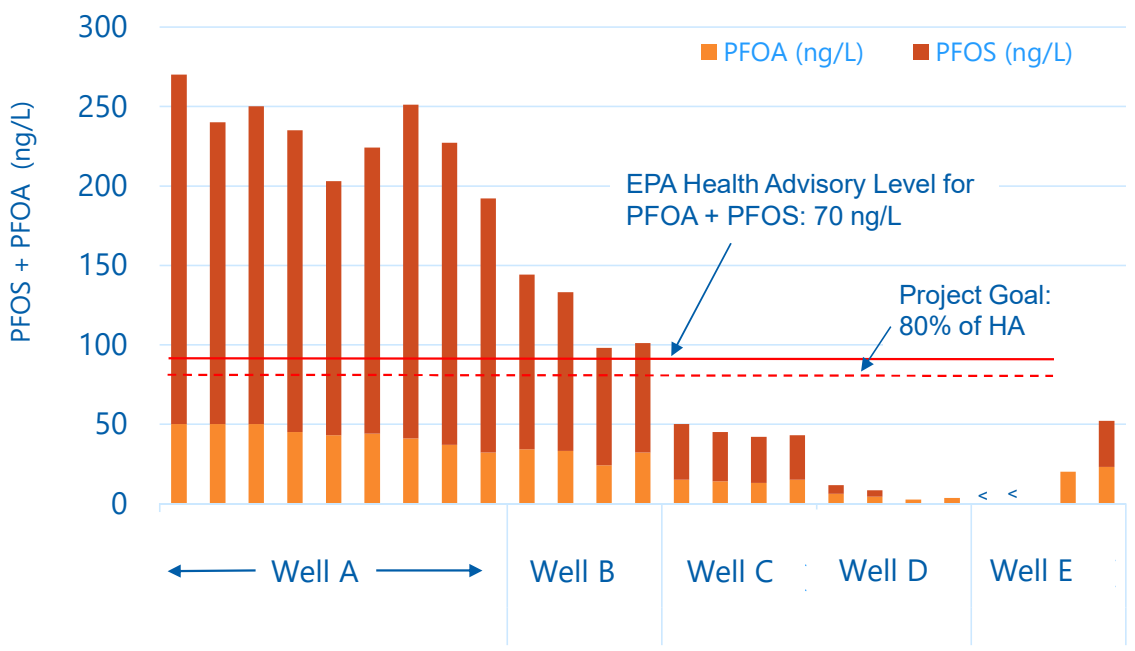
PFOS and PFOA Recently Detected in a Municipal Well Field

Initial Detections:

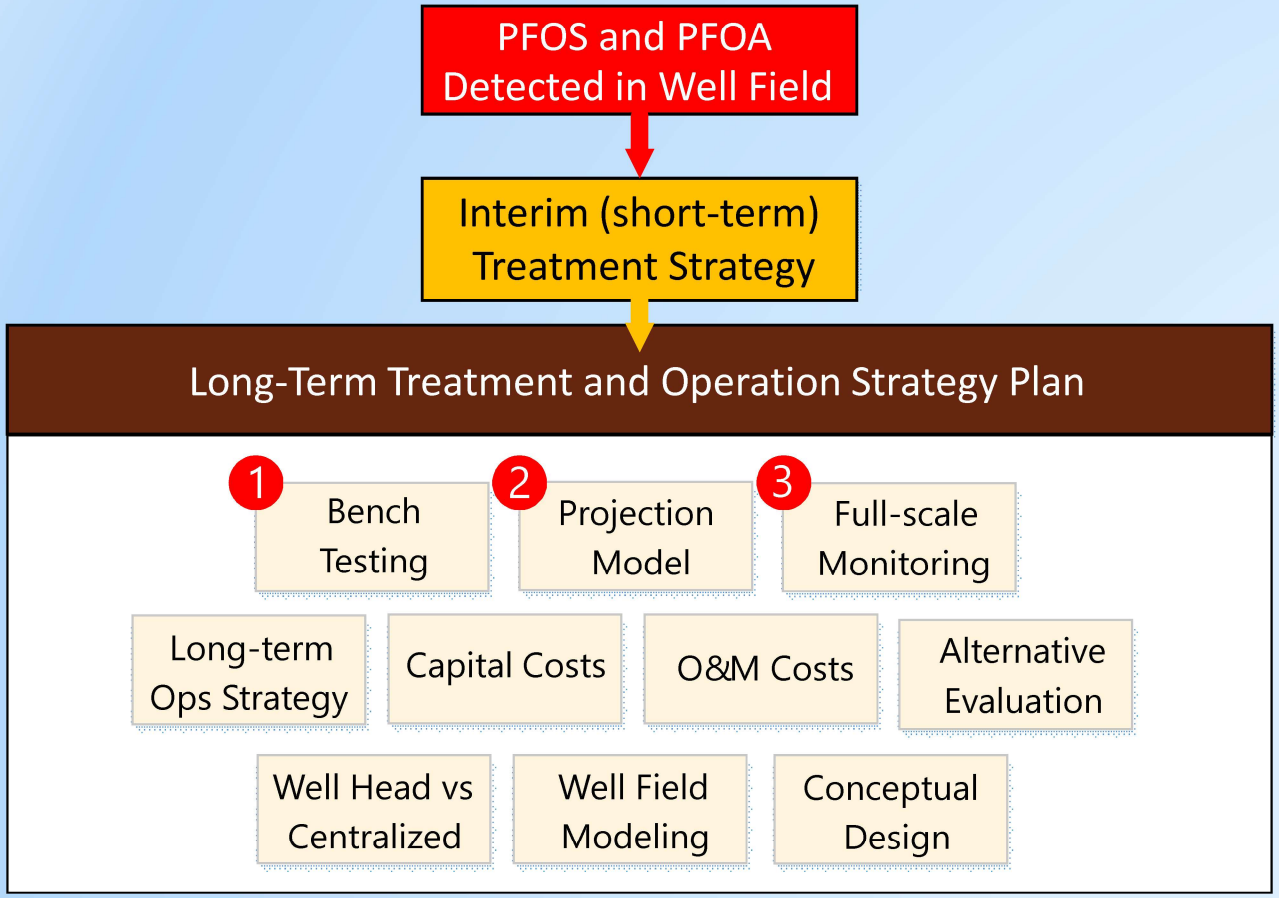
- PFOA ranged 5 – 200 ng/L
- PFOS ranged 6 – 50 ng/L

EPA Health Advisory:
PFOA+PFOS < 70 ng/L

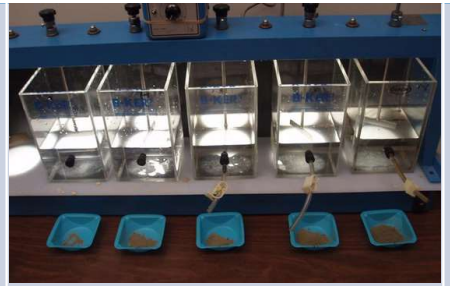
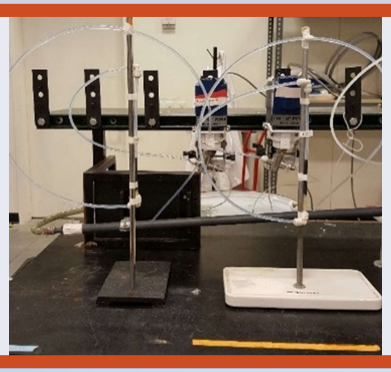
Initial Carollo Sampling Results:



Carollo Developed a Plan to Remove PFOS and PFOA: *Immediate and Long-term*

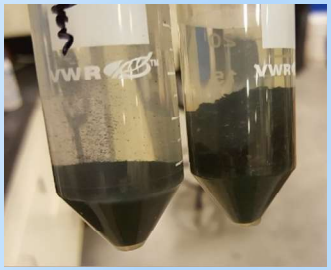


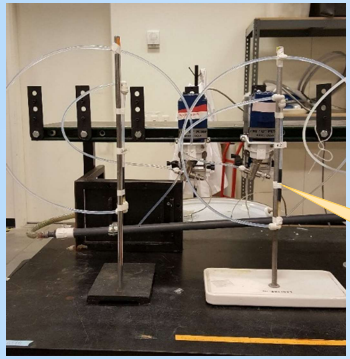
Two Types of Bench Testing Are Typically Conducted for GAC Adsorption Evaluation

Type	Apparatus	Outcome	Level of Effort
Isotherm (jar testing)		• Assess theoretical total capacity • Compare different carbon or media relative to each other • Cannot correlate with full-scale operation	• Static and less sophisticated • Fast and cost effective • Easier to conduct – 5+ gal sample – Can perform in hours to days
RSSCT* (Column Testing)		• Correlates better with full scale operation • Answers adsorption rates • Instrumental for operation model calibration • Can be used to estimate change-out frequency	• Dynamic and more sophisticated • Need special training • More difficult to conduct – 50+ gal sample – Can perform in days to weeks

**RSSCT = Rapid Small Scale Column Test*

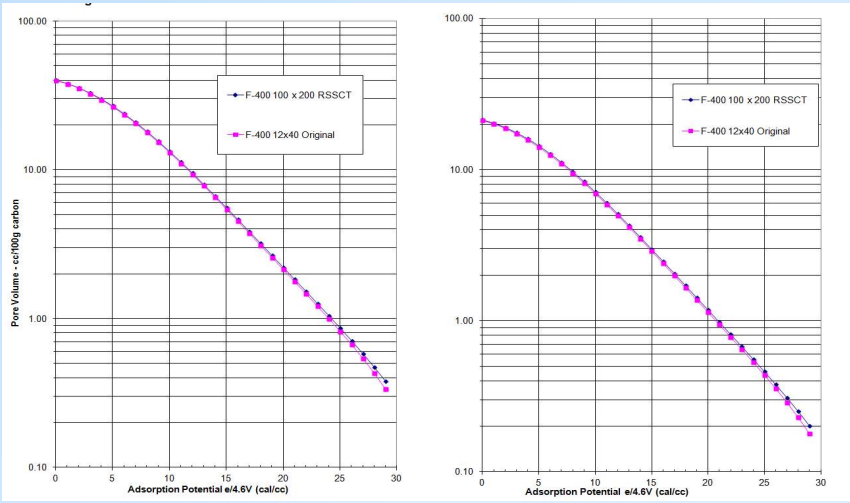
Carbon Prep for Column Testing Considers Scale-up Hydraulic Conditions and Pore Structure





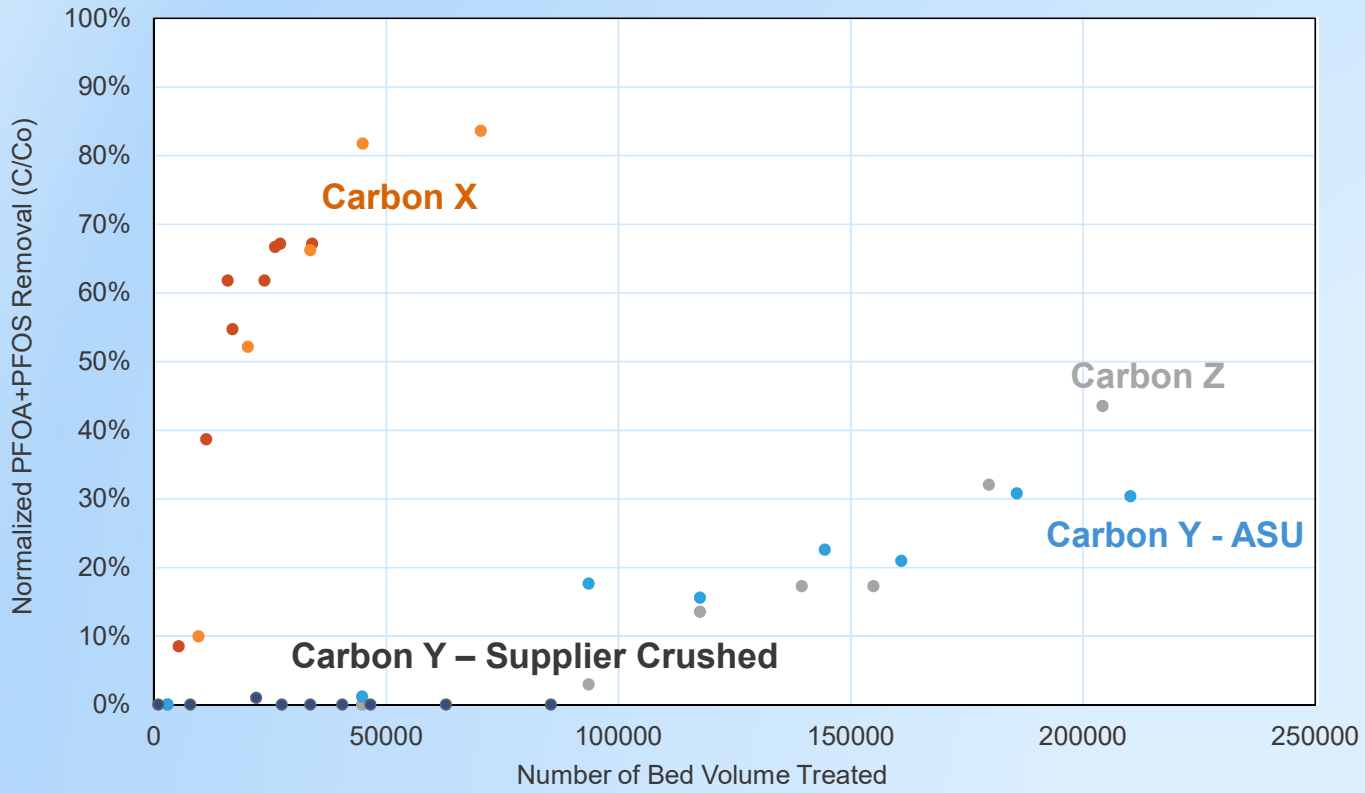
Testing column

Original Carbon **Crushed Carbon**

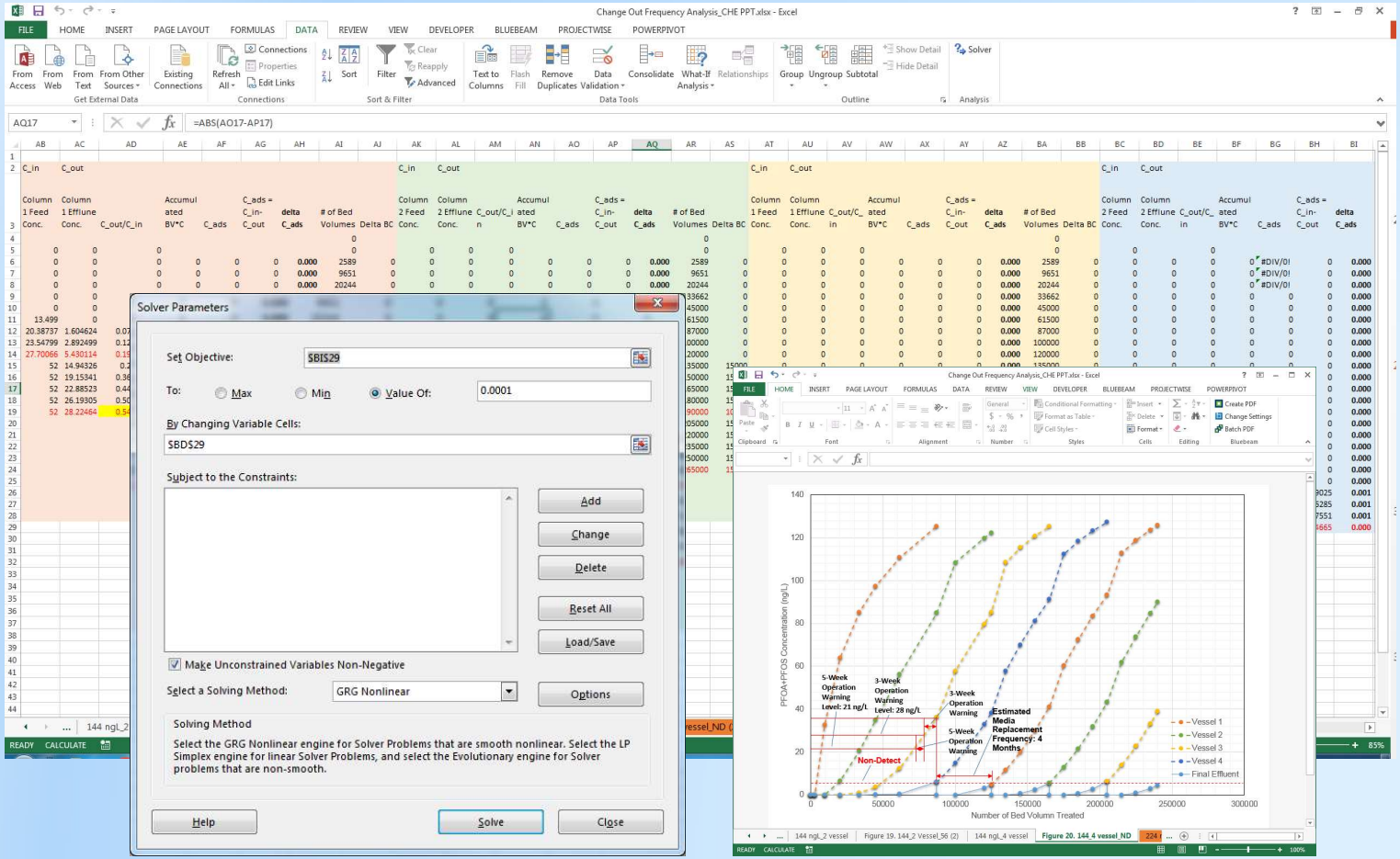


TACTIC Analysis = Total Adsorption Capacity with Temperature Influence Correction

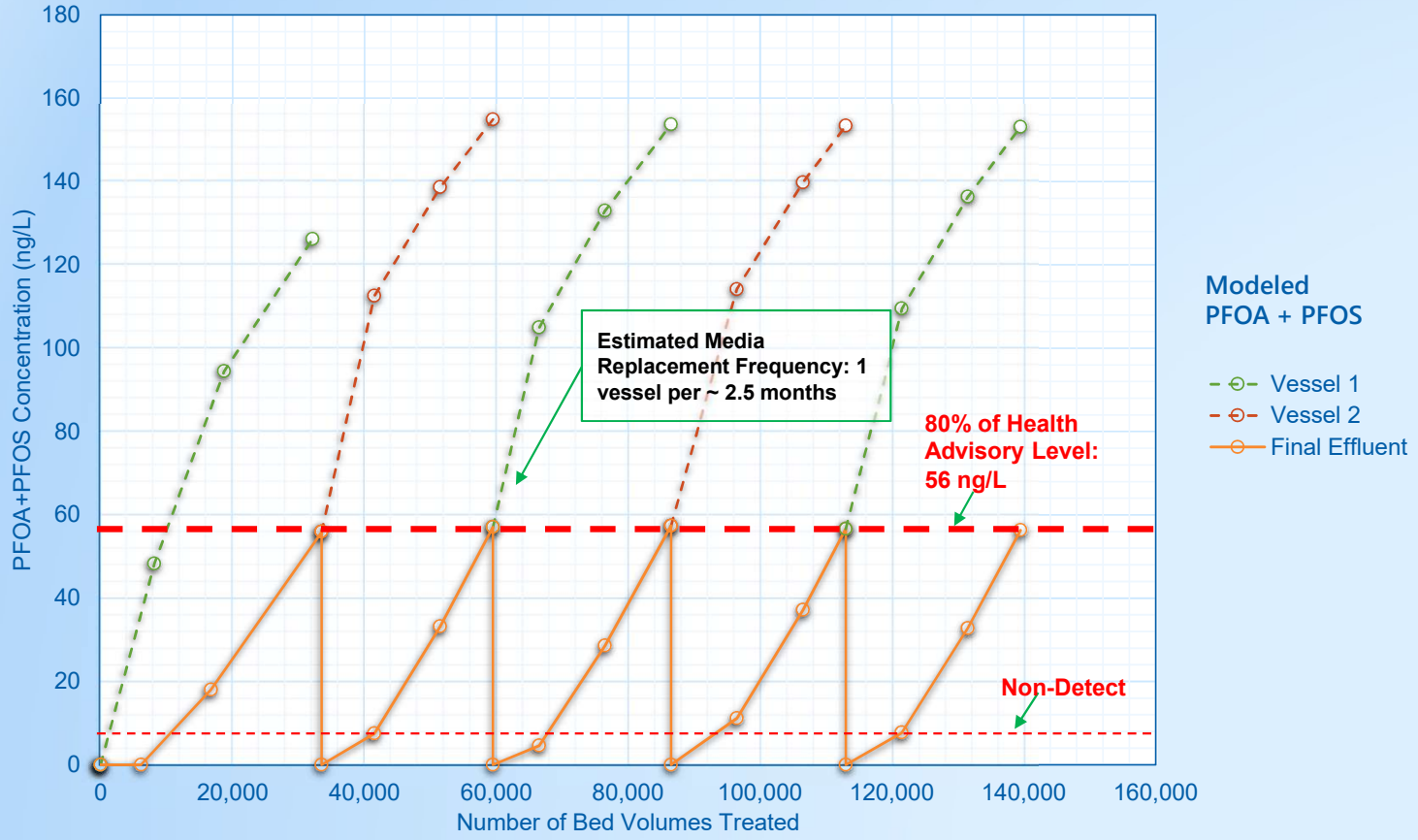
Column Testing: "Similar" Carbons Perform Very Differently!



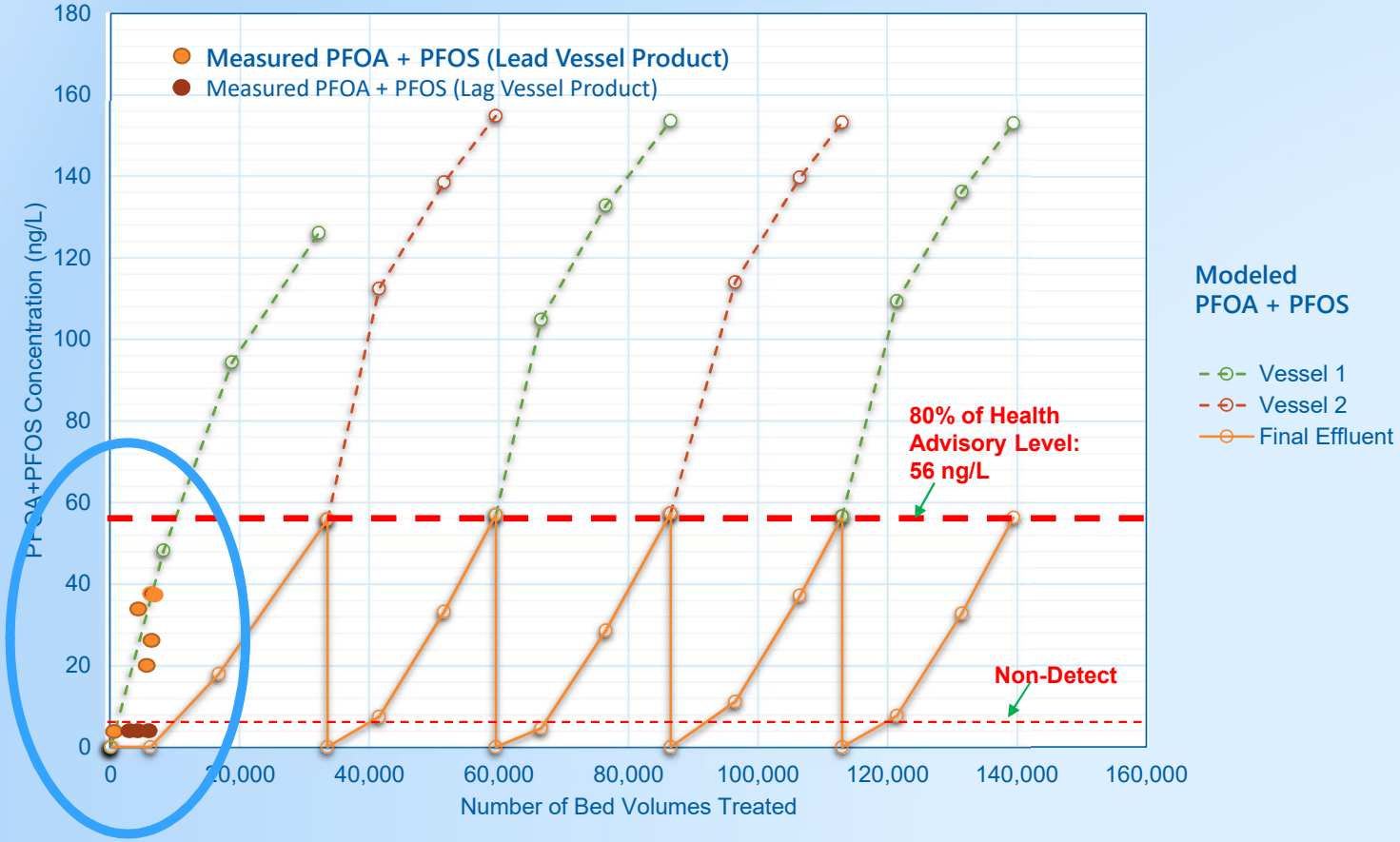
Column Test Data Fed into Performance Projection Model



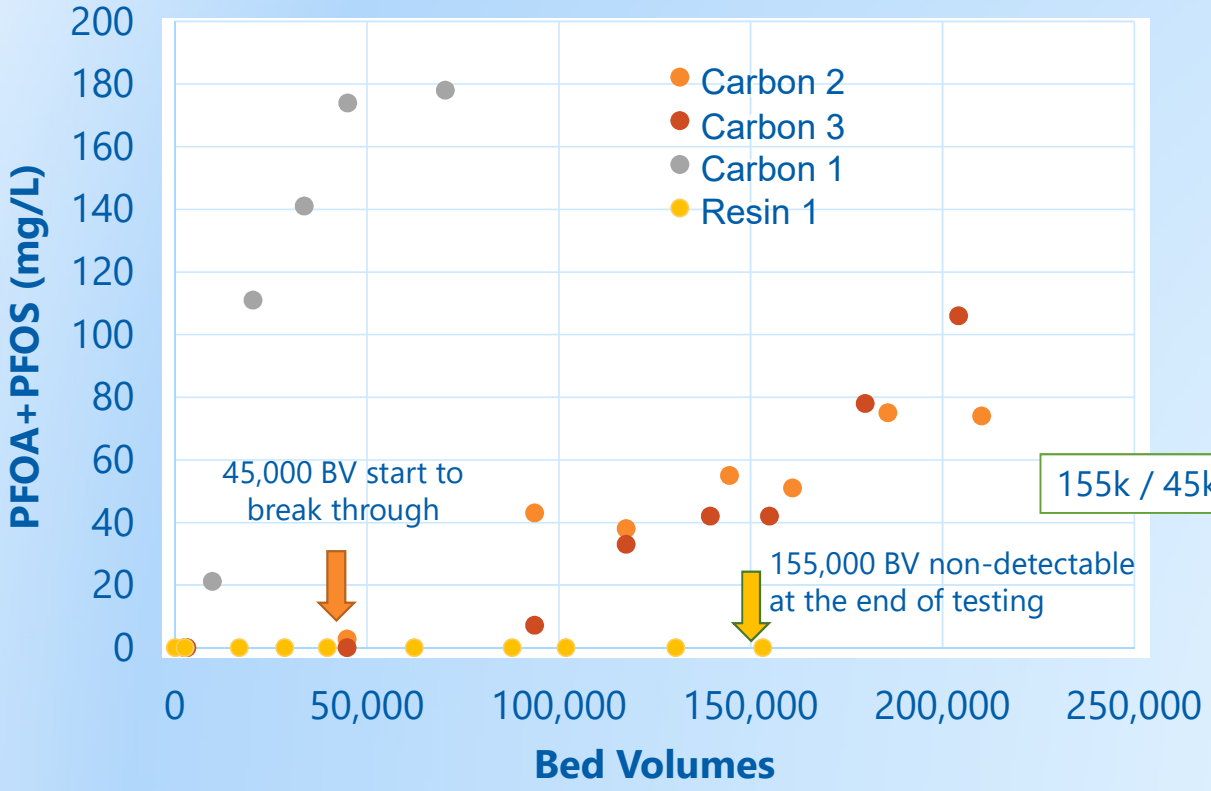
Performance Projection Model Predicts Change Out Frequency and Supports Cost Comparison, Design, and Future Operation



Full-scale Operating Data on Interim Treatment Units (to date) Match Model Predictions



Second Phase Testing for Long-term Treatment: Purolite IX Resin > 3.4 x More Effective than GAC



155k / 45k = 3.4+ times longer

Purolite®

PFA694E

Purolite IX Also Cost 3.4 x More than GAC…

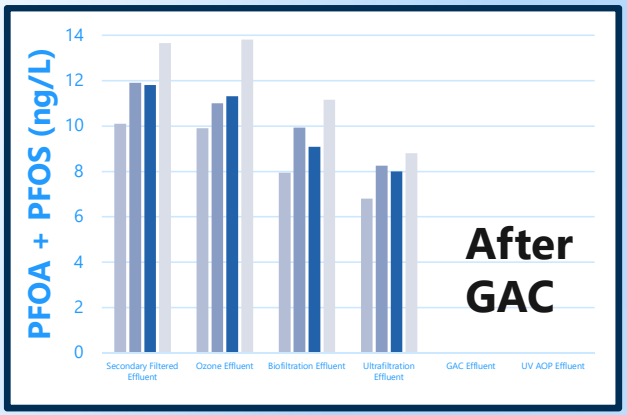
	GAC	Ion Exchange
Retrofit Capital Costs	No cost, per vendor's inputs	
Media Replacement Costs ($/replacement)	$33,000	$111,080
Cost Ratio	1 : 3.4	
Number of Bed Volume for Vessel 1 Breakthrough	45,000	155,000
Breakthrough BV Ratio	1 : 3.4	

Additional Testing Was Recommended.

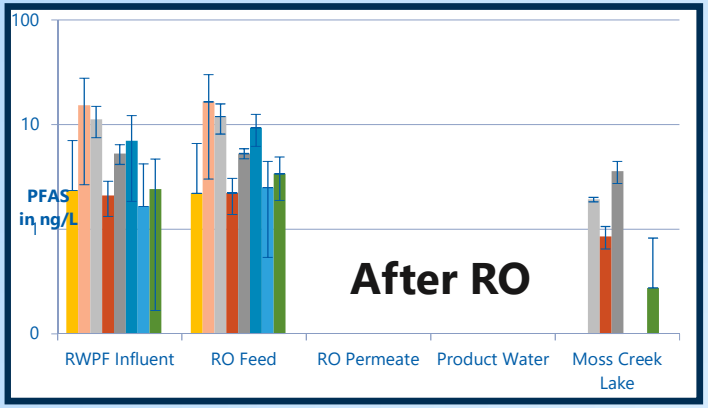
Case Study & Groundwater PFAS Treatment Take-homes:

1. **"Conventional" treatment for PFAS trends toward adsorption**
   - GAC is a great interim option for "emergency response"
   - Media (GAC or IX resin) selection for long-term treatment is *site specific*
2. **Long-term economics can be evaluated through testing**
   - Rapid small-scale column tests (RSSCTs)
   - Modeling to estimate O&M costs
   - Confirmation through pilot testing (single well location, e.g.)
3. **RO is typically not implemented** for two reasons:
   - Capital cost
   - Concentrate disposal

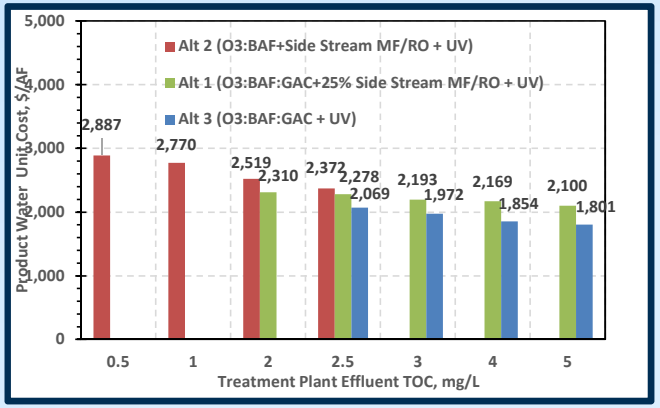
PFAS Are Not Just a Groundwater Contamination Issue…



Effluent PFAS Removed Through GAC in pureALTA DPR (FL)



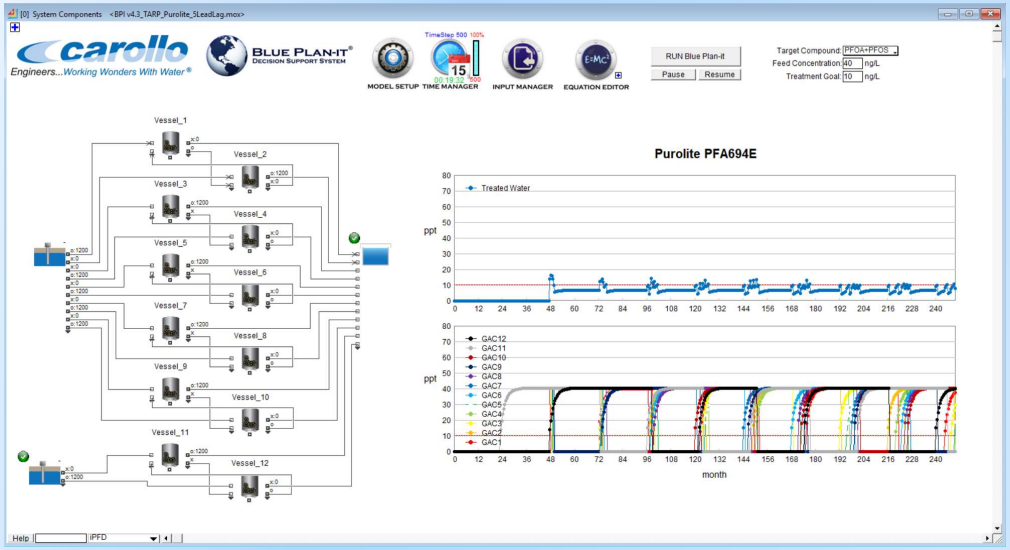
Effluent PFAS Removed by RO in Big Spring DPR Facility (TX)



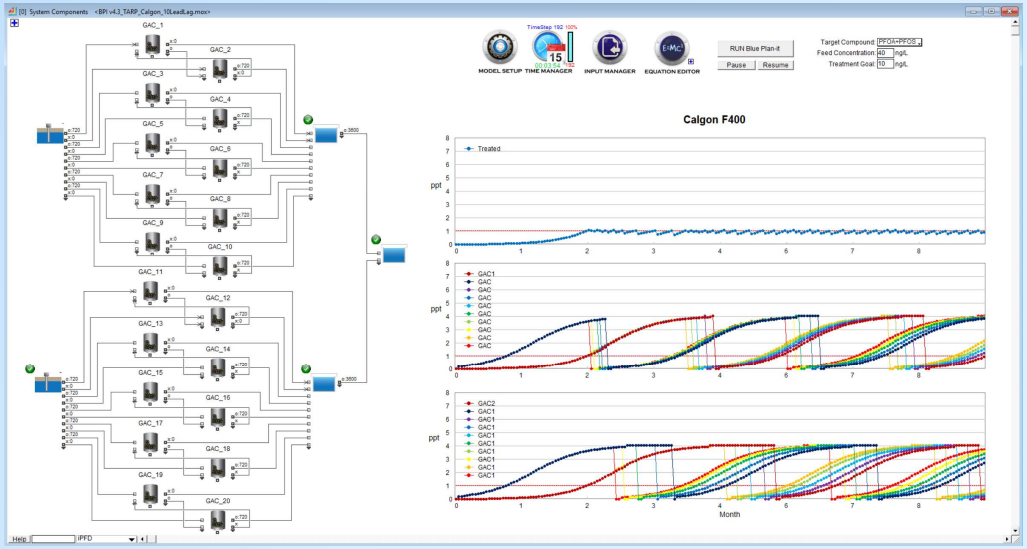
GAC Cost for DC Tillman IPR (CA)

Innovative Approaches

Innovation in “Conventional Treatment:” Dynamic Model Optimizes PFAS Removal by GAC and IX



Typical IX Breakthrough Curve

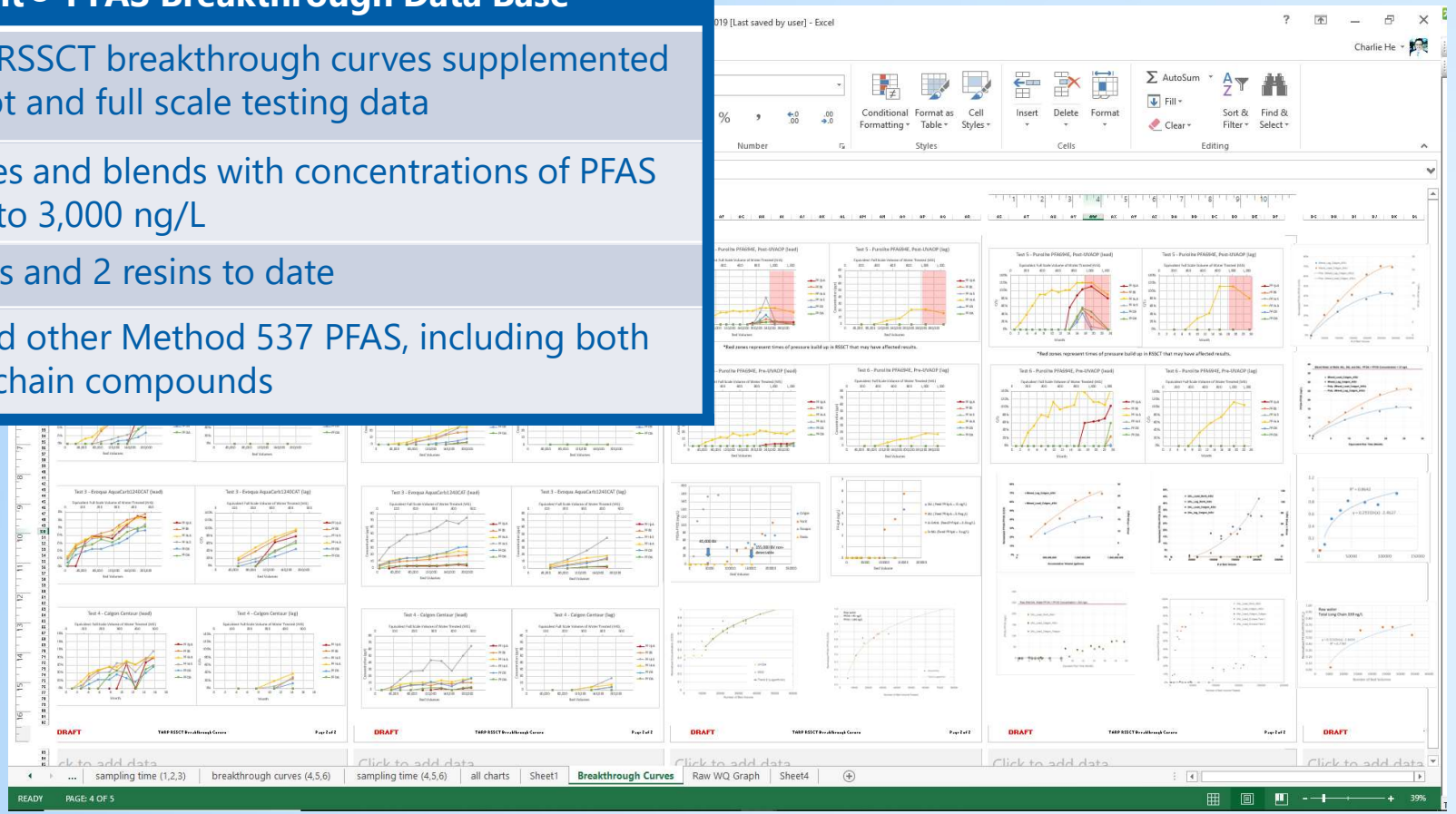


Typical GAC Breakthrough Curve

Growing PFAS Breakthrough Dataset Improves Model Accuracy

Blue Plan-it® PFAS Breakthrough Data Base

- Over 40 sets of RSSCT breakthrough curves supplemented by available pilot and full scale testing data
- 15 water samples and blends with concentrations of PFAS ranging from 0 to 3,000 ng/L
- Tested 6 carbons and 2 resins to date
- PFOA, PFOS, and other Method 537 PFAS, including both long and short chain compounds



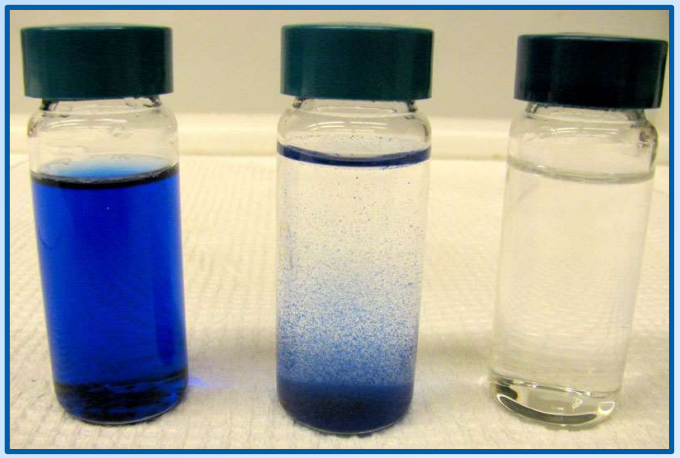
Coming Soon to Carollo:
Collaboration with ASU Using Mobile NEWT Trailer

- Demonstration scale testing
- Continuous testing for IX, GAC, RO, and UV AOP*
- Fill in industry gap on
  - PFAS RSSCT Testing Accuracy
  - PFAS RSSCT using IX Resins

**UV AOP is for simultaneous treatment of other contaminants*

Novel Adsorbents

DEXSORB™ by Cyclopure



OSORB® by ABS Materials

- Effective for short (C3) and long (C8) chain PFAS
- Selective adsorbents (minimal competition with NOM)
- Can be regenerated

Commercially available in 2020

Thank you!

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