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Technical Excellence Practical Experience Client Responsiveness

Drinking Water Treatment System Design for PFAS Removal with FLUORO-SORB Adsorbent

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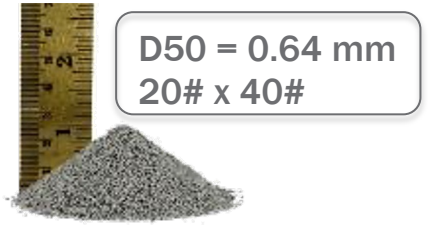
AGENDA

- Introduction to Surface-Modified Clay (FLUORO-SORB ® Adsorbent)
  - How Does It Work?
  - Deployment in Filtration Vessels
  - PFAS Adsorption Mechanism
- Published Studies of PFAS Adsorption Performance
  - Pilot column and RSSCT Results
- Operational Considerations
- System Cost Comparison

FLUORO-SORB® ADSORBENT FOR PFAS TREATMENT

FLUORO-SORB® 100



FLUORO-SORB® 200

FLUORO-SORB® 400

- Proprietary surface-modified clay media for the removal of PFAS from water or wastewater by partitioning.
- Commercially available since May 2019
  - Manufactured in ISO9001:2015 certified production plant in the United States
  - Certified for drinking water use by NSF/ANSI 61

NSF
Certified to NSF/ANSI 61

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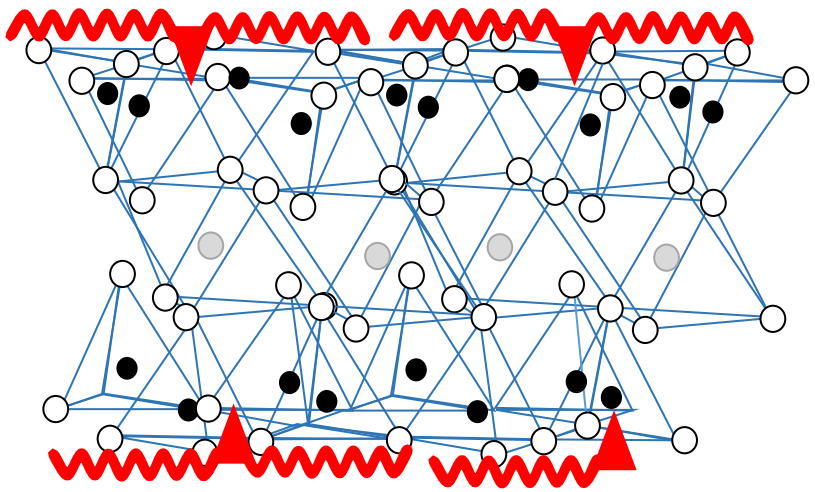
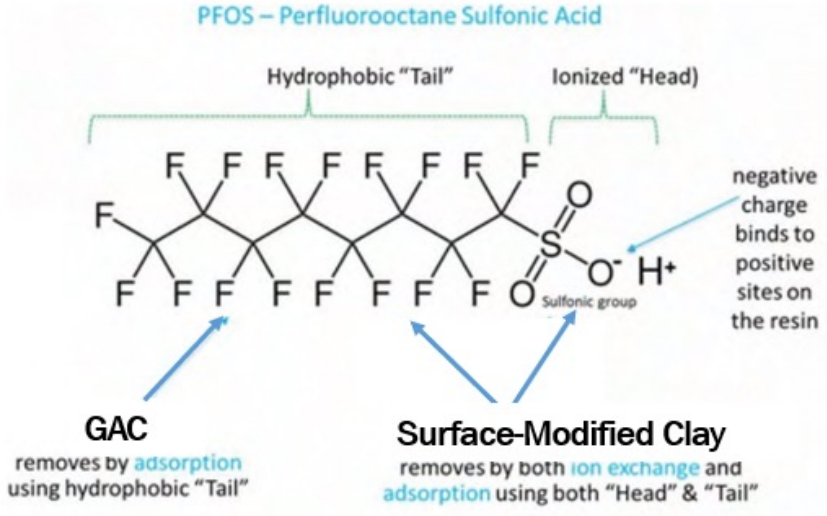
FLUORO-SORB® ADSORBENT FOR PFAS TREATMENT

- Surface-modified clay adsorbents are created by bonding a modification agent to the surfaces of sodium bentonite clay platelets.

Surface-Modified Clay (SMC)



- The modification agent has a high affinity for a variety of PFAS:
  - Hydrophobic interactions with the PFAS fluorinated chain
  - Electrostatic interactions with the PFAS anionic head group



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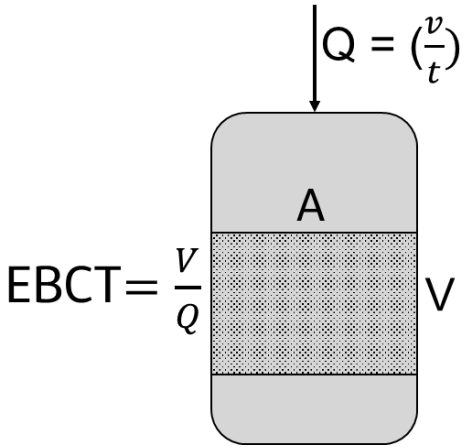
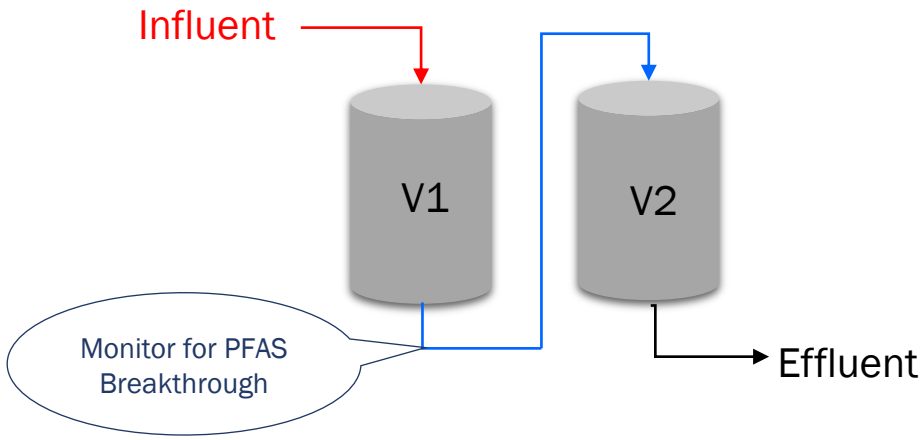
FILTRATION VESSEL DEPLOYMENT OF FLUORO-SORB® ADSORBENT

- Down-flow operation with Empty Bed Contact Time (EBCT) 2-3 mins
  - ➢ EBCT is amount of time that the influent is in contact with the media bed
- Typical system configuration is lead-lag vessels in series
- Lead-lag system is operated until PFAS breakthrough at 60-100% of the influent in the lead vessel
- Media change out occurs - new media placed in the lead vessel and changing the lag vessel to the lead.
- Existing GAC and IX resin vessels can be used for FLUORO-SORB® Adsorbent



Lead-Lag System Configuration



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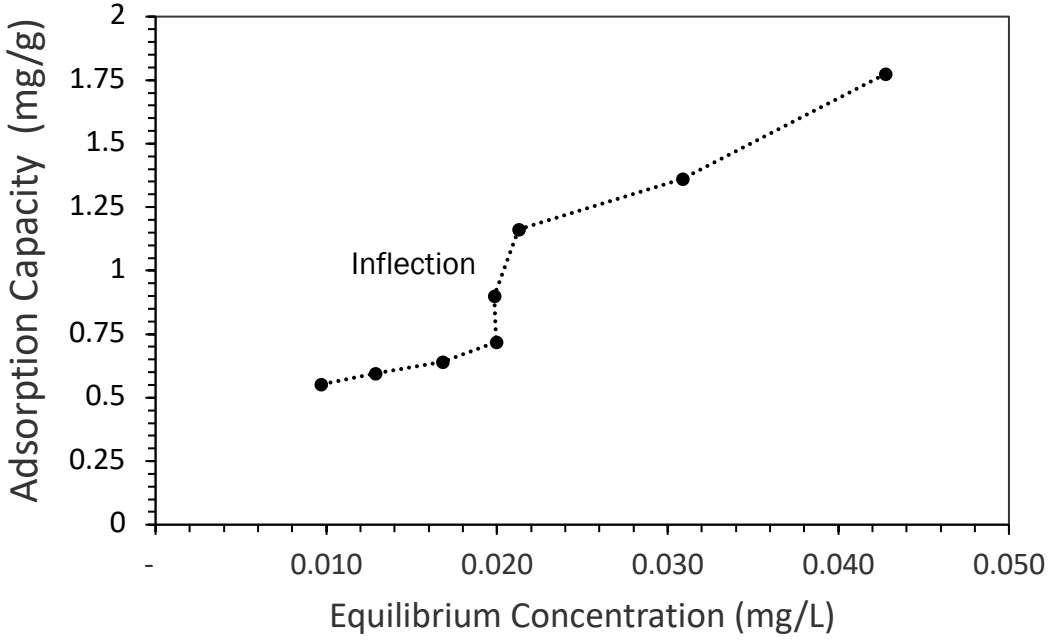
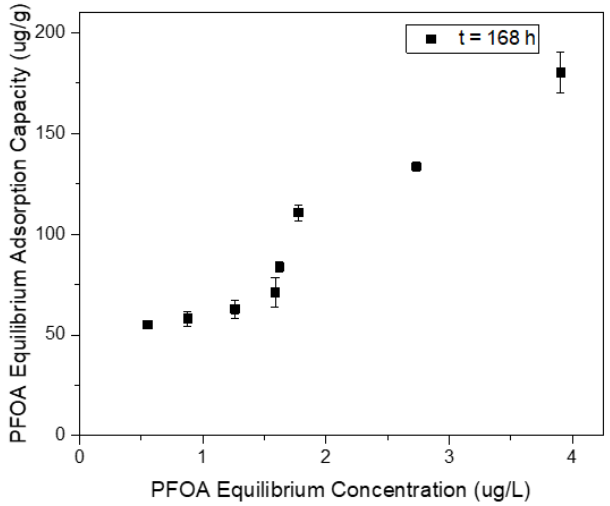
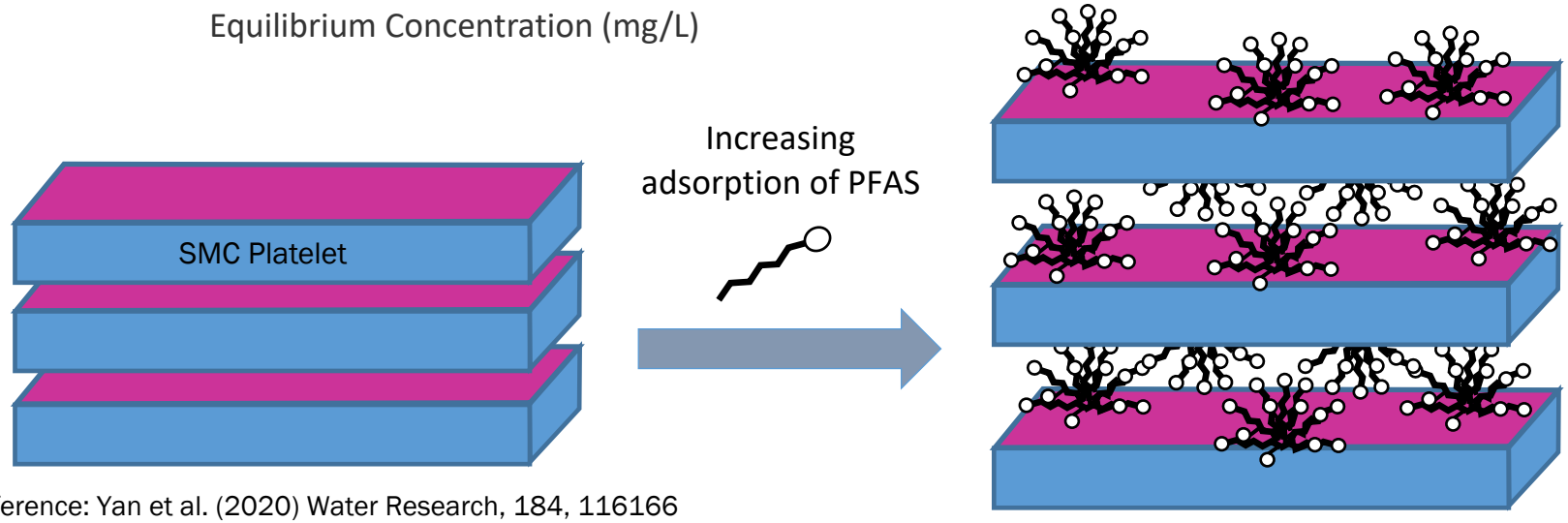
SURFACE-MODIFIED CLAY ADSORPTION CAPACITY







Reference: Yan et al. (2020) Water Research, 184, 116166

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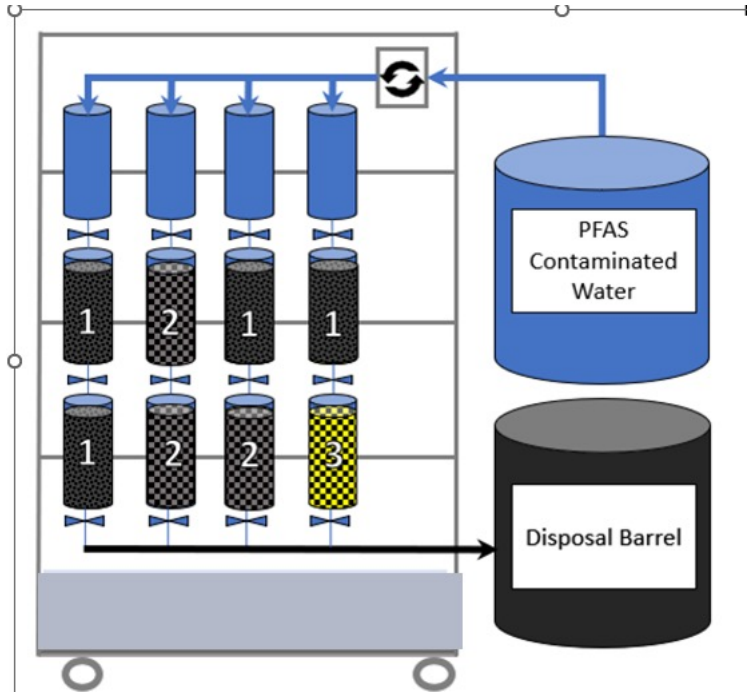
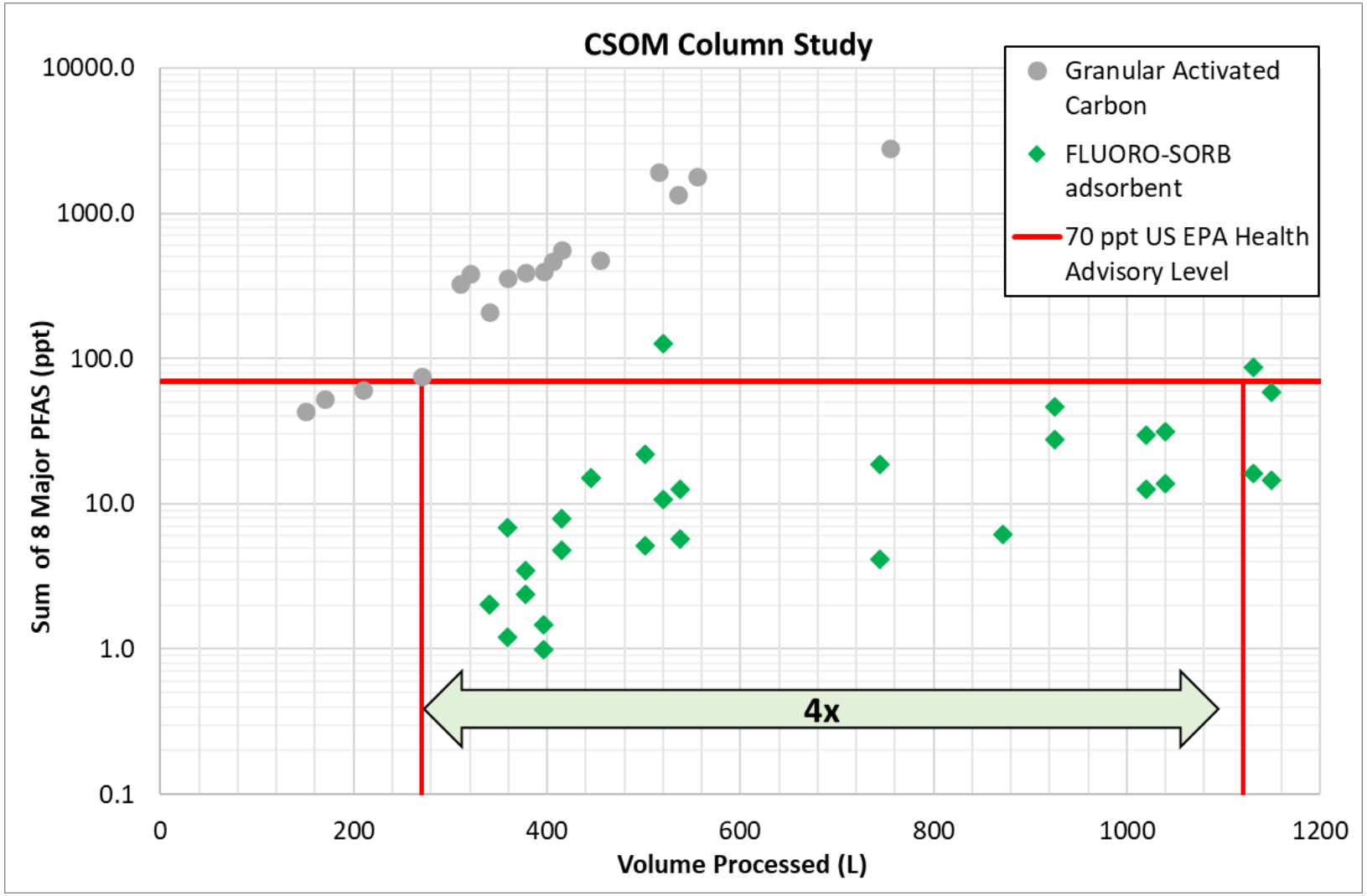
COLUMN TESTING – MEDIA COMPARISON
COLORADO SCHOOL OF MINES

- PFAS contaminated groundwater from a former military installation in the United States
- FLUORO-SORB® adsorbent compared to Granular Activated Carbon (GAC) in lead lag column system
- Fluoro-sorb treated 4x more water than GAC



Reference: Marshall, Robert Eric (2019) "Performance and Cost-Effectiveness of Commercially Available Adsorptive Technologies for Treatment of Per– and Polyfluoroalkyl (PFAS) Impacted Groundwater", Master's Thesis, Colorado School of Mines, Golden, CO, July 2020.

MEDIA COMPARISON – PFAS CONTAMINATED GROUNDWATER



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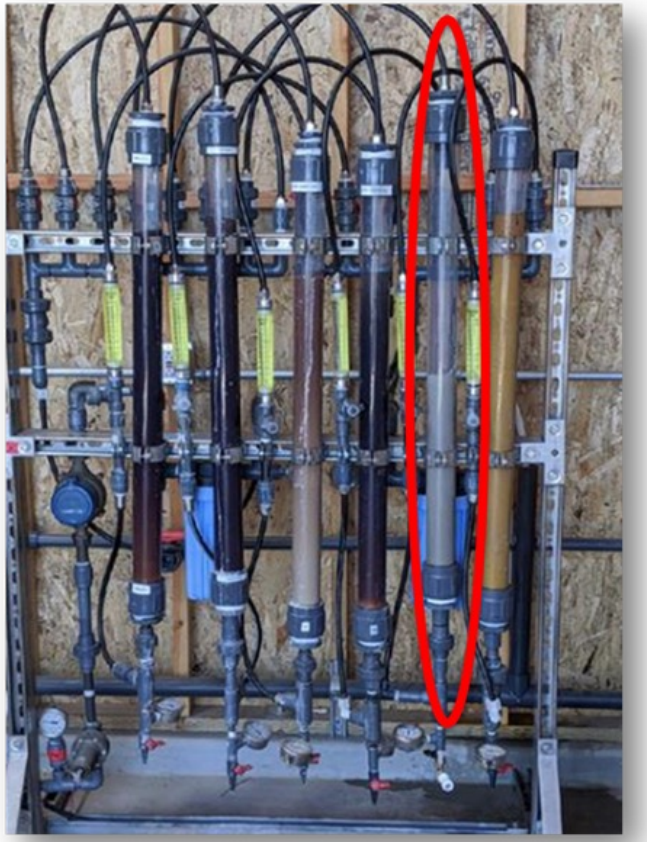
ORANGE COUNTY WATER DISTRICT (OCWD) PFAS TESTING PROGRAM

- **Objective: Identify adsorbents that can remove PFAS from groundwater that is used as drinking water**
- **Performed Rapid Small Scale Column Tests (RSSCTs) in the laboratory with well water from across Orange County, CA**
- **Pilot column testing was performed using water from a well in Anaheim, CA (Bessie Well)**
- **FLUORO-SORB® 200 adsorbent showed the longest bed life of 13 other adsorbents, prior to breakthrough at the PFOA CA Response Level of 10 ng/L**



Reference:
- Pannu, M. and Plumlee M. (2021). Orange County Water District PFAS Phase I Pilot-Scale Treatment Study, Final Report
- Medina, R., Pannu M.W., Grieco, S.A., Hwang, M., Pham, C., and Plumlee, M.H. (2022) Pilot-scale comparison of granular activated carbon, ion exchange, and alternative adsorbents for PFAS removal. AWWA Water Science, e1308.

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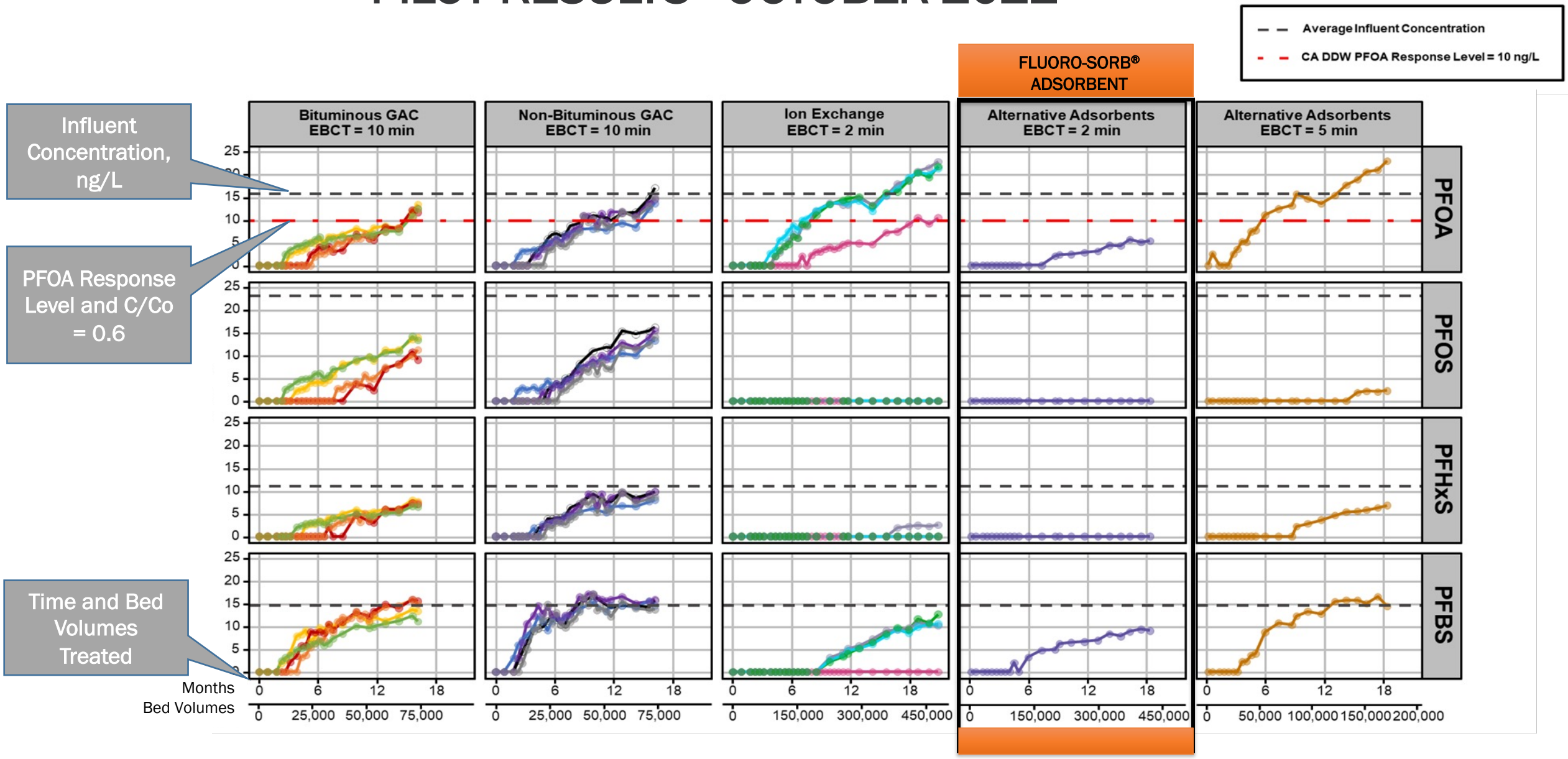
PILOT RESULTS - OCTOBER 2021



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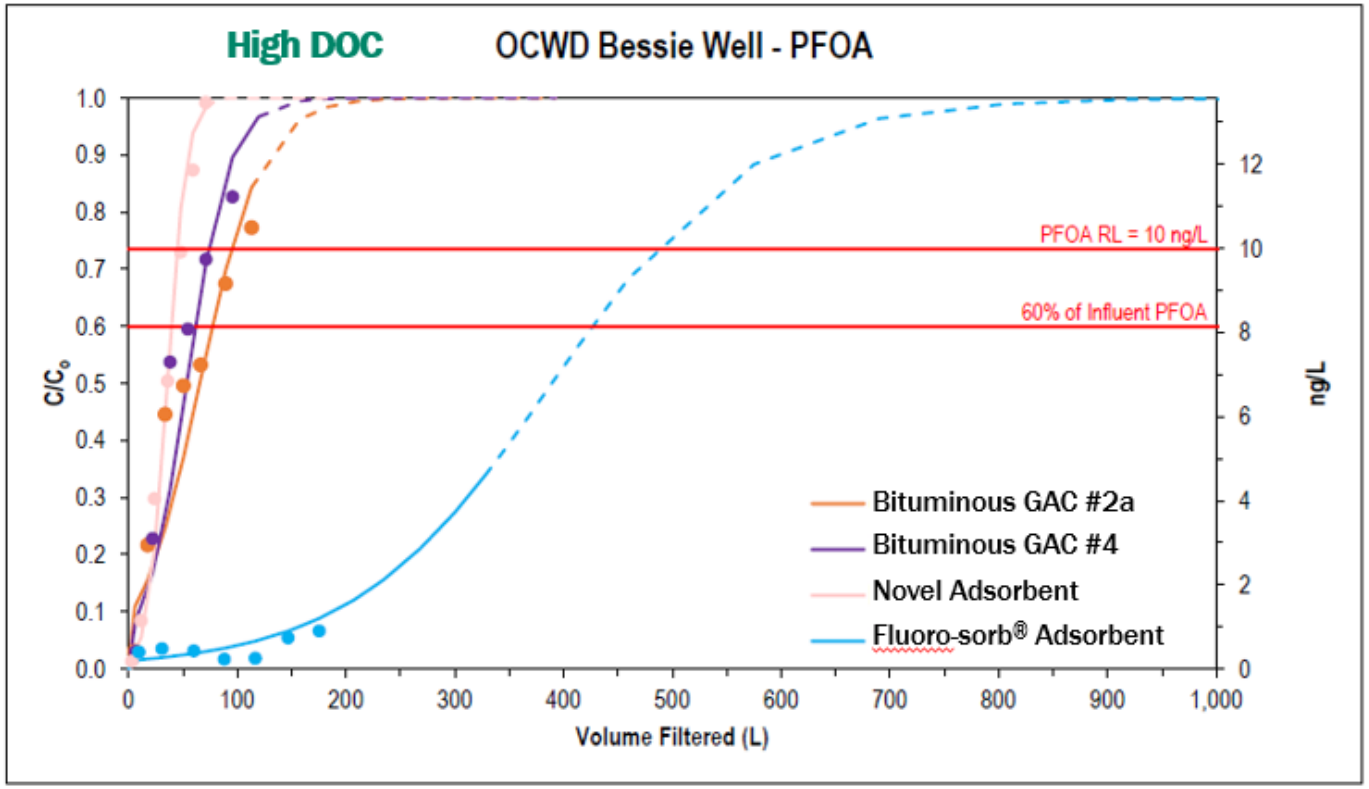
IMPACT OF ORGANIC MATTER

0.7 cm diameter
1-3 cm bed depth

- Rapid Small Scale Column Tests (RSSCTs) are small columns with ground media that are used to assess performance in a short time frame
- RSSCTs were performed for source water that had a range of dissolved organic carbon (DOC) levels (0.2 – 2 mg/L)

- FLUORO-SORB® Adsorbent performance was not significantly affected by the DOC concentration; GAC performance varied widely (+/-500%)
- FLUORO-SORB® adsorbent treated 7x the volume of water as GAC in the high DOC water



Grieco, S. A., Chang, J., Maio, Elizabeth (Lily) Y., and Hwang, M. (2021). Comparing conventional and emerging adsorbents for per- and polyfluoroalkyl substances: Kinetic

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Operational Considerations

Parameter	Range of Values
PFAS Adsorption Capacity	High for long chain PFAS, moderate for short chain PFAS
Empty Bed Contact Time (EBCT)	2 to 3 minutes
Hydraulic Loading Rate	2 to 11 gpm/ft^2 field tested, 11 to 16 gpm/ft^2 laboratory tested
Total Organic Carbon (TOC)	Low to no media life impact up to 25 mg/L
Total Dissolved Solids (TDS)/Anions	Low to no media life impact up to 5000 mg/L
Free chlorine	Tolerant at a continuous 1 mg/L
Volatile Organic Carbons (VOCs) Petroleum hydrocarbons	No treatment unless very low water solubility, e.g. napthalene
Pre-treatment	Bag filter or equivalent for suspended solids
Pressure drop	Greater than granular activated carbon, similar to anion exchange resin (AIX)
Backwashing	Start up backwashing for media fines removal, operational backwash as needed
Treatability Testing	Rapid Small Scale Column Tests (RSSCTs) or pilot column test
Media Unit Price	Low to moderate

System Cost Comparison - 250 gpm with Media Disposal Capital Costs

	IX (Buffered Product)	FLUORO-SORB (200)	GAC (F400-01)
ESTIMATED CAPITAL COSTS (CAPEX)			
Flow (gpm)		**250**	
Vessel Diameter (in)	72	72	120
Qty of Vessels	1	1	1
EBCT (min, per vessel)	3.0	3.0	10.0
Active Media Volume (total cuft/vessel)	100	100	335
Total Active Media Volume (cuft)	100	100	335
Total Capital Cost (Equipment, Media, Start-Up)	**$170,000**	**$150,000**	**$360,000**
Estimated Footprint of System (sqft)	36	36	100
Estimated Footprint of Building (sqft - Assumes 3' clearance in each direction)	144	144	256
Estimated $/sqft of building	$400	$400	$400
Estimated Building Cost *(if needed)	$57,600	$57,600	$102,400
Engineering Costs	$30,000	$30,000	$30,000
Estimated CAPEX (System + Building + Eng)	**$227,600**	**$207,600**	**$462,400**

System Cost Comparison – 250 gpm with Media Disposal Operational Costs

	IX (Buffered Product)	FLUORO-SORB (200)	GAC (F400-01)
ESTIMATED OPERATING COSTS (OPEX)			
Media Capacity Projection (Bed Volumes)	305,000	274,000	85,000
Media Capacity Projection (Gallons)	228,140,000	204,952,000	212,993,000
Utilization (%)	100%	100%	100%
Utilization (Gallons per Day)	360,000	360,000	360,000
Media Capacity Projections (Years)	1.7	1.6	1.6
Media Replaced at Change Out (cuft))	100	100	335
Media Cost ($/cuft)	$395	$220	$118
Media Cost Only ($/event)	$39,500	$22,000	$39,530
Turnkey Media Services - Removal, Disposal, Replacement, Re-Commissioning ($/event)	$27,992	$27,992	$54,165
Total Event ($)	$67,492	$49,992	$93,695
Annualized OPEX Based on Gallons Capacity and Utilization ($/year)	**$38,873**	**$32,051**	**$57,802**
Op Cost per Thousand Gal	**$0.79**	**$0.59**	**$1.10**
10 YR LIFE CYCLE COST (CAPEX and OPEX)	**$616,327**	**$528,110**	**$1,040,424**

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CONCLUSIONS

FLUORO-SORB® ADSORBENT IS AN EFFECTIVE AND ECONOMICAL WAY TO TREAT PFAS

- High adsorption capacity for a variety of PFAS
- Fast adsorption kinetics
- Short EBCT, small footprint
- Resistant to competitive adsorption by organic matter and anions
- Low life cycle cost compared to IX and GAC

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