



CETCO®

ADSORBENT MEDIA COMPARISON FOR THE REMOVAL OF PFAS FROM WATER AND WASTEWATER TREATMENT SYSTEMS

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CETCO - Mineral Technologies Inc.

Missouri Waste Coalition Conference 2023





CETCO is a wholly owned subsidiary of MINERALS TECHNOLOGIES INC., a resource- and technology-based company that develops, produces and markets worldwide a broad range of specialty mineral, mineral-based and synthetic mineral products and related systems and services.

| 2022 SALES | PUBLICLY TRADED | COUNTRIES | PRODUCTION LOCATIONS | R&D CENTERS | EMPLOYEES |
|-----------------------|------------------|-----------|----------------------|-------------|------------------|
| \$2.13 BILLION | NYSE: MTX | 35 | 158 | 12 | >4,000 |

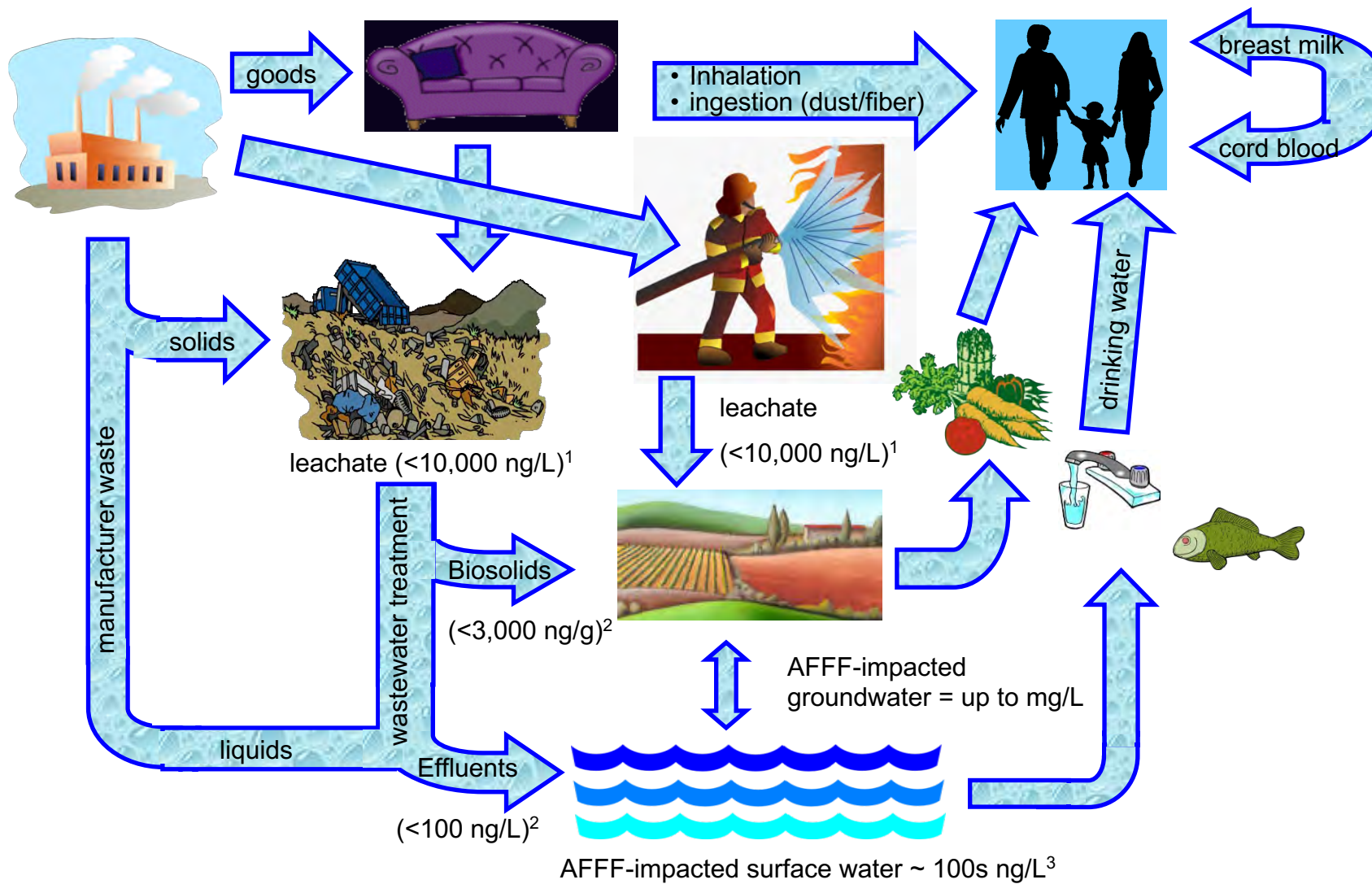
Performance Materials

- Leading global supplier of tailored bentonite-based solutions serving a broad range of customers in consumer and industrial markets.
- Examples: metalcasting, household & personal care, basic minerals, environmental products (CETCO), building materials (CETCO), and off-shore water filtration (CETCO).

AGENDA

- **PFAS Background Information**
- **Design considerations for PFAS treatment systems**
- **Introduction to Surface-Modified Clay (FLUORO-SORB® Adsorbent)**
- **Initial University Research Showing PFAS Adsorption Performance**
- **Pilot column and RSSCT Results**
- **Site Estimate and Startup Information**

PFAS EXPOSURE PATH



Adapted from Oliaei 2013, Environ Pollut Res

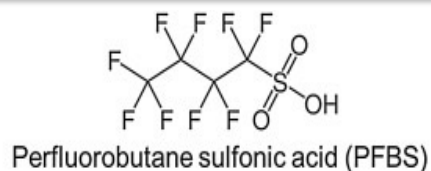
¹Allred et al., 2014. J Chrom; ² Schultz et al., 2006. Environ Sci Technol; Higgins, 2005. Environ Sci Technol; ³Ahrens et al., 2015. Chemosphere

PFAS - Perfluoroalkyl & Polyfluoroalkyl Substances

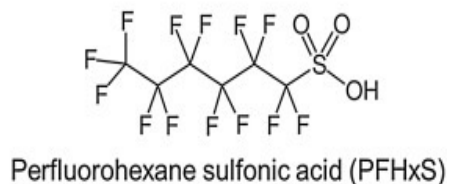
- Thousands of PFAS were synthesized and manufactured for variety of uses
- Evolving recognition of which specific PFAS are contaminants of concern

Perfluorosulfonic acids

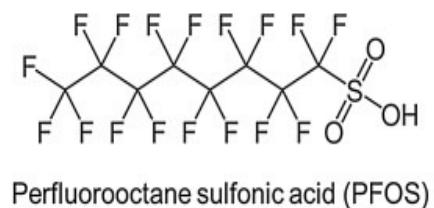
C4



C6

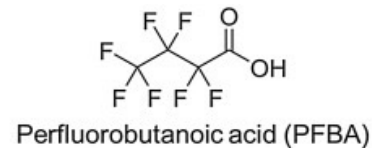


C8

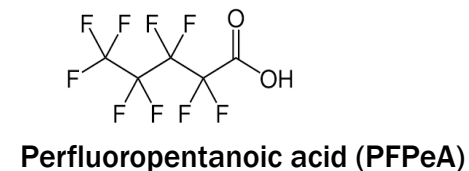


Perfluorocarboxylic acids

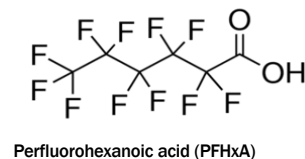
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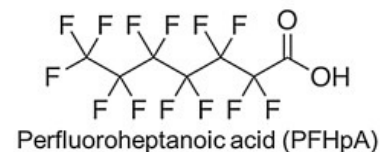
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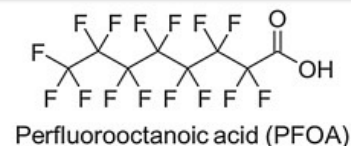
C6



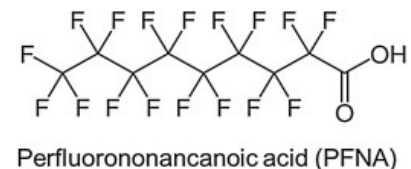
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C8

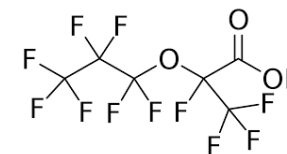


C9



Gen X

C6



EPA PROPOSED NATIONAL PRIMARY DRINKING WATER REGULATION (NPDWR)

| Compound | Proposed MCLG | Proposed MCL (enforceable levels) |
|--|--------------------------------|---|
| PFOA | Zero | 4.0 parts per trillion (also expressed as ng/L) |
| PFOS | Zero | 4.0 ppt |
| PFNA | 1.0 (unitless) Hazard Index | 1.0 (unitless) Hazard Index |
| PFHxS | | |
| PFBS | | |
| HFPO-DA (commonly referred to as GenX Chemicals) | | |

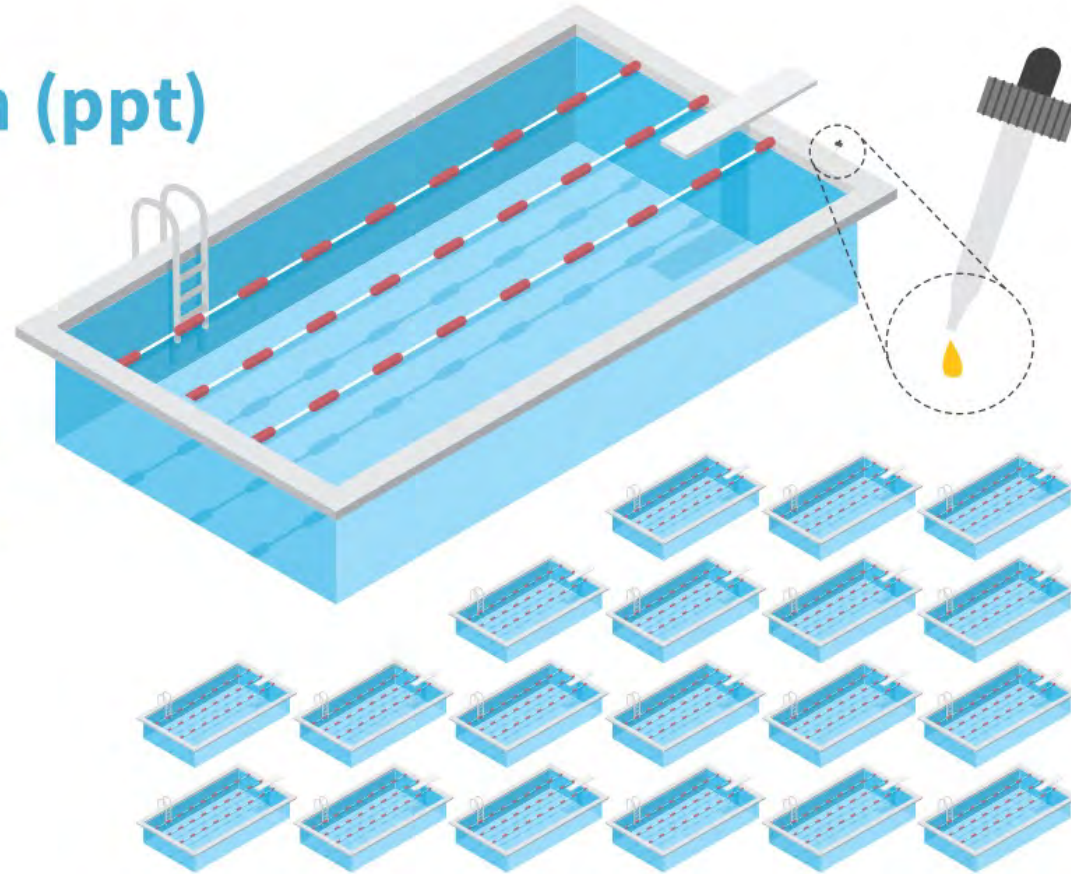
MCGL = non-enforceable, maximum contaminant level goals

MCL = legally enforceable, maximum contaminant levels

1 part per trillion (ppt)

**IS EQUIVALENT TO A
SINGLE DROP OF
WATER IN**

**20 olympic-sized
swimming pools**



Source: <https://www.michigan.gov/documents/pfasresponse>

CURRENT TREATMENT OPTIONS

Granular Activated Carbon (GAC)



FLUORO-SORB® Adsorbent



Ion Exchange Resin (IER/IX)



Chemical/Physical Treatment



Reverse Osmosis



FLUORO-SORB[®] ADSORBENT FOR PFAS TREATMENT

- Proprietary clay-based adsorbent media for the removal of PFAS from water or wastewater
- Commercially available since May 2019
 - Manufactured in ISO9001:2015 certified production plant in Aberdeen, Mississippi
 - Meets NSF/ANSI 61 Certification
- Partnerships with multiple universities for testing and engineering firms field piloting



FLUORO-SORB[®] 100



FLUORO-SORB[®] 200



FLUORO-SORB[®] 300



FLUORO-SORB[®] 400



Certified to
NSF/ANSI 61

VERSATILITY IN DEPLOYMENT



FLUORO-SORB® 100



FLUORO-SORB® 200

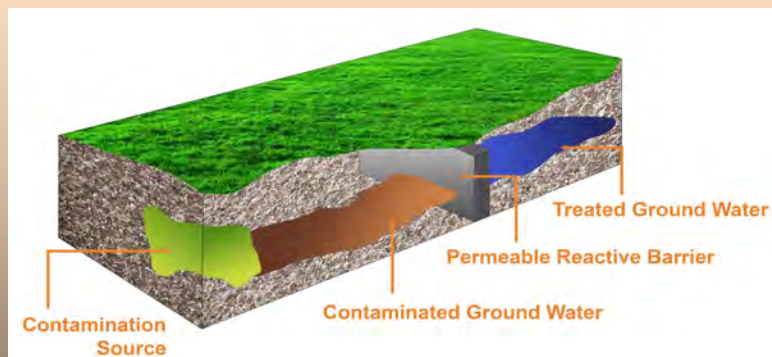


FLUORO-SORB® 400

Soil Stabilization and Solidification



Permeable Reactive Barrier



Water/WasteWater Filtration Dissolved Air Flotation



Sediment Capping - REACTIVE CORE MAT® (RCM)

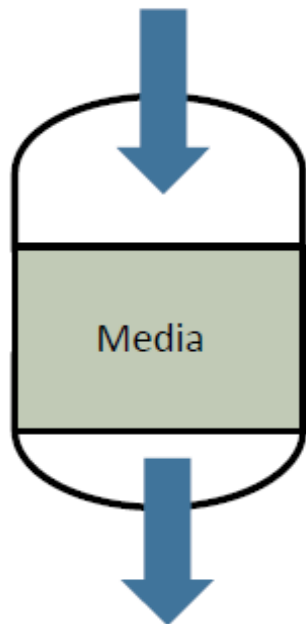




Key Design Considerations

- Type of PFAS compounds present
- Media Selection
- HLR + Empty Bed Contact Time (EBCT)
- Available Space
- Lifecycle Costs
- Residuals Management

PFAS – EMPTY BED CONTACT TIME (EBCT)



Amount of Time that the water with the contaminant is in Contact with the media bed

$$\text{EBCT} = \frac{(\text{Bed volume, ft}^3 \text{ of Media}) \times (7.48 \text{ gallons/ ft}^3)}{\text{Flow Rate (gpm)}}$$

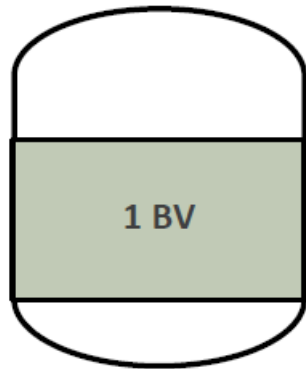
- GAC EBCT = ~10 Minutes per vessel (typical design)
- IX/FS EBCT = ~3 Minutes per vessel (typical design)

PFAS – UNDERSTANDING BED VOLUMES

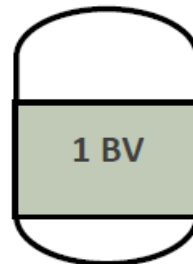
Bed Volume = Volume of a Media Bed

$$1 \text{ BV} = \frac{\text{EBCT} \times \text{Flow Rate (gpm)}}{7.48 \text{ gallons/ ft}^3}$$

| FLOW | EBCT | BV, VOLUME OF MEDIA NEEDED TO ACHIEVE EBCT |
|-----------|--------|--|
| 1,000 gpm | 10 min | 1,337 cubic feet |
| 1,000 gpm | 3 min | 401 cubic feet |



1 BV w/ 10 min EBCT =
More media volume



1 BV w/ 3 min
EBCT = Less media

Thus, 1 BV (quantity) of GAC with 10 min EBCT \neq 1 BV (quantity) of FS with 3 min EBCT

HOW DOES EBCT RELATE TO FOOTPRINT?

**10 Min
EBCT Media**

1,000 gpm



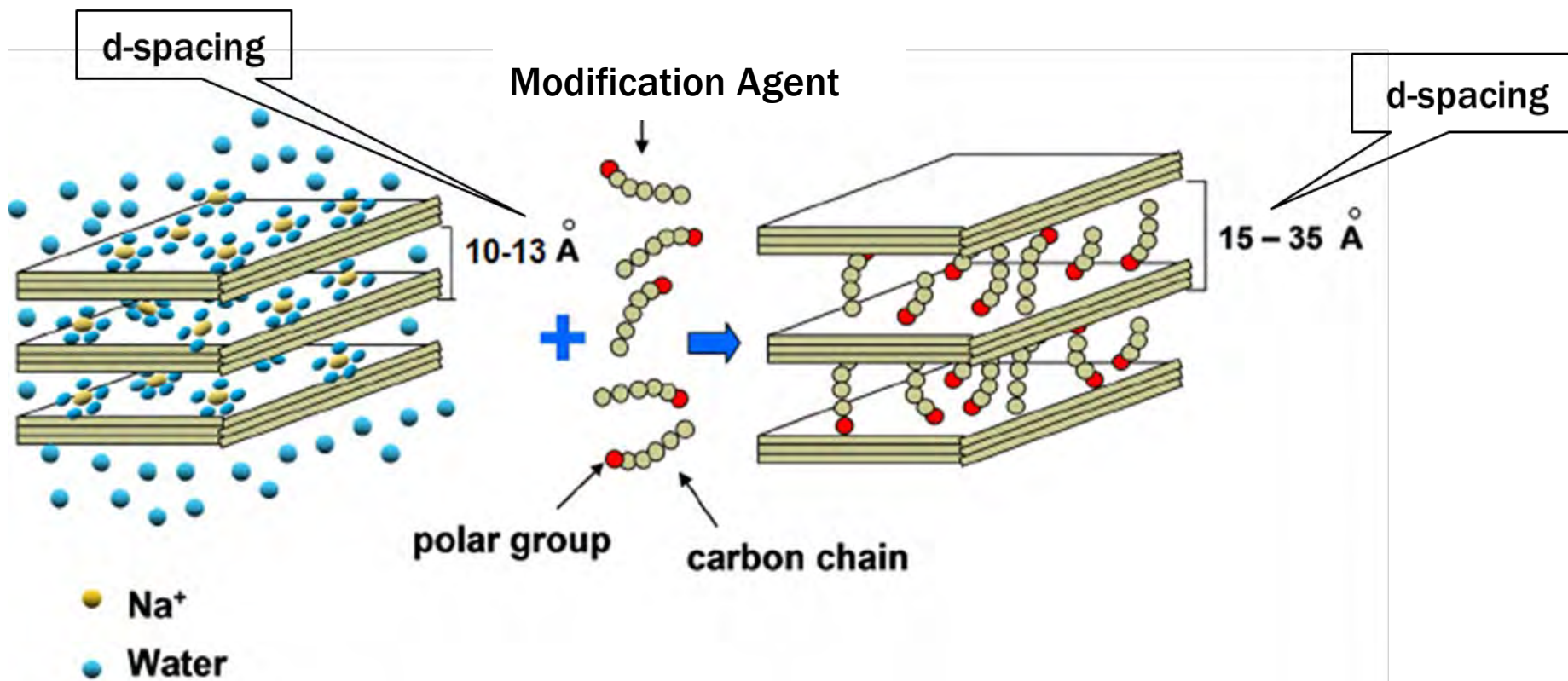
**3 Min
EBCT Media**

1,000 gpm

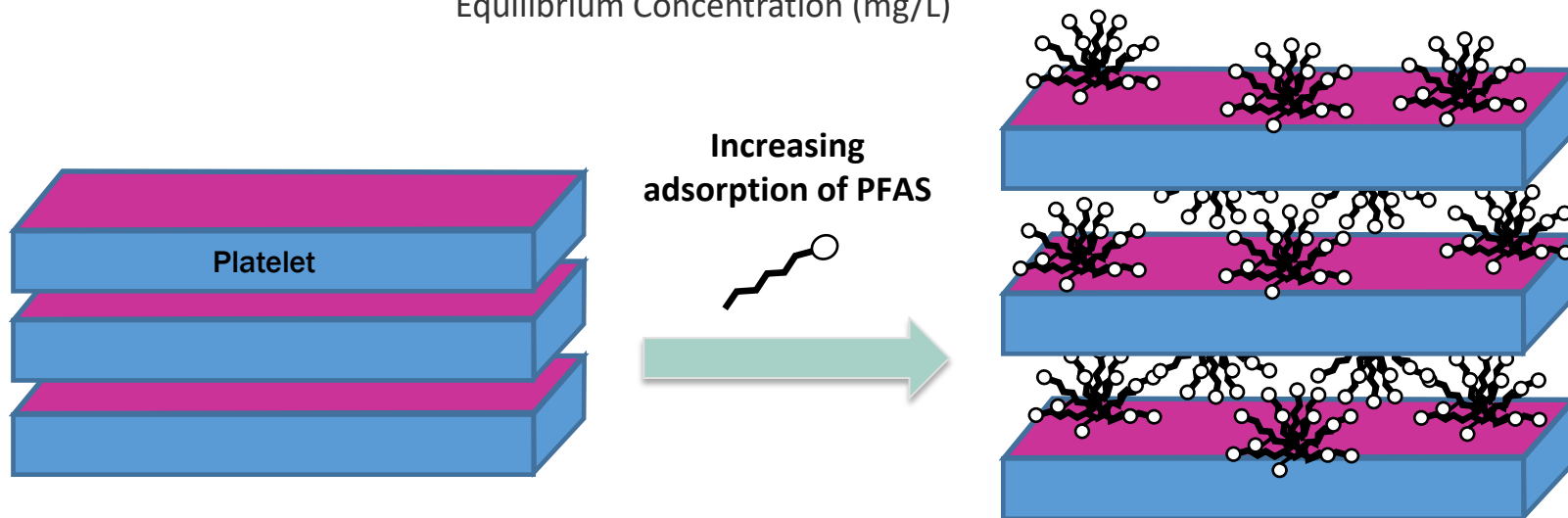
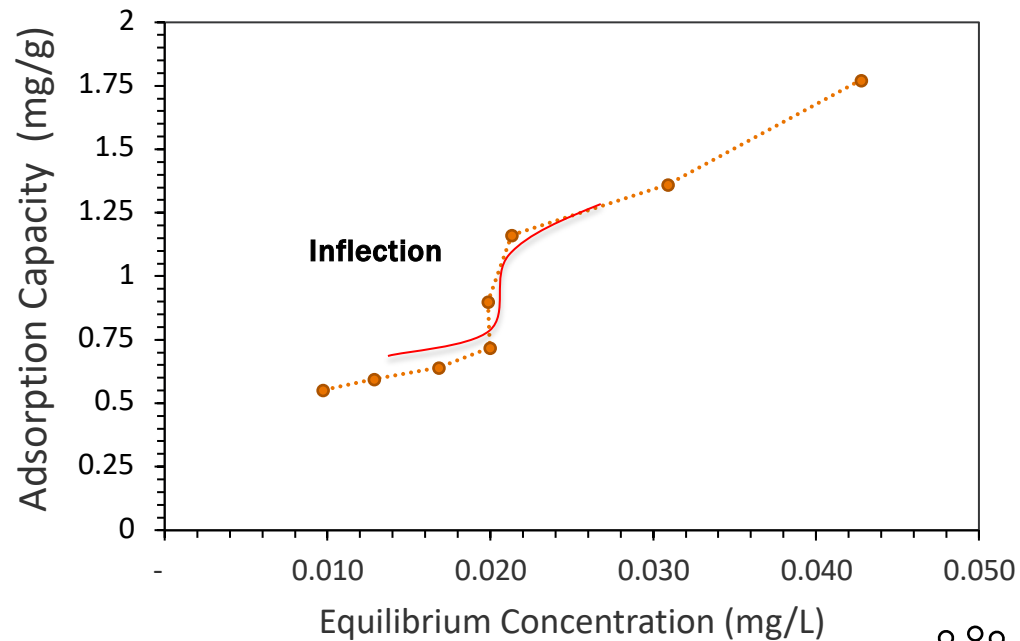


WHAT IS FLUOROSORB?

- Surface-modified clay adsorbents are obtained by converting a sodium bentonite clay to an adsorption media using a modification agent that has high affinity for a variety of PFAS
- The intralayer space or d-spacing increases as the modification agent bonds with the clay.
- PFAS are removed from water or stabilized in soil by adsorption – it is more energetically favorable for PFAS to partition into the adsorbent than remain in the water or soil.



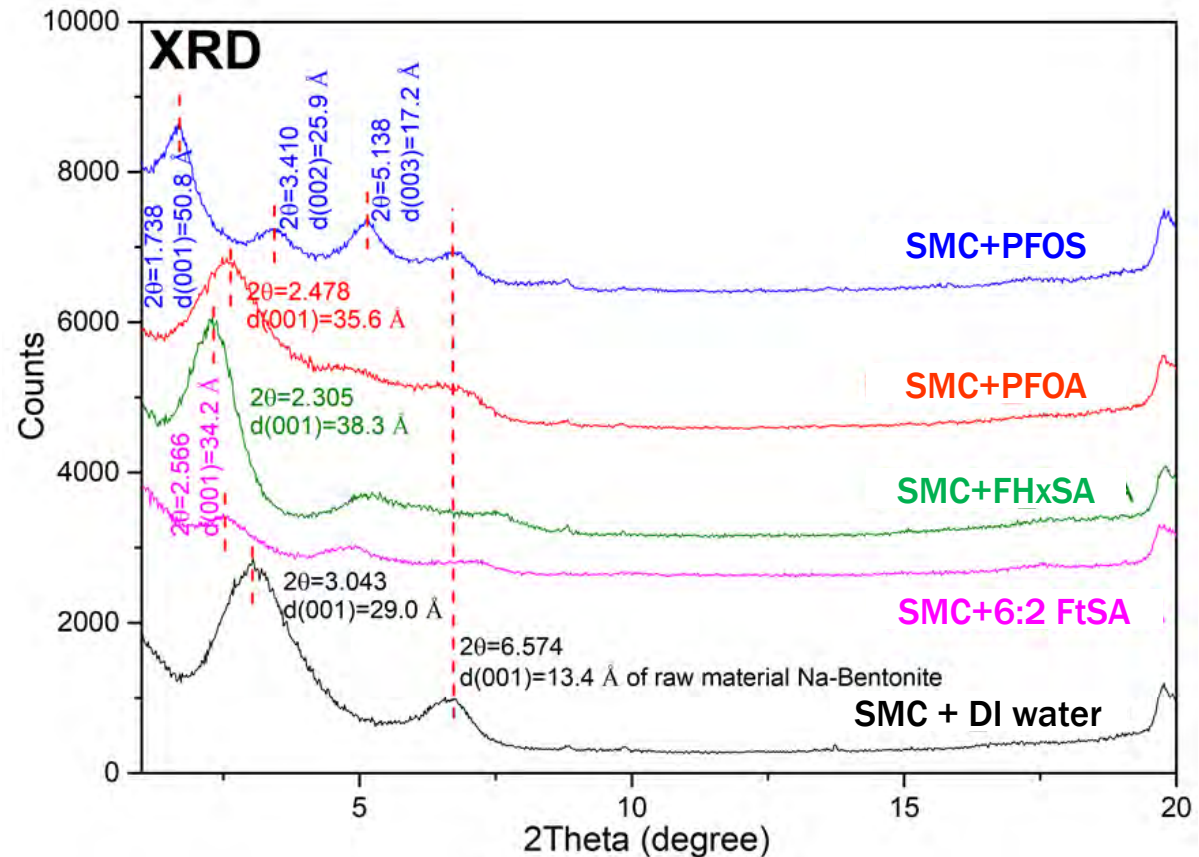
FLUORO-SORB® ADSORBENT PFAS REMOVAL MECHANISM



PFAS ADSORPTION BEHAVIOR

XRD shows the d-spacing increases as PFAS are adsorbed
 SMC = Surface-Modified Clay

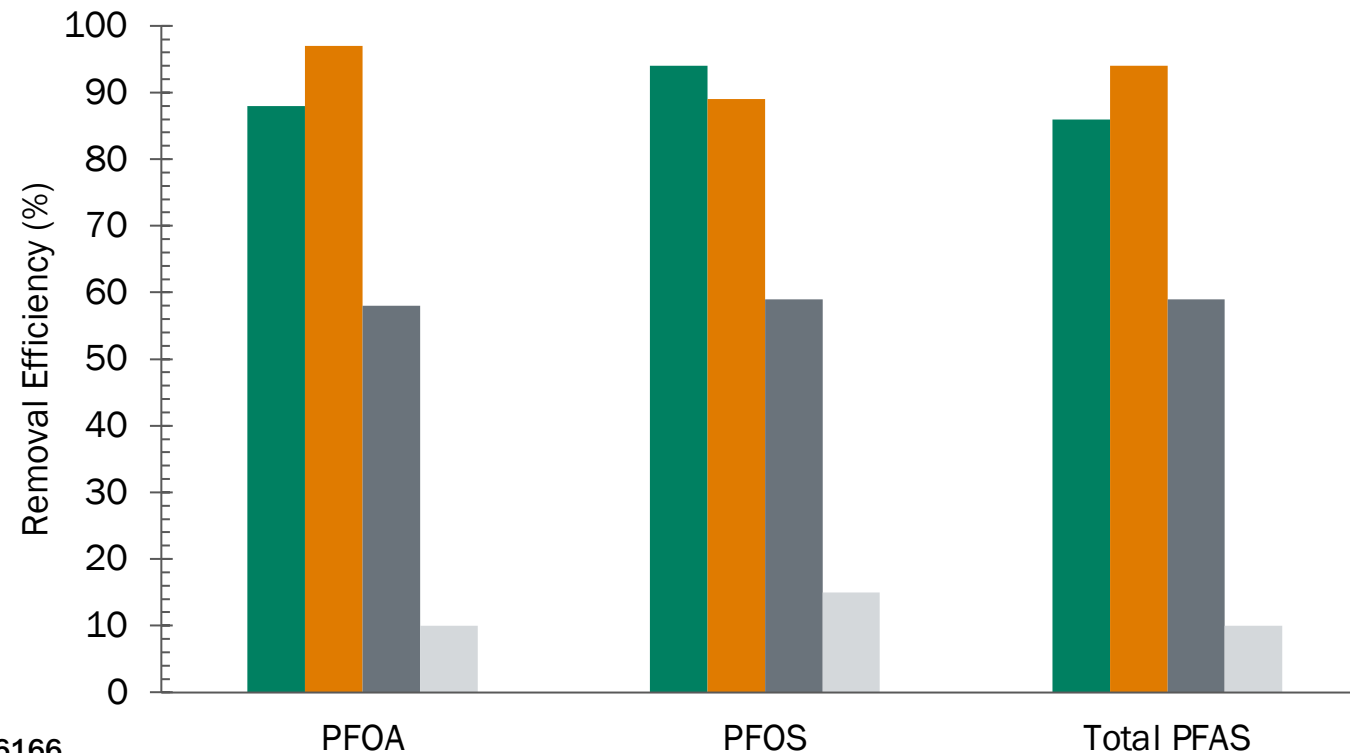
| substance | d-spacing |
|--------------|-----------|
| SMC+DI water | 29.0 Å |
| SMC+PFOS | 50.8 Å |
| SMC+PFOA | 35.6 Å |
| SMC+FHxSA | 38.3 Å |
| SMC+6:2 FtSA | 34.2 Å |



COMPARATIVE ASSESSMENT

- PFAS contaminated groundwater from a firefighting area at a former airfield
- Batch adsorption experiments - 40 mg FLUORO-SORB® adsorbent was mixed with 400 ml of contaminated groundwater for 168 hours and the supernatant analyzed for PFAS concentration

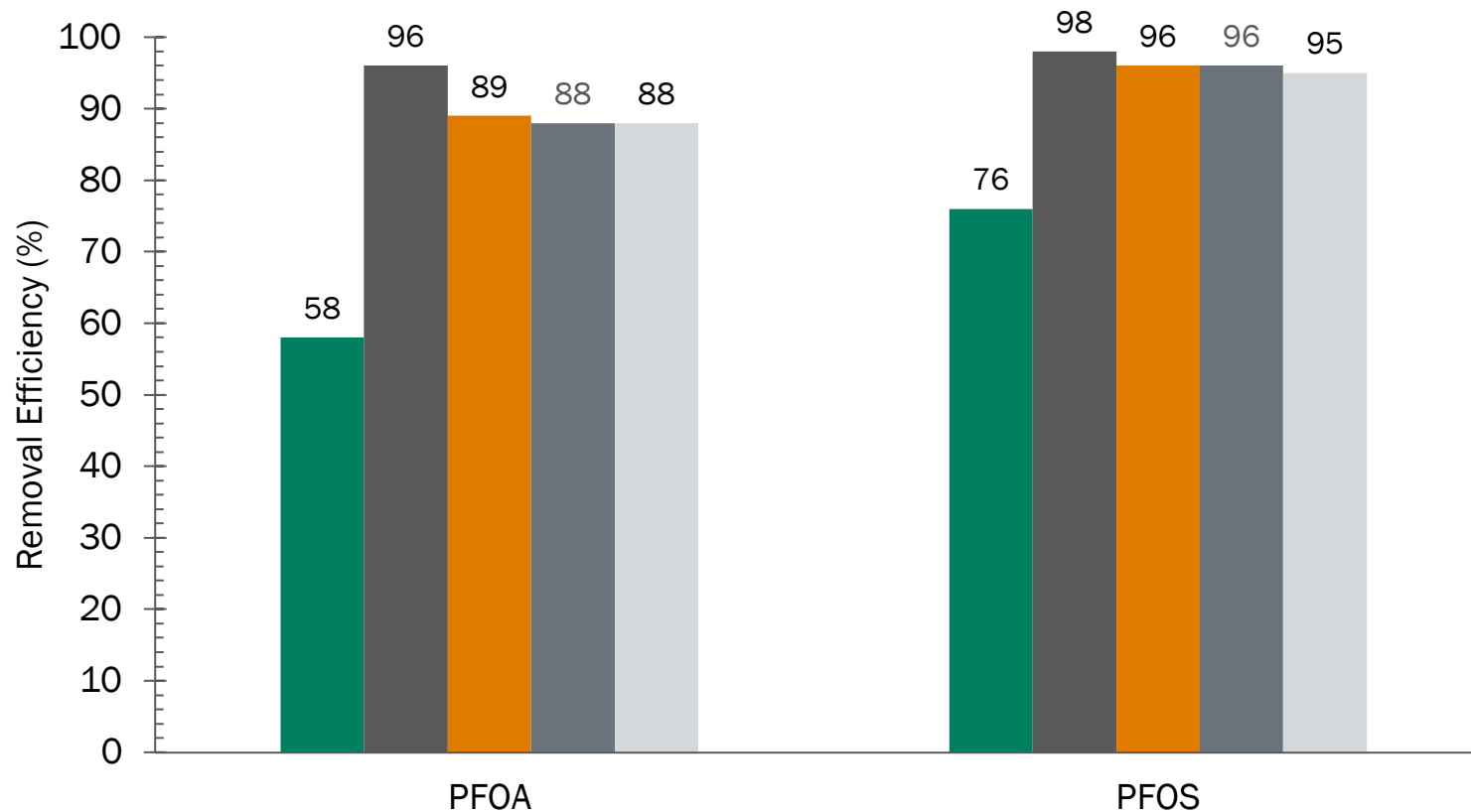
■ FLUORO-SORB 200 ■ Ion Exchange Resin ■ Granular Activated Carbon ■ Biochar



IMPACT OF CO-CONTAMINANTS

- **FLUORO-SORB[®]** adsorbent can effectively treat mixed waste streams and is proven to not be negatively impacted by co-contaminants

■ NOM 100.0 mg/L ■ Diesel 100.0 mg/L ■ 1,4 Dioxane 1.0 mg/L ■ BTEX 1.0 mg/L ■ TCE 1.0 mg/L



RSSCTS WITH FLUORO-SORB[®] ADSORBENT TREATMENT OF PFAS IN LANDFILL LEACHATE

Constant Diffusivity Scaling

| Parameter | Vessel | RSSCT |
|--|-----------|-------------|
| Average particle diameter (mm) | 0.630 | 0.107 |
| Bed height (in) | 82 | 0.98 |
| Column diameter (in) | 120 | 0.37 |
| Bed volume | 4,000 gal | 1.7 mL |
| Water flow | 400 gpm | 5.82 ml/min |
| Filtration rate (gpm/ft ²) | 5 | 2.13 |
| EBCT (min) | 10.0 | 0.29 |

- Duplicate columns for each media
- Stainless steel column “housing”
- Fed upflow by peristaltic pump



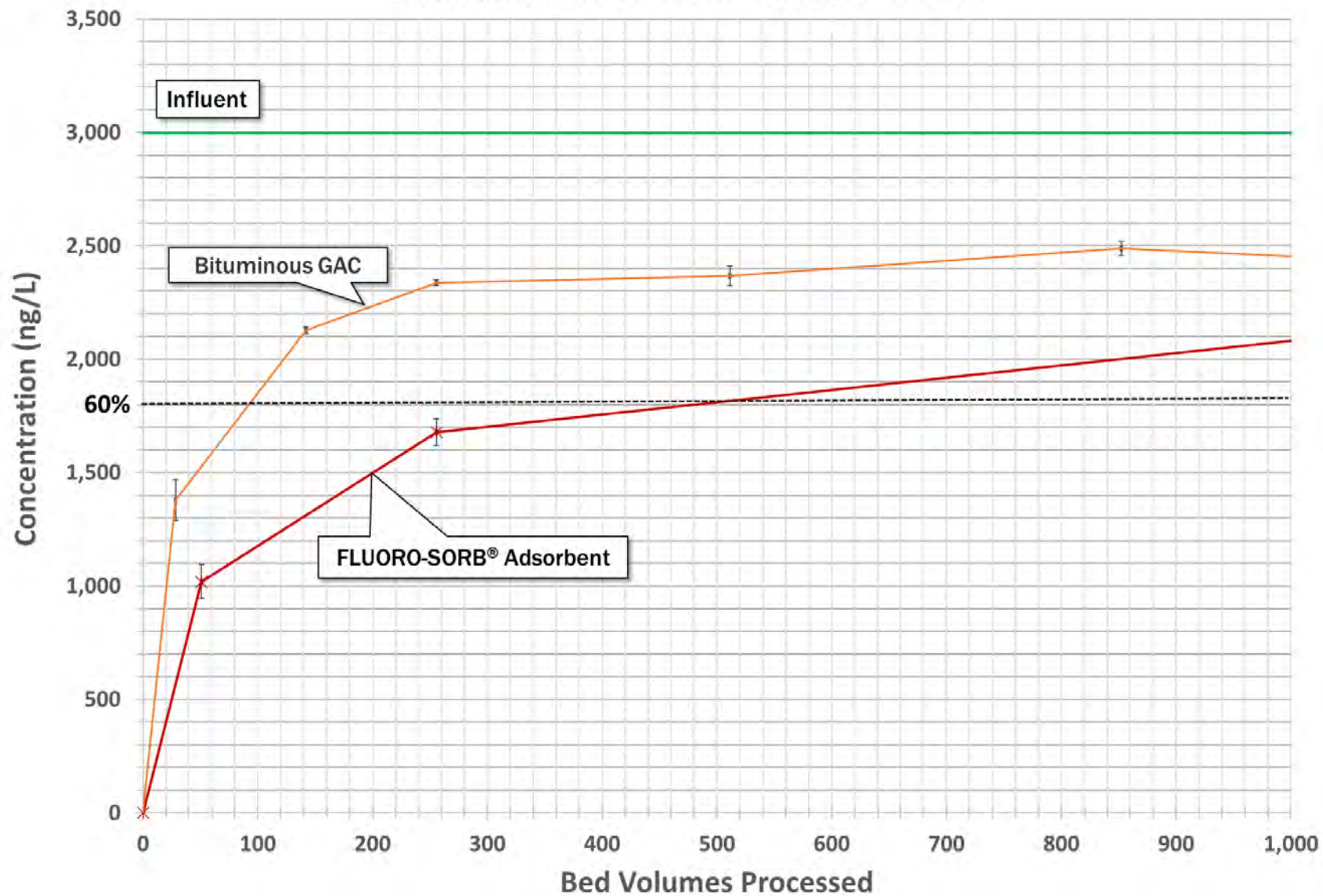
Tests performed at Colorado School of Mines, Golden, CO

LANDFILL LEACHATE WATER PARAMETERS

| Parameter | Value |
|--|--------|
| pH | 6.5 |
| Conductivity ($\mu\text{S}/\text{cm}$) | 76,600 |
| TOC (mg/L) | 560 |
| Ca (mg/L) | 6420 |
| Fe (mg/L) | 32.6 |
| Mg (mg/L) | 436 |
| Mn (mg/L) | 5.9 |
| NO_3^- (mg/L) | 0.4 |
| SO_4^{2-} (mg/L) | 64 |

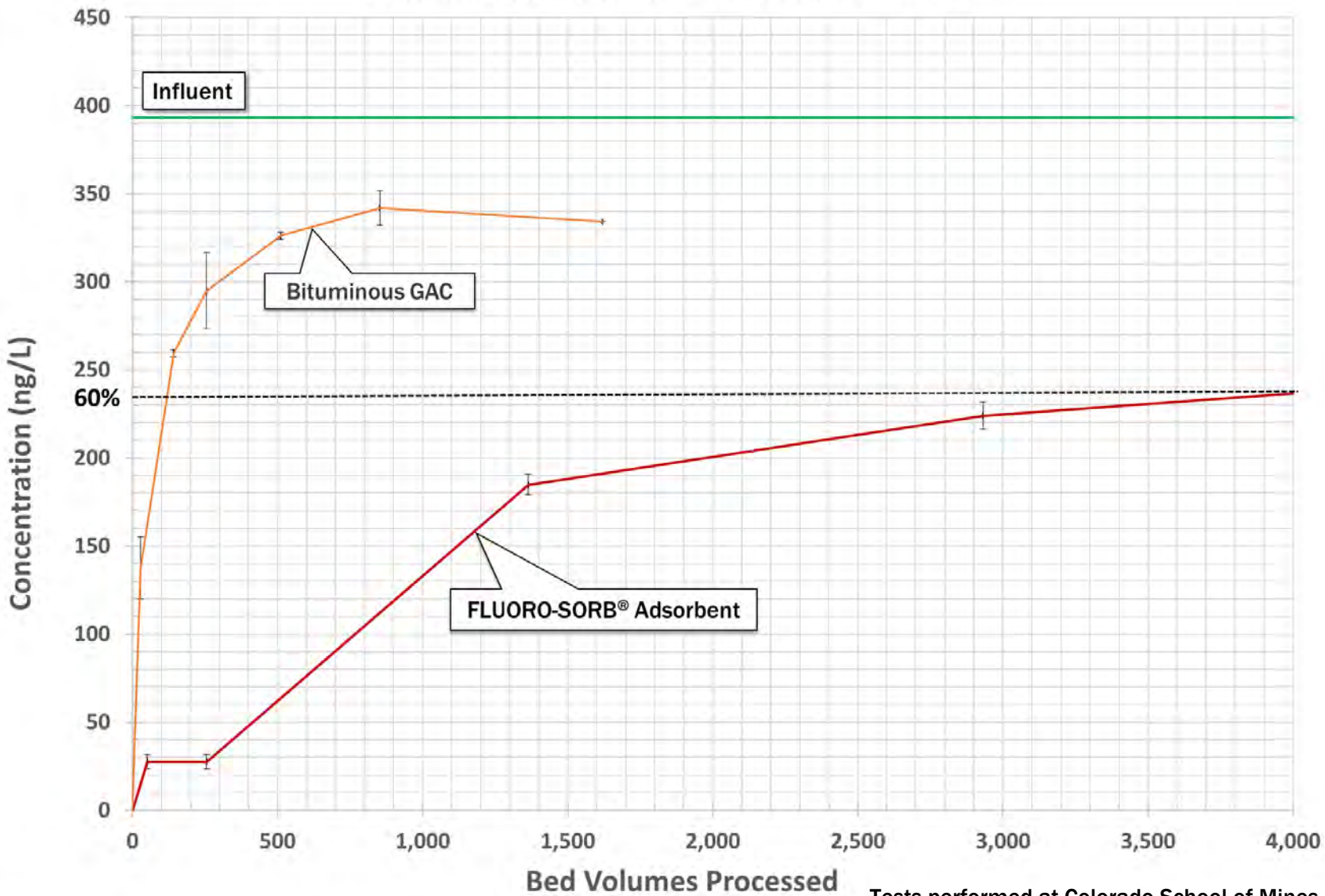
Tests performed at Colorado School of Mines, Golden, CO

Landfill Leachate RSSCT Results - PFHxA



Tests performed at Colorado School of Mines

Landfill Leachate RSSCT Results - PFOA



Tests performed at Colorado School of Mines

ORANGE COUNTY WATER DISTRICT (OCWD) PFAS TESTING PROGRAM

GAC, IX, NOVEL ADSORBENTS

- **Objective:** Identify adsorbents that are best suited to remove PFAS from Orange County groundwater that is to be used as drinking water
- Performed Rapid Small Scale Column Tests (RSSCTs) in the laboratory using well water from across Orange County
- Pilot testing adjacent to OCWD well in Anaheim, CA (Bessie Well)
- PFAS in Bessie Well:
 - 14 – 23 ng/L PFOA
 - 19 – 27 ng/L PFOS



References:

Orange County Water District, Jacobs (2021). PFAS Treatment Testing Study Final Report. June 2, 2021.

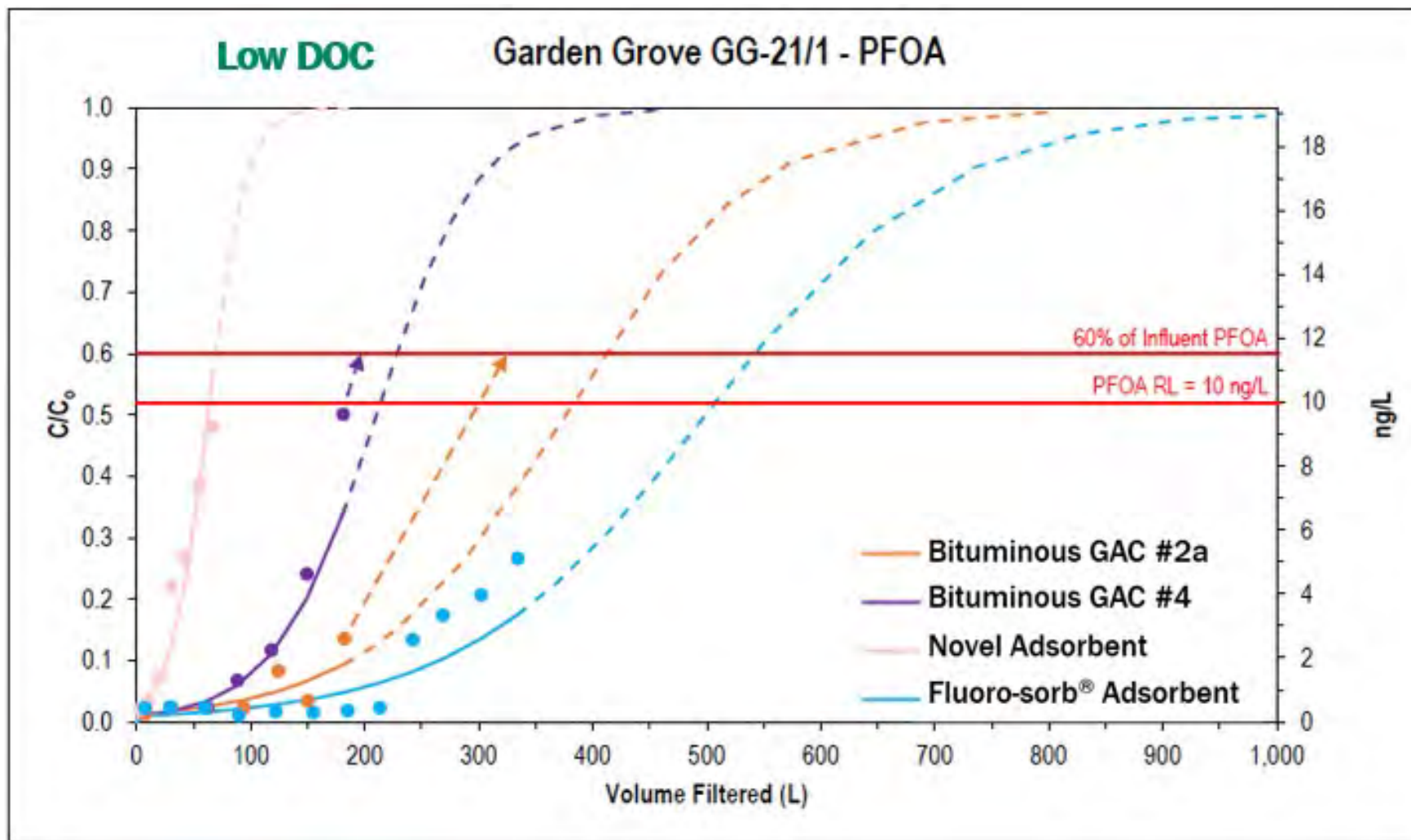
Orange County Water District (2021). PFAS Phase 1 Pilot Scale Treatment Study Final Report. March 24, 2021.

WATER QUALITY SUMMARY

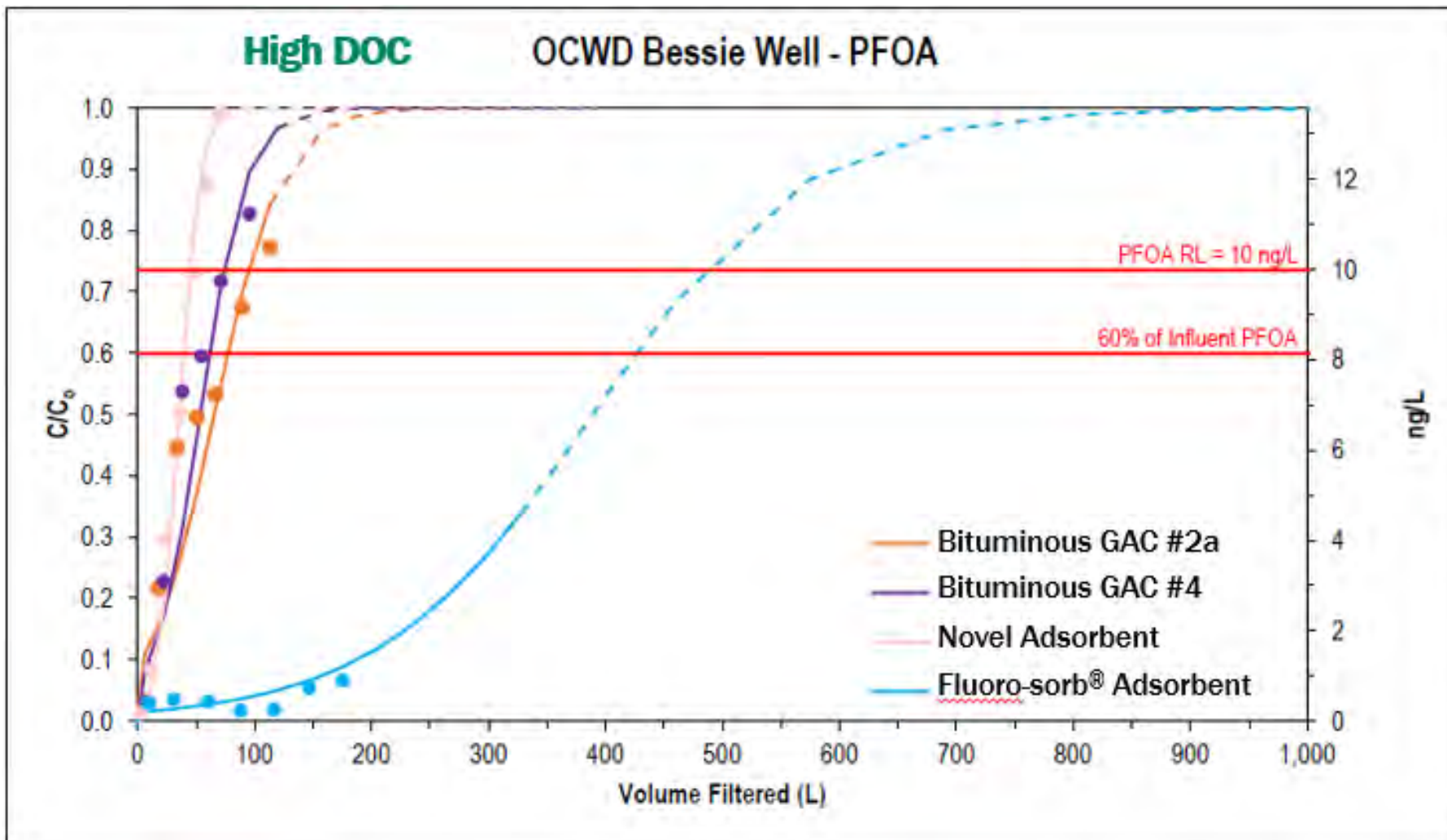
BESSIE WELL

| Parameter Name ^a | Abbrev. | Unit | Median | Range | Date range |
|--|----------------|------|--------|-------------|------------|
| Total Alkalinity (as CaCO ₃) | TotAlk | mg/L | 210 | 189 - 217 | 2001-2019 |
| pH | pH | - | 7.6 | 7.3 – 8.2 | 2001-2019 |
| Chloride | Cl | mg/L | 128.0 | 89.6 – 146 | 2001-2019 |
| Nitrate Nitrogen | NO3-N | mg/L | 1.74 | ND – 4.62 | 2001-2019 |
| Perchlorate | ClO4 | ug/L | ND | ND | 2001-2019 |
| Sulfate | SO4 | mg/L | 126 | 114 – 149 | 2001-2019 |
| Total Dissolved Solids | TDS | mg/L | 600 | 518 – 662 | 2001-2019 |
| Total Organic Carbon (unfiltered) | TOC | mg/L | 1.50 | 1.28 – 1.99 | 2001-2019 |
| | | | | | |
| Perfluoro octanoic acid | PFOA | ng/L | 16.9 | 14.4 – 23.4 | 2016-2019 |
| Perfluoro octane sulfonic acid | PFOS | ng/L | 25.4 | 19.0 – 27.2 | 2016-2019 |
| Perfluoro butane sulfonic acid | PFBS | ng/L | 17.3 | 12.4 – 19.0 | 2016-2019 |
| Perfluoro hexane sulfonic acid | PFHxS | ng/L | 9.9 | 7.9 – 11.6 | 2016-2019 |
| Perfluoro nonanoic acid | PFNA | ng/L | 2.1 | ND – 4.22 | 2016-2019 |
| Other PFAS compounds | - ^b | ng/L | ND | ND | 2016-2019 |

RSSCT RESULTS FOR GARDEN GROVE WELL



RSSCT RESULTS FOR OCWD BESSIE WELL



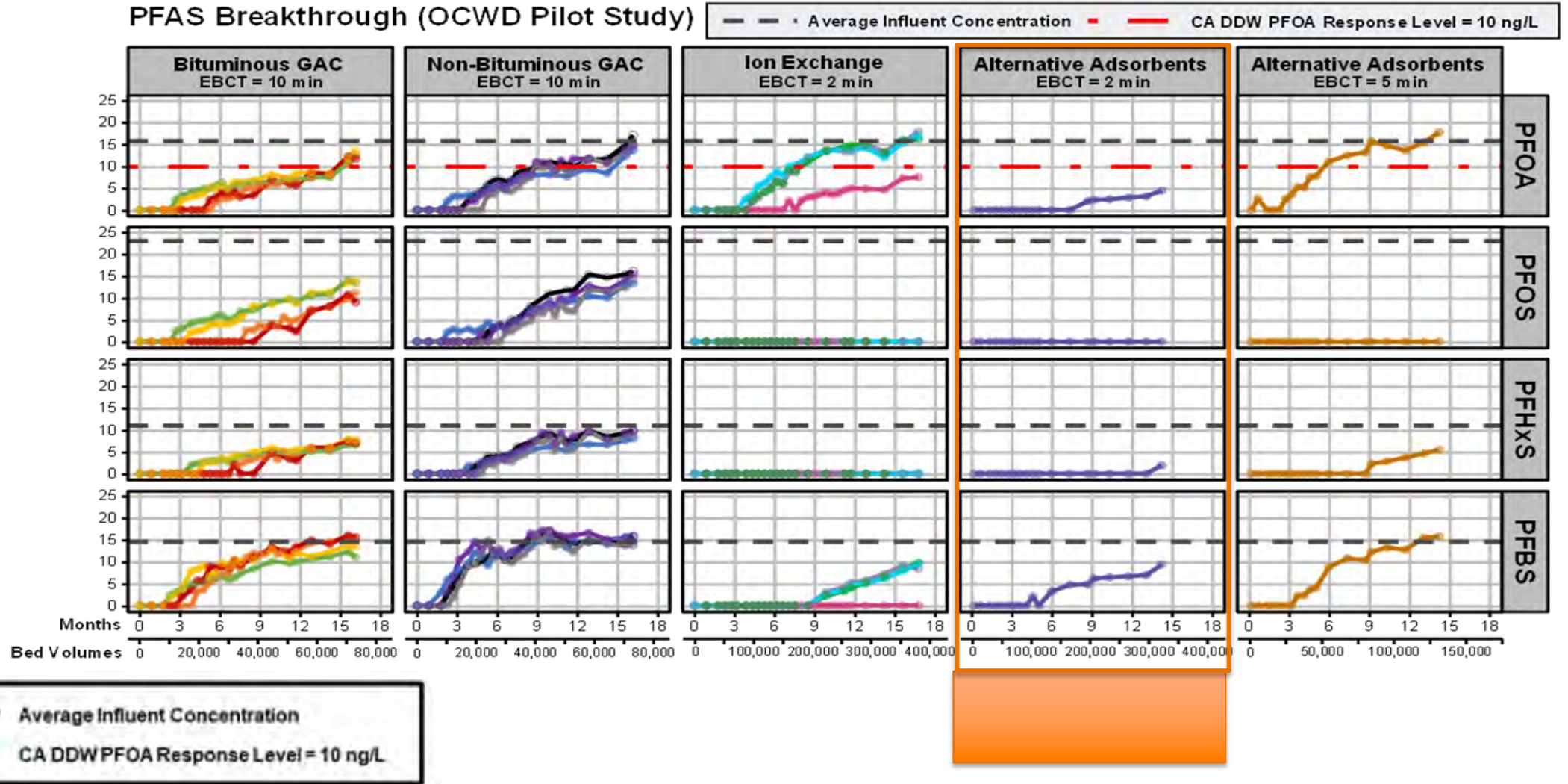
OCWD PILOT TEST SYSTEM BESSIE WELL

- 8 GAC: 10-minute EBCT
- 4 IX: 2-minute EBCT
- 2 Novel Adsorbents
 - Other
5-minute EBCT
 - **CETCO FLUORO-SORB®**
adsorbent: 2-minute EBCT



PILOT RESULTS JULY 2021

**FLUORO-SORB®
ADSORBENT**



WE ENCOURAGE YOU TO RUN YOUR OWN TRIALS

WE PROVIDE:

- Free product samples
- Technical support for testing program and data review
- Bed life estimates

Contact us at:

marat@vadoseRT.com or

cetco@mineralstech.com



CONCLUSIONS

FLUORO-SORB® ADSORBENT IS AN ECONOMICAL AND EFFECTIVE TREATMENT MEDIA FOR PFAS

- **Significantly more** adsorptive than GAC with an EBCT as low as 2 minutes
- Binds **entire spectrum** of PFAS without being impacted by mixed waste streams
- Commercially available **today** without need for additional capital investment
- **NSF-certified** for drinking water treatment



OUR STANDARDS. YOUR PEACE OF MIND.



CETCO®

cetco@mineralstech.com | cetco.com