PFAS Technical Group

April 22, 2022

Agenda

- Welcome and introductions
- Drinking water system treatment technologies for PFAS - Dung (Zoom) Nguyen, CDM Smith
- Groundwater & wastewater remediation technologies for PFAS - Dillon Gilbowkj & Geoff Pellechia, Evoqua
- Conclusions & next steps

PFAS Treatment Using Commercial Technologies

Bench Testing and Design Considerations

Zoom Nguyen

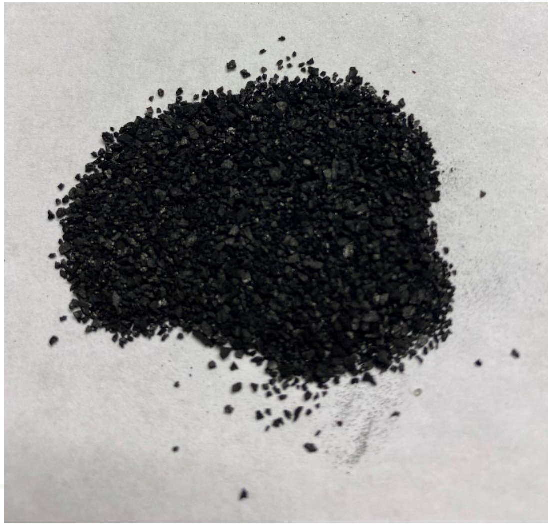
Charles Schaefer

04/22/2022

CDM Smith

PFAS Treatment in Water

- Focus on drinking water for full-scale treatment
- Granular activate carbon (GAC) and anion exchange resin (AER) most common approaches
  - NF/RO
  - Emerging technologies (novel sorbents, foam fractionation)
- Treatment effectiveness using GAC/AER often not well understood
  - Longevity among various GAC/AER products
  - Impacts of water geochemistry or pre-treatment
  - Various classes of PFAS
- Need for scalable bench-scale testing in relatively short timeframes



Rapid Small Scale Column Tests (RSSCTs) for Evaluating PFAS Removal Using GAC/AER

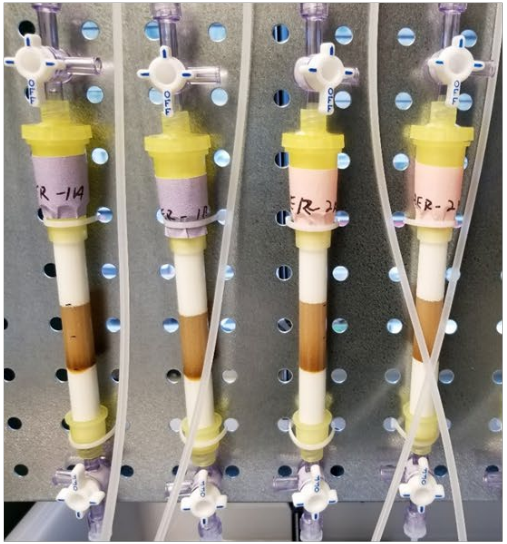
- By reducing the particle size, column testing can be performed using a much shorter residence time than required for a full-scale system, thus obtaining rapid results

- Smaller particle sizes allow for smaller column diameters, and ultimately less water needed for the study

- Our approach: GAC/AER particle size reduction of 3 to 4X
  - limit any potential laboratory artifacts
  - proper evaluation of possible permeability losses

- Scaling requirements
  - to neglect dispersion: $200 < ReSc < 200{,}000$
  - constant diffusivity: $\frac{EBCT_G}{EBCT_U} = \left(\frac{d_G}{d_U}\right)^2$ *Is this appropriate for PFAS?*

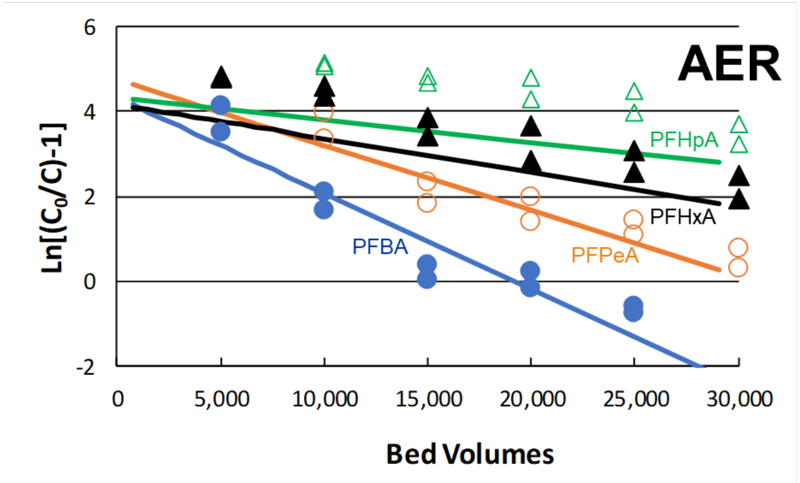
RSSCT Testing to Assess Scaling

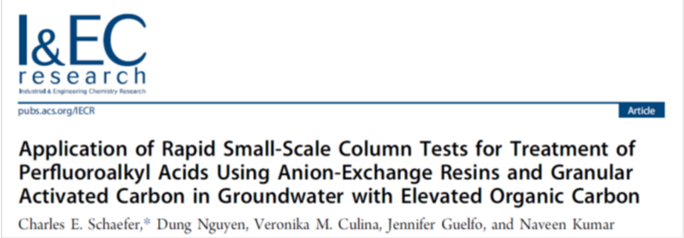


1 cm diam. columns for GROUND
(2.5 cm for UNGROUND)

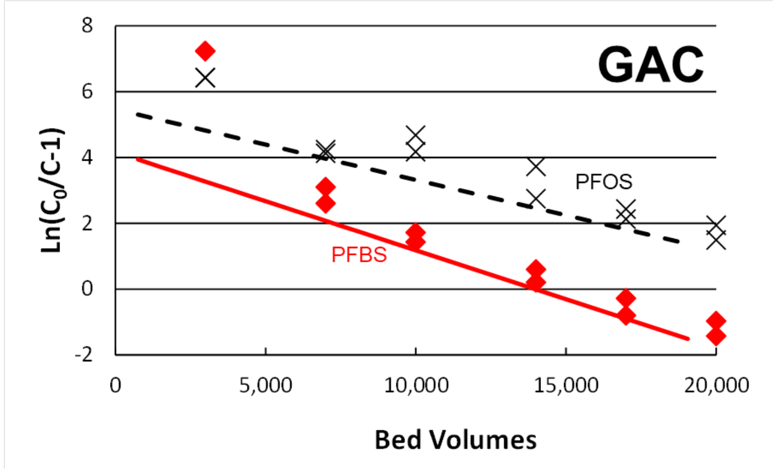
- 1 GAC & 2 AERs
- Low (<1 mg/L) and high (2.5 mg/L) TOC natural waters
- Comparison of GROUND to UNGROUND particles
- GROUND particle size ~0.2 mm
- Evaluate PFAS elution (perfluoroalkyl acids)

RSSCT Scaling Results



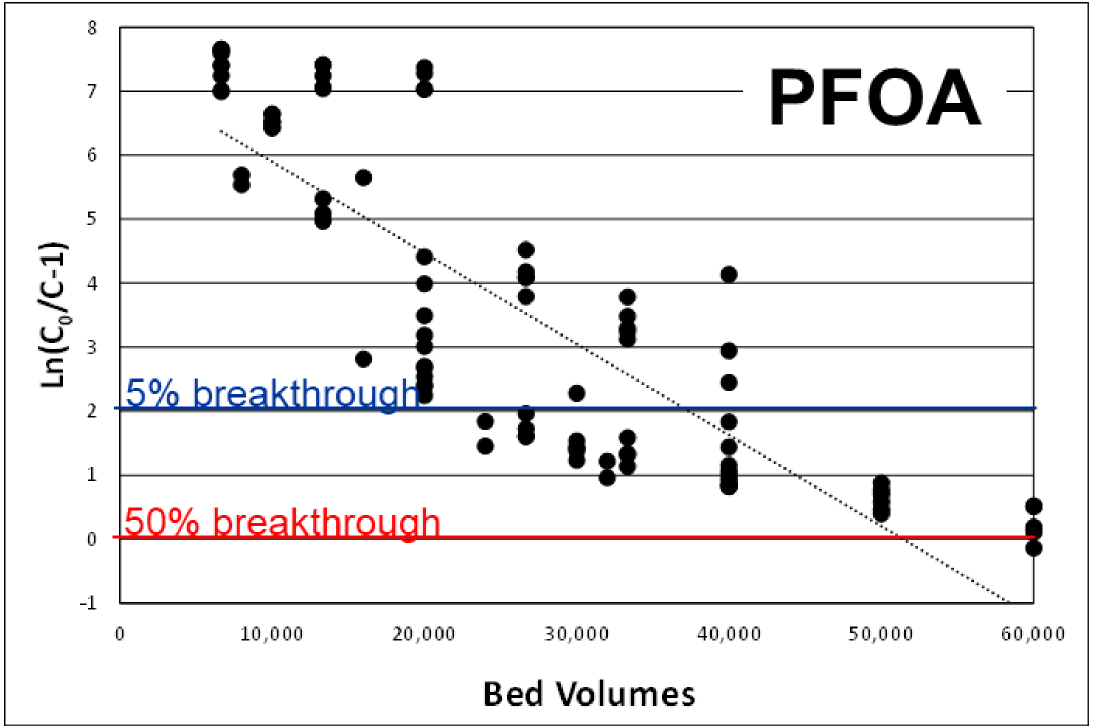


- Constant diffusivity model confirmed for both GAC and AER, and for high and low TOC waters
- Need to scale q_0 as $(r_U/r_G)^{0.5}$



Still very much an area of active research

Summary of RSSCT Results - GAC

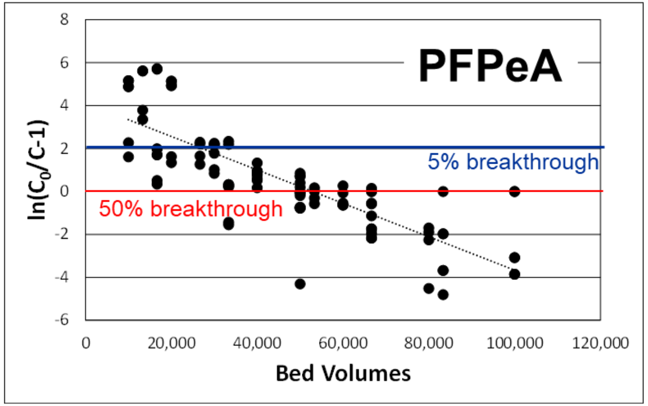


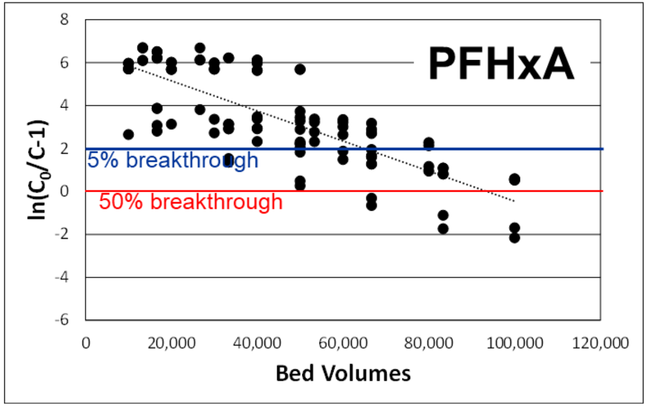
- 20 studies
- Low-TOC waters
- Coal-based GACs
- Results consistent with the Thomas model

$$ln\left[\frac{C_0}{C} - 1\right] = \left(\frac{kmq_0}{Q}\right) - [EBCT]kC_0BV$$

- Bench results consistent with pilot-/full-scale findings

Summary of RSSCT Results - AER



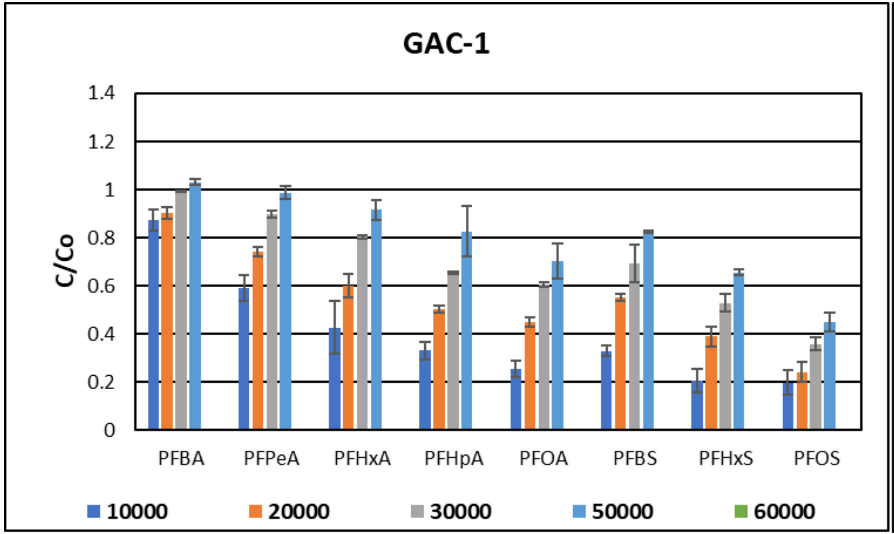


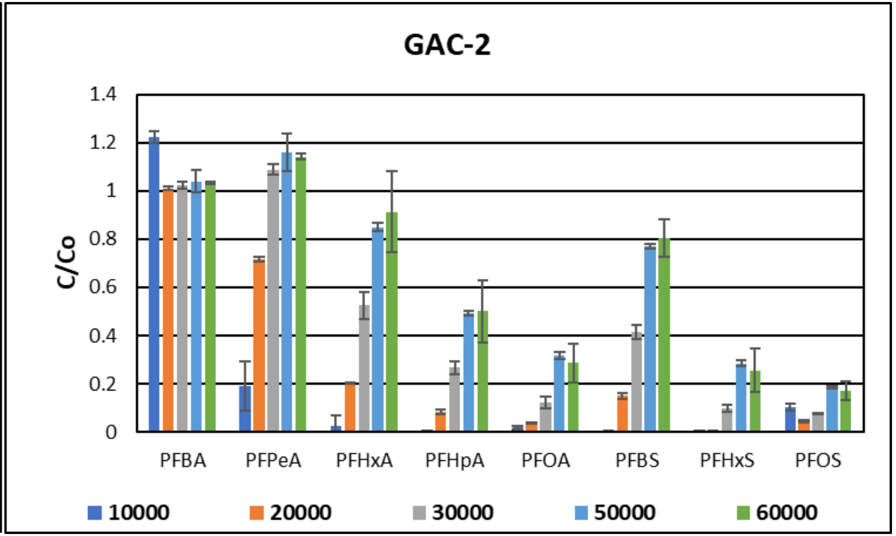
- 20 studies
- Low-TOC waters
- PFAS-selective AERs
- Results consistent with the Thomas model

$$ln\left[\frac{C_0}{C}-1\right]=\left(\frac{kmq_0}{Q}\right)-[EBCT]kC_0BV$$

- Bench results consistent with pilot-/full-scale findings
- Tighter range compared to GAC

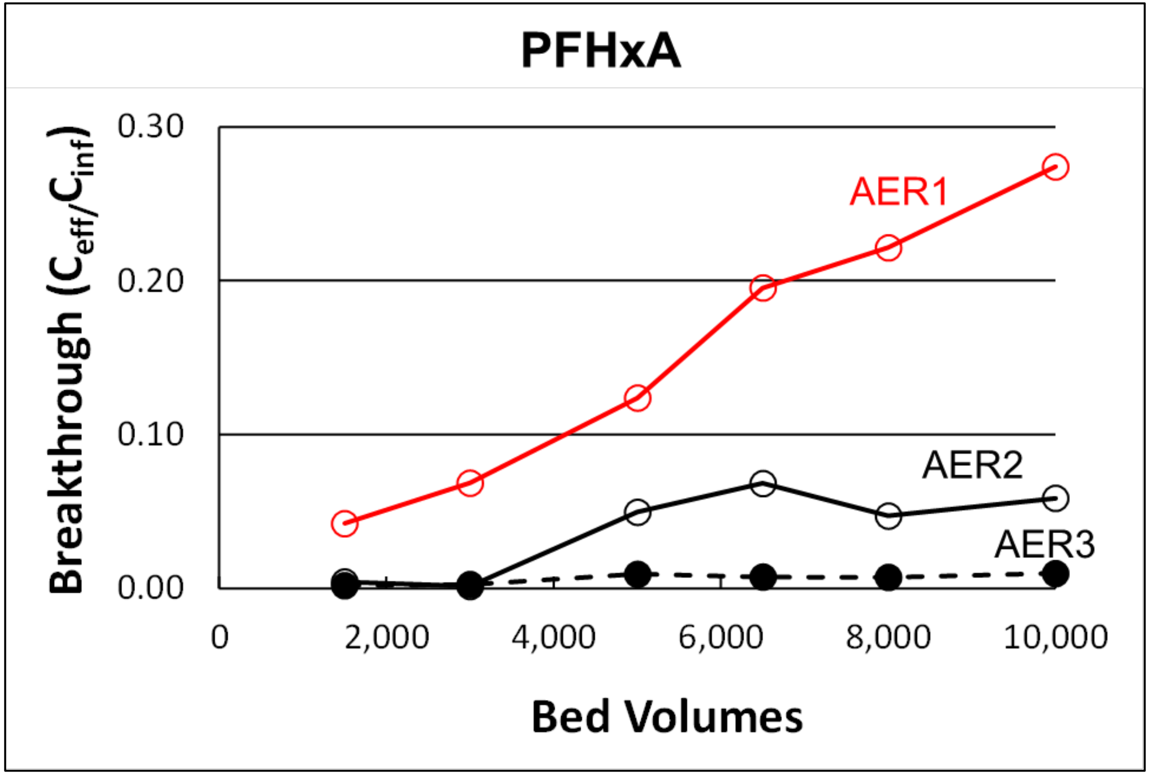
GAC Comparison





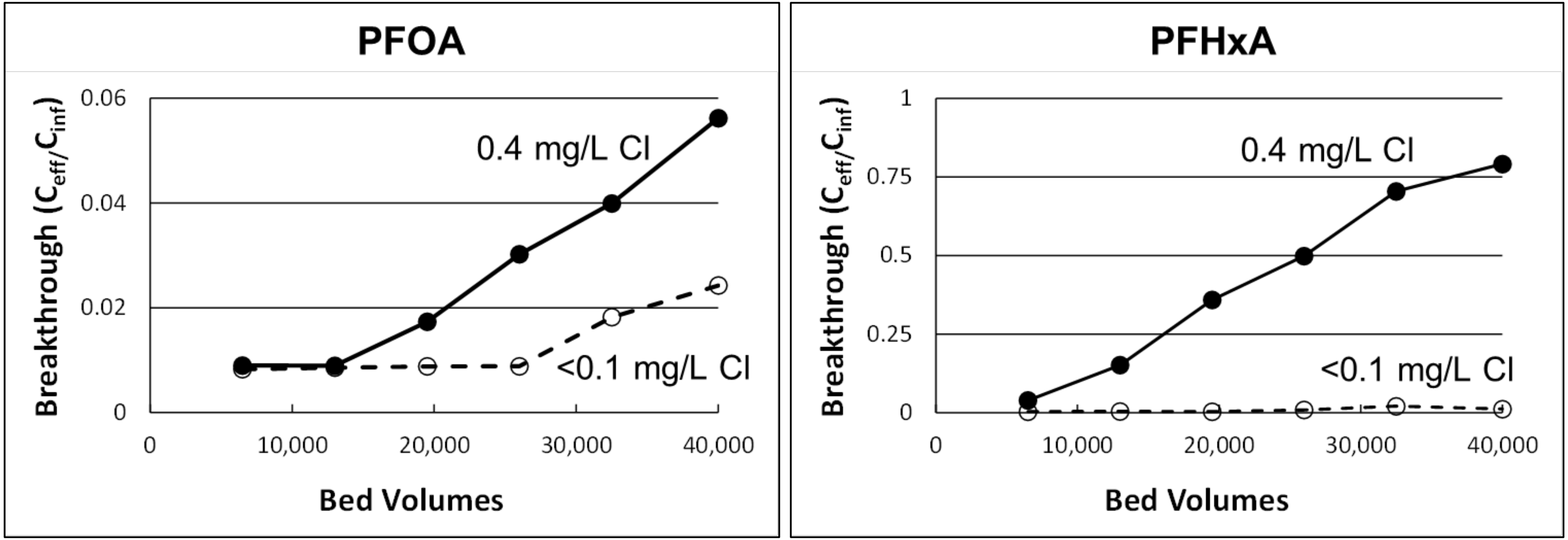
- Long-chained PFAAs are removed more effectively than short-chained counterparts
- PFCAs generally break through faster than PFSAs of the same C:F chain length
- Varying performance among commercially-available GAC products

AER Comparison



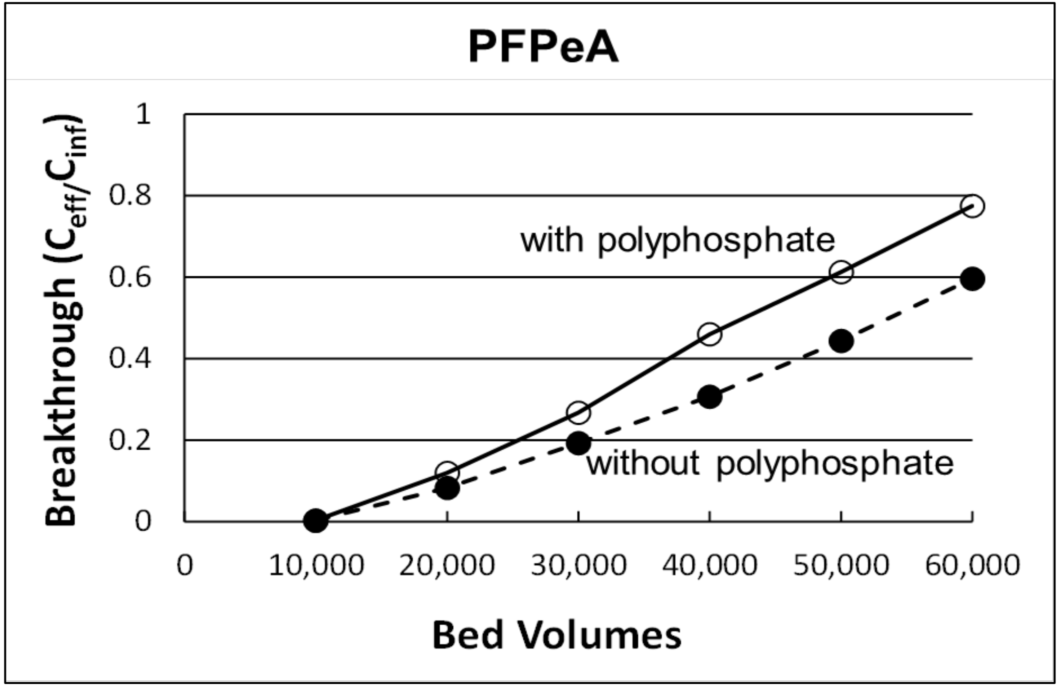
Varying performance among commercially-available AER products

Impacts of Residual Chlorine on AER

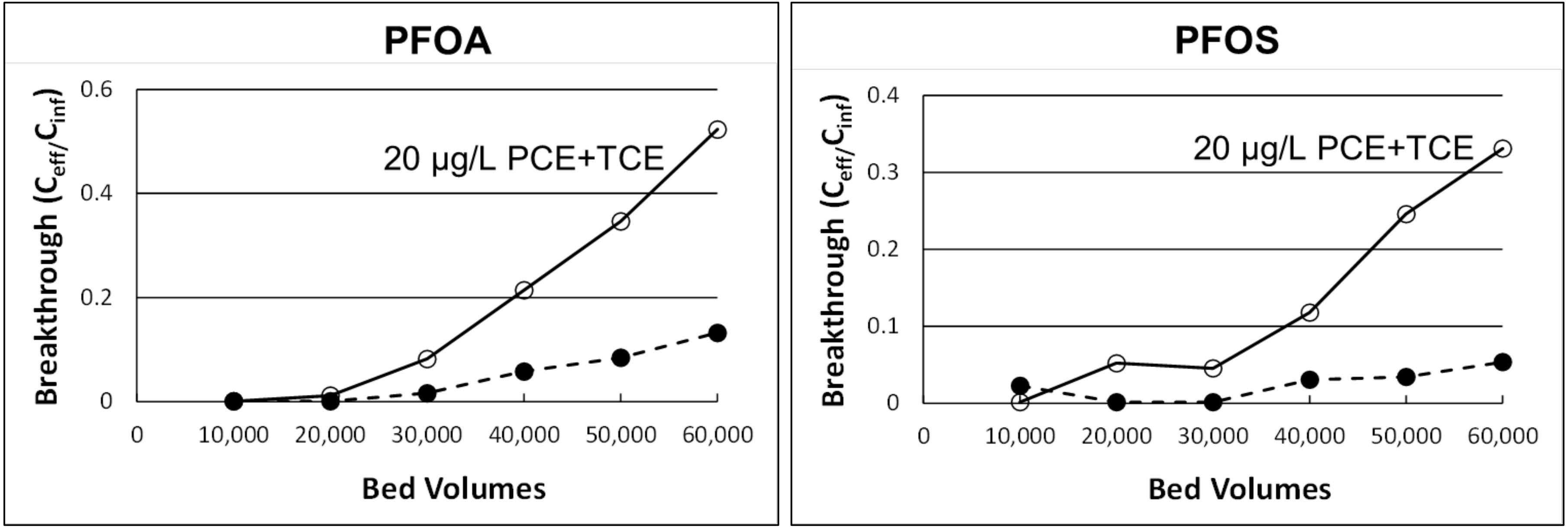


Residual chlorine does not adversely impact GACs (data not shown)

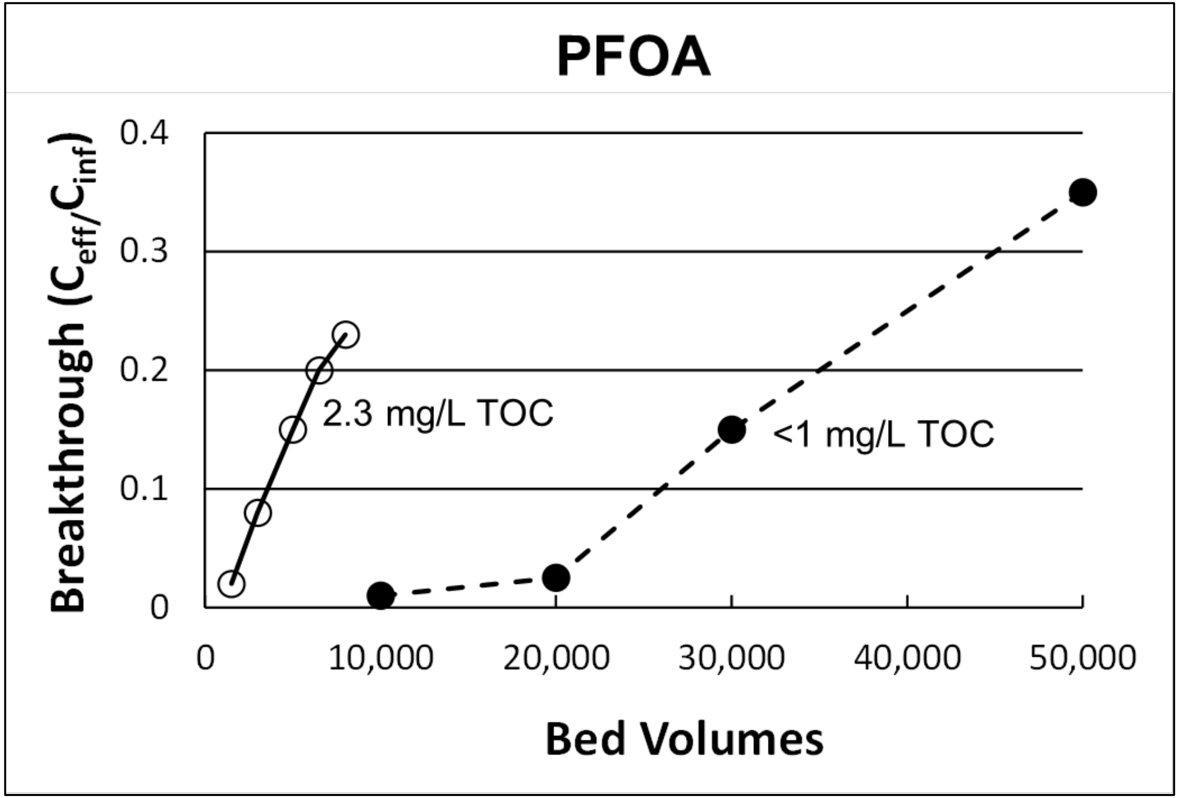
Impacts of Corrosion Inhibitors on AER



Impacts of cVOCs on GAC

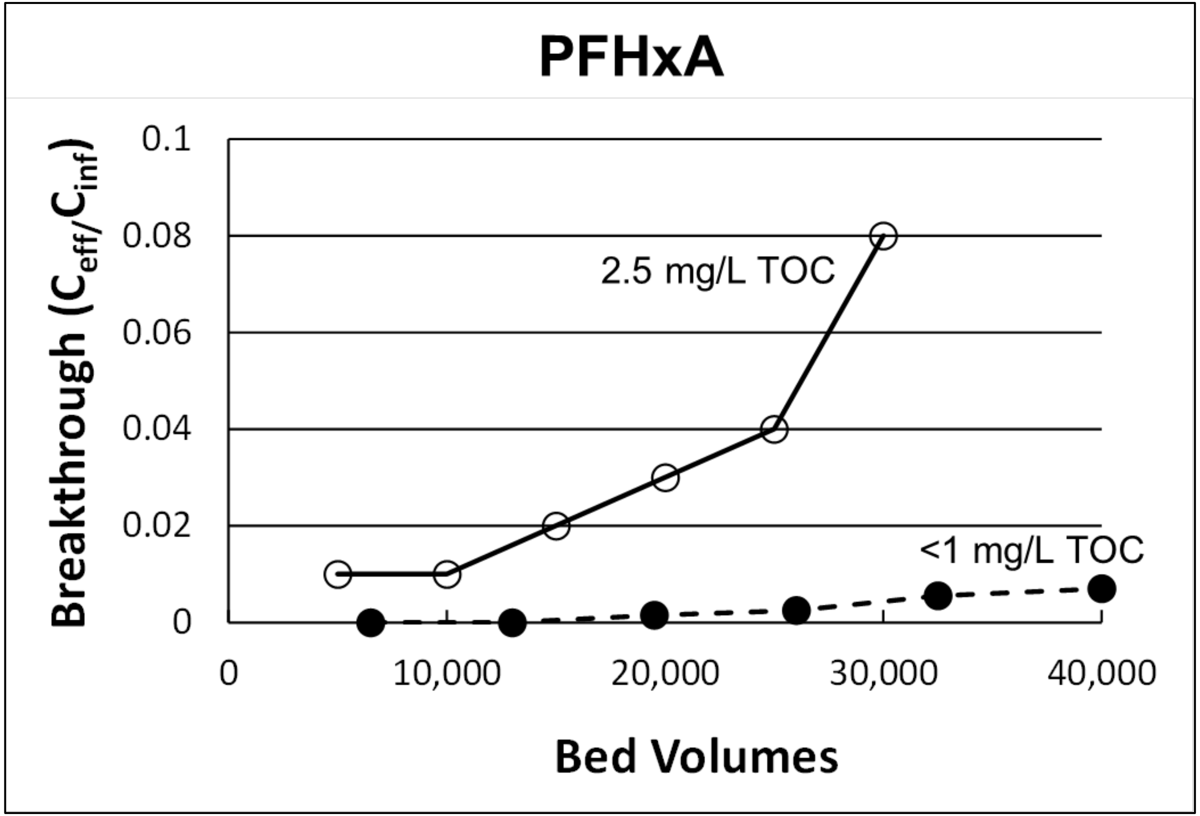


Impacts of TOC on GAC (Site 1)



High TOC = surface water; low TOC = groundwater

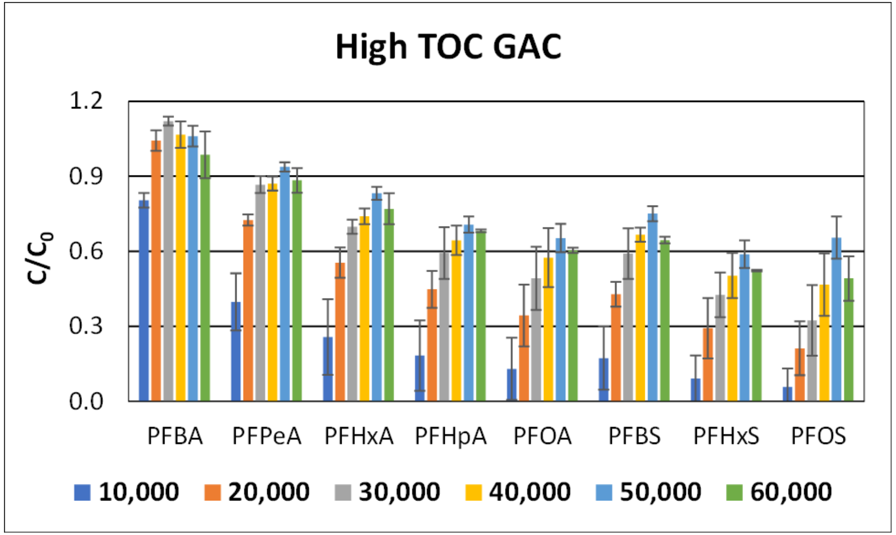
Impacts of TOC on AER (Site 1)



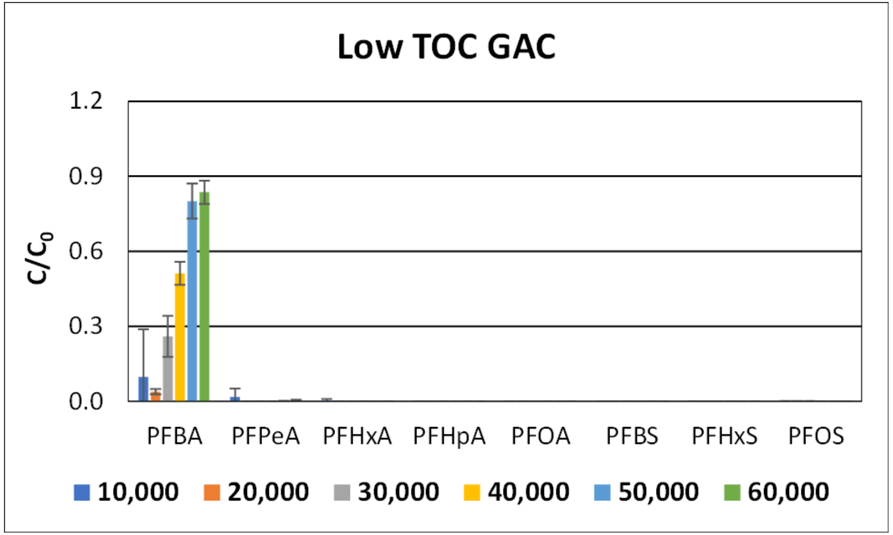
High TOC = surface water; low TOC = groundwater

Impacts of TOC on GAC (Site 2)

~ 3 mg/L



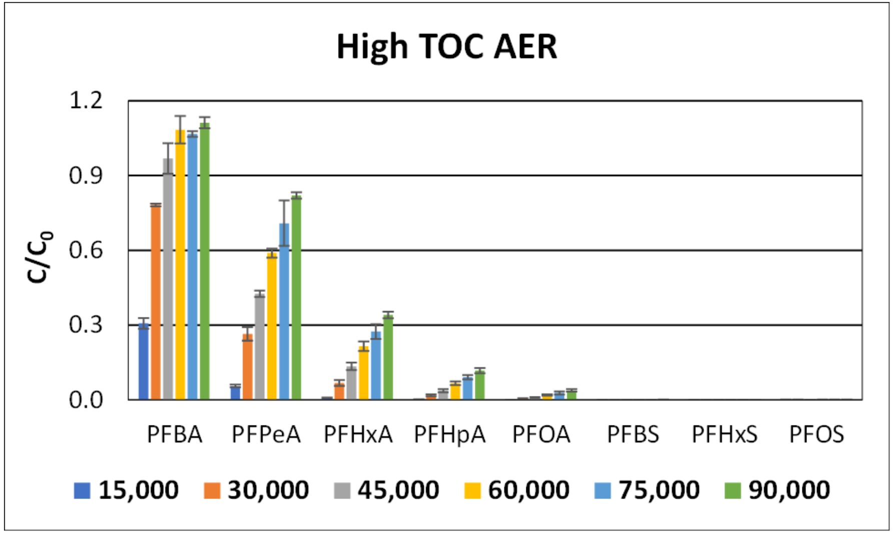
0.3-0.4 mg/L



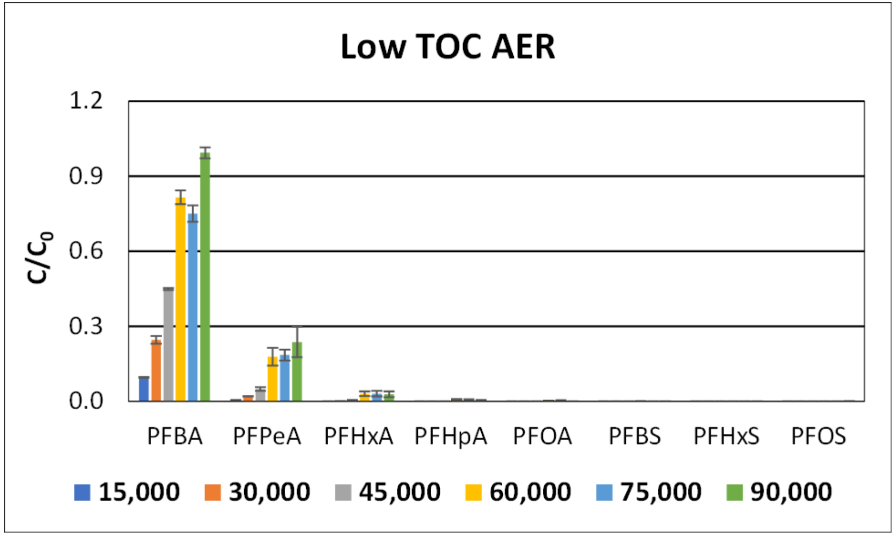
TOC was removed using a cheap coconut carbon prior to PFAS treatment

Impacts of TOC on AER (Site 2)

~ 3 mg/L



0.3-0.4 mg/L

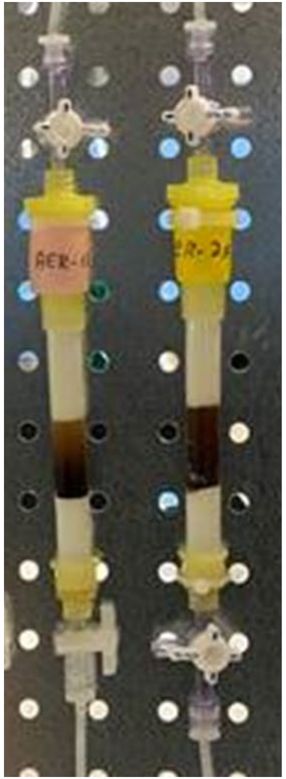


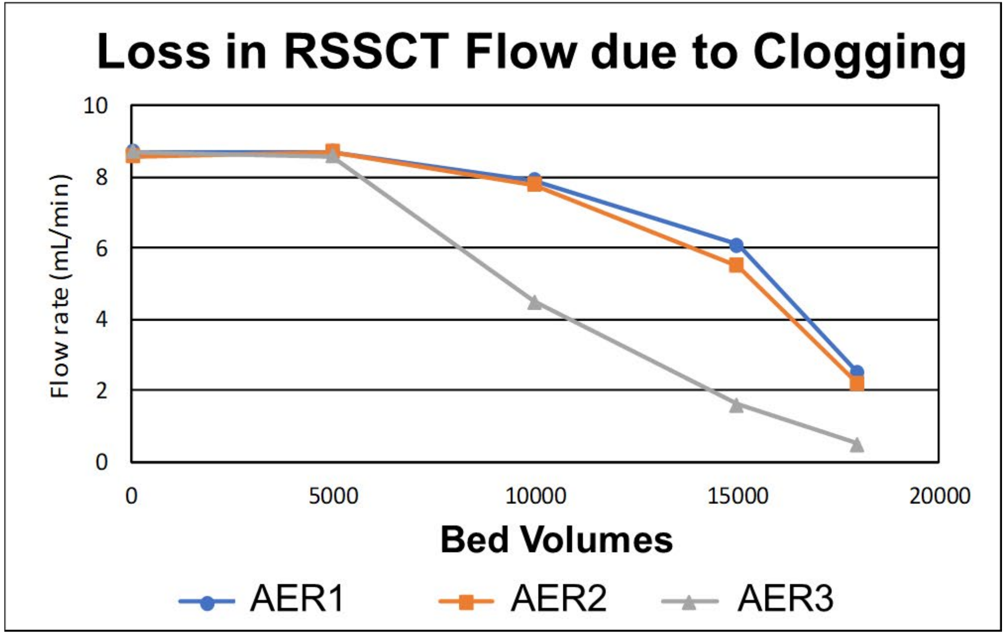
TOC was removed using a cheap coconut carbon prior to PFAS treatment

Impacts on Secondary Water Quality

GAC type	Bed volumes	pH (SU)	Total arsenic (μg/L)
GAC-1	50	8.6	4
	500	7.7	<1
GAC-2	50	7.9	<1
	500	7.8	<1

Permeability Loss in AERs





Conclusions

- Long-chained PFAAs are generally removed effectively using GAC or AER
- AERs are generally more effective than GAC in removing short-chained PFAAs
- Wide range of treatment performance among commercially-available products
- Factors impacting treatment performance:
  - Water chemistries
  - Residual treatment chemicals
  - Co-contaminants

  Can individually/collectively impact performance different GAC/AER products & from site to site
- Impacts on secondary water quality must be taken into consideration

Conclusions (cont'd)

- When appropriately applied, RSSCT can be a useful tool to:
  - Compare technologies, products, residence time
  - Evaluate pre-treatment requirements
  - Provide parameters for pilot-/full-scale design/implementation
  - Assess OPEX & CAPEX

- Other considerations:
  - Product cost, type (novel sorbent?) & availability
  - Pre-treatment requirements
  - Residence time/vessel size/footprint
  - Permeability loss/pressure drop
  - Treatment targets
  - Regulatory approval/perception/risk communication
  - Spent media handling & disposal
  - Analytical method/laboratory

Questions?

NguyenDD@cdmsmith.com

A SINGLE-SOURCE SOLUTION PROVIDER FOR COMPLEX CHALLENGES

DILLON GILBOW & GEOFF PELLECHIA

Agenda

- Evoqua - Who we are, what we do, where we are.
- Environmental Solutions Division
- PFAS Solutions
- Design Considerations
- Best Practices
- Case Studies
- Q&A

Who We Are \e-vōk-wä\

Water is a critical yet finite resource. We believe there is power and purpose in combining expertise, innovation and a commitment to maintaining this resource, now and in the future.

Evoqua Water Technologies is a leading provider of water and wastewater treatment solutions, offering a broad portfolio of products, services and expertise to support industrial, municipal and recreational customers.

Headquartered in Pittsburgh, Pennsylvania, Evoqua and our brands have over a 100-year heritage of innovation. We help more than 38,000 customers solve water challenges at over 200,000 installations worldwide and operate in more than 150 locations across ten countries. Every day, millions of people and thousands of companies rely on us as their trusted advisor to help them meet their water needs.

PRODUCTS

TECHNOLOGIES

SYSTEMS

SERVICES

We Hold Top Positions Across a Variety of Markets

OUR TWO SEGMENT APPROACH

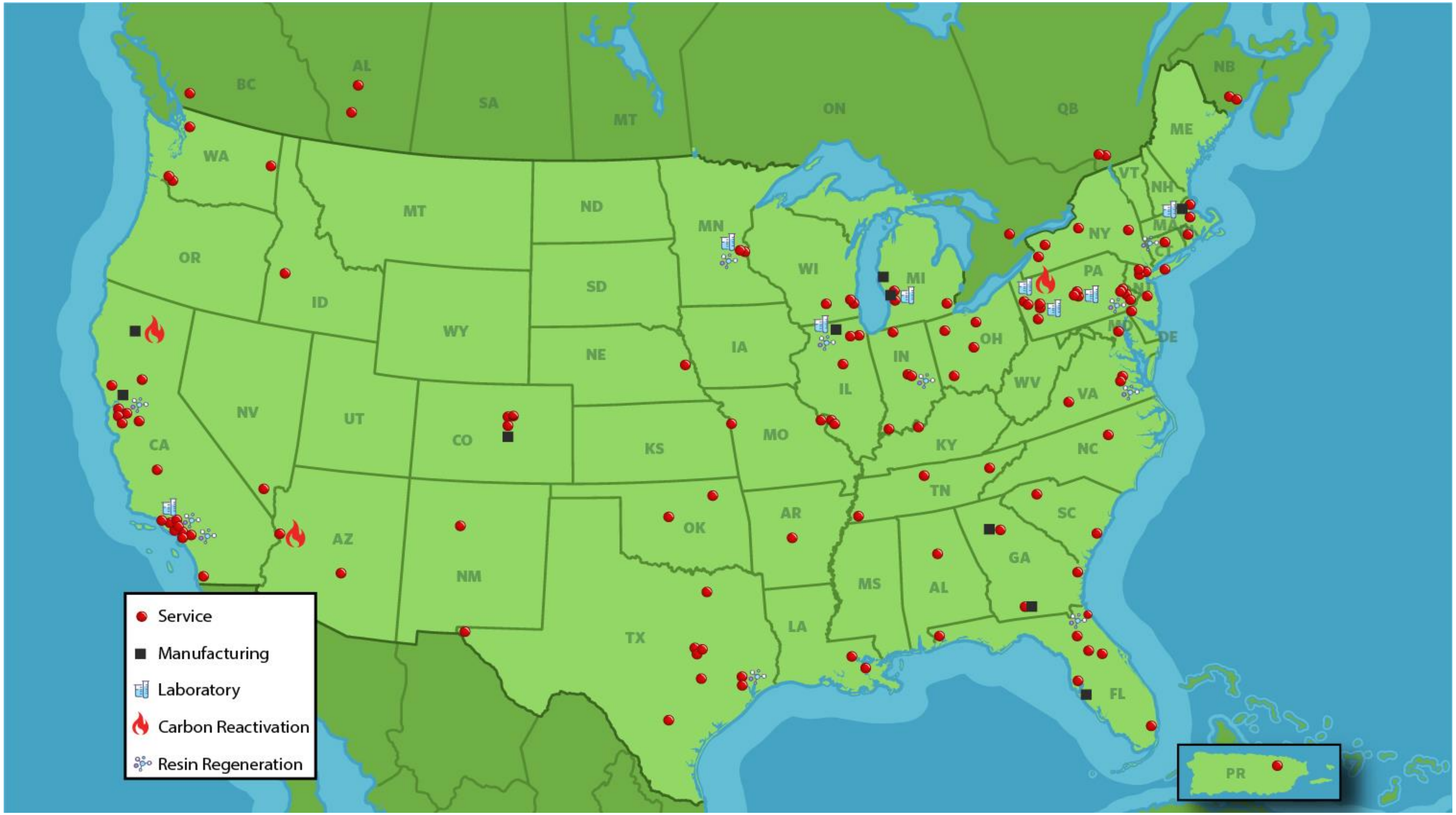
We are organized into a **two-segment structure** designed to serve the needs of our customers worldwide.

Our structure has created a customer-facing project and service organization called **Integrated Solutions and Services** (“ISS”) and a product technology group, **Applied Product Technologies** (“APT”), focused primarily on sales through indirect product channels.

- Aerospace & Defense
- Aquaculture
- Aquatics
- Commercial & Facilities
- Construction
- Food & Beverage
- General Industry
- Life Sciences
- Marine
- Metals & Mining
- Microelectronics
- Municipal Drinking Water
- Municipal Wastewater
- Oil & Gas
- Pharmaceutical
- Power Generation
- Refining & Chemicals
- Renewable Energy

evoqua WATER TECHNOLOGIES

Evoqua Locations North American Map



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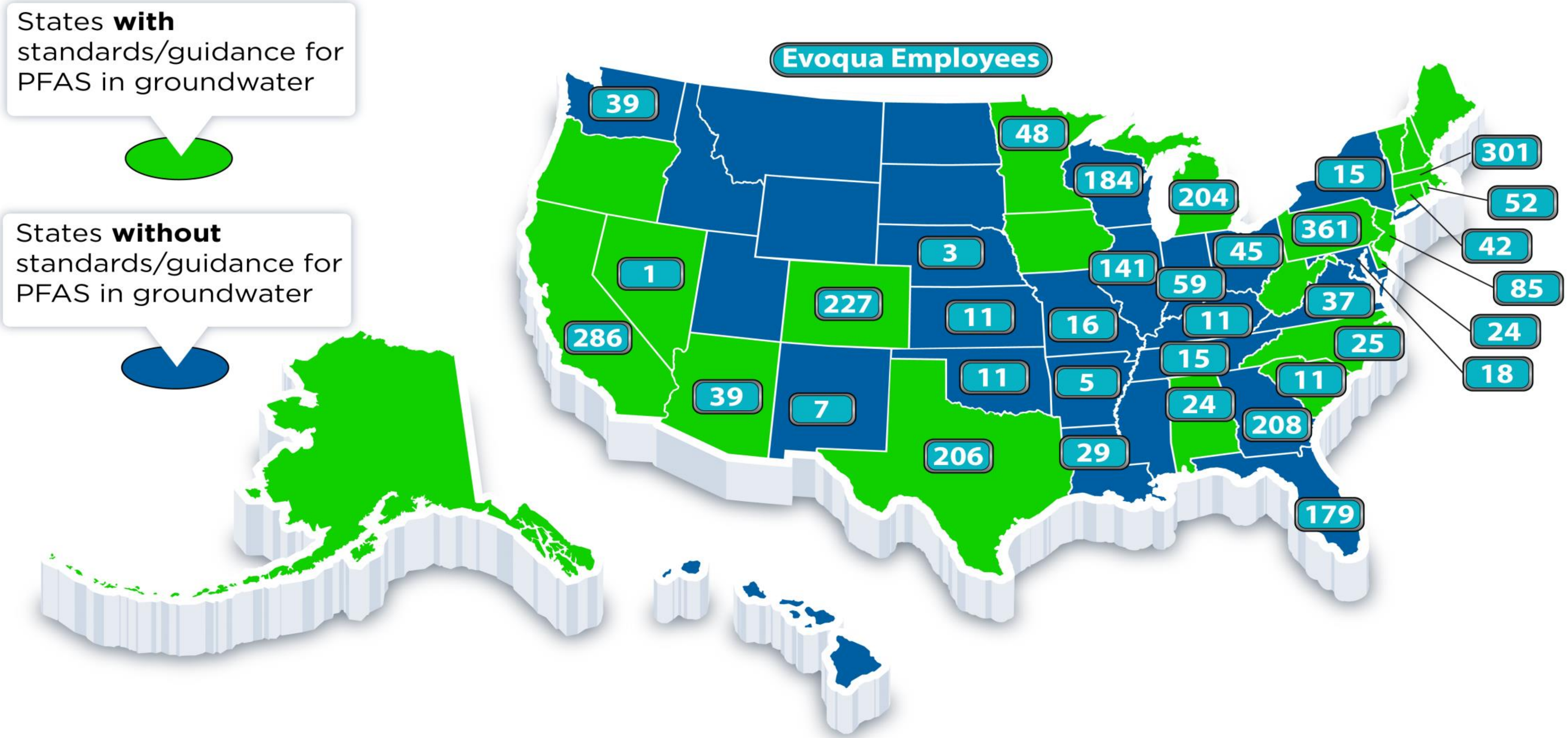
WATER TECHNOLOGIES

Evoqua Employee with PFAS Groundwater Regulations



Environmental Solutions Division

Equipment, media and services group, keeping customers safe, sustainable, and in compliance, by removing organic and inorganic contaminants from water and vapor streams.

Key Contaminants:

- **PFAS**
- TCE/PCE
- MTBE
- 1,4-Dioxane
- Arsenic
- Iron / Manganese
- Perchlorate
- Nitrate
- Chrome VI

…And Many More

Key Evoqua Products:

- Granular Activated Carbon (GAC) and Reactivation Services
- Ion Exchange and Regeneration Service
- Advanced Oxidation Process (AOP)
- Emergency, mobile, and permanent solutions
- Adsorptive Media

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WATER TECHNOLOGIES

SOLUTIONS

PFAS Removal Solutions – Media

Adsorption and Separation

Granular Activated Carbon

- Named Best Available Technology by EPA for organic contaminant removal
- Removes other organic contaminants
- Minimal maintenance

Single Pass Ion Exchange

- Lower EBCT / Higher flowrate
- Small footprint
- No chemicals or liquid waste
- Spent resin can be incinerated
- Minimal maintenance

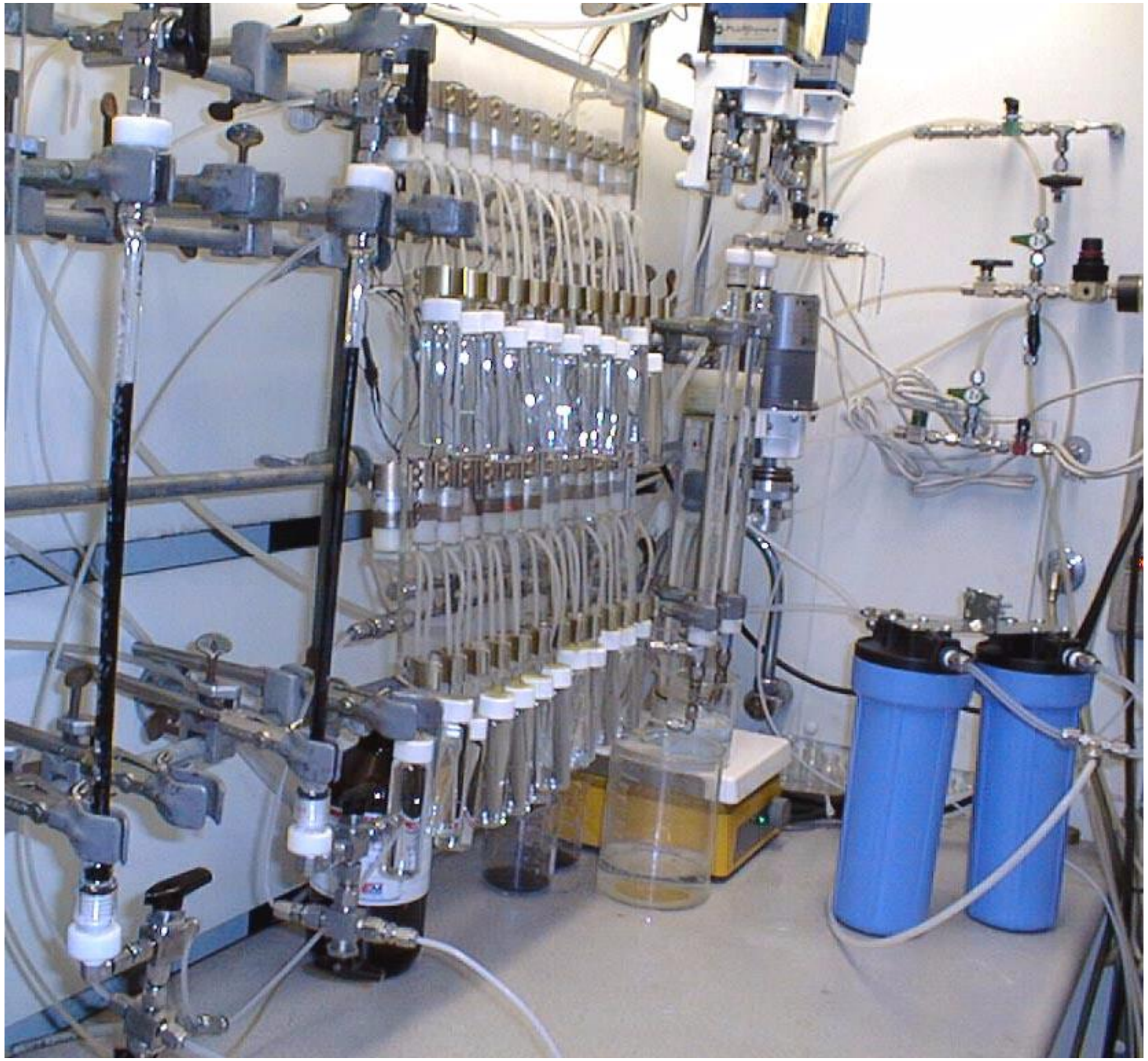
Membranes

- Highly effective
- Removes dissolved solids
- **Concentrates Waste**

EVOQUA WATER TECHNOLOGIES

Rapid Small-Scale Column Test (ASTM D6586) RSSCT

- Prediction of contaminant adsorption on GAC
- Test method outlined and approved by ASTM D28 Activated Carbon Test Methods Committee
- Can simulate months to years of full-scale operation within days to weeks of lab-scale time
- Good comparative method with some predictive ability



evoqua WATER TECHNOLOGIES

Pilot Scale Performance Testing

- Pilot scale can be used to test the effectiveness of the technology for contaminant removal before a full-scale system is installed for community's drinking water.
- Uses small diameter (3" to 6") columns to simulate operating conditions of full scale adsorber.
- Matching hydraulic loading rate and shortening bed depth (e.g. 0.5 full scale) can decrease time to reaching conclusions.
- Requires more time and labor, however pilot studies provide more accurate predictions of bed life in full-scale applications

EVOQUA WATER TECHNOLOGIES

PV-Series High Pressure Liquid Phase Adsorption Systems

Models

PV-500, PV-1000, PV-2000, PV-5000,

PV-10000, PV-30-SYS, PV-48-SYS

- Durable, lined carbon steel vessels
- 500-10,000 lb. GAC media per adsorber
- Suitable for higher pressure (<75 psig) applications
- Flow rates from 25-500 GPM per adsorber
- Applications: groundwater remediation, wastewater treatment, pilot testing, UST cleanup, drinking water and spill cleanup

evoqua
WATER TECHNOLOGIES

HP® Series Liquid Phase Adsorption Systems (ASME code)

Models

HP-810, HP-1020, HP-1220, HP1230, HP1240, HP1560, HP-2000, HP2000SS, IX-48

- Durable, lined carbon steel vessels, ASME Code
- Dual stage system with interconnecting piping
- 10,000 – 60,000 lb. GAC media per adsorber
- 8’, 10’, 12’and 15’ diameter vessels
- Rated to 125 psig (IX-48 rated 100 psig)
- Flow rates from 500 - 1500 GPM per adsorber
- Applications: drinking water, groundwater remediation, food and beverage
- Carbon-Ion Exchange (CIX)

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WATER TECHNOLOGIES

Mobile Units

When your operation cannot be interrupted

- Rapid or emergency response
- Temporary or semi-permanent installation

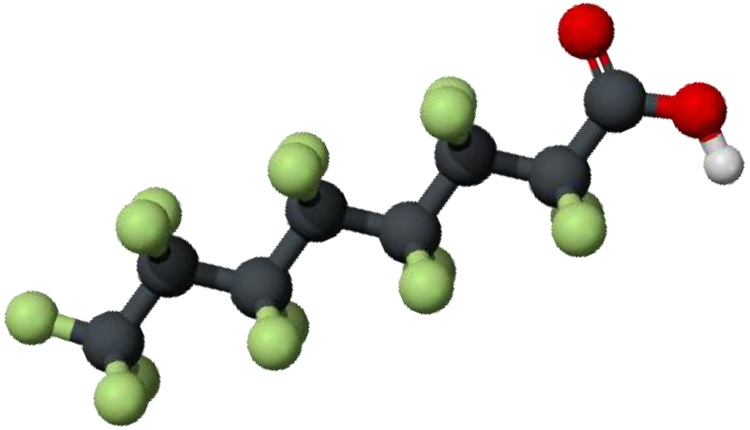
- More than drinking water applications …

    - Construction site water treatment (50-2000+ gpm)
    - Industrial process water
    - Industrial wastewater

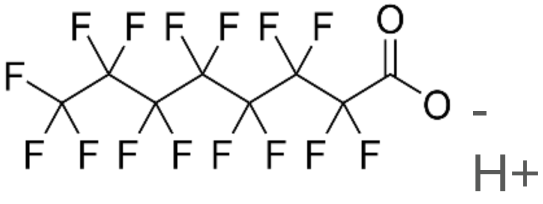
- Footprint: variable / skid-mounted and tailored to site constraints

PFAS – Structure

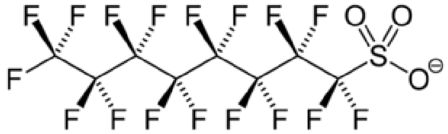
Removal Mechanisms

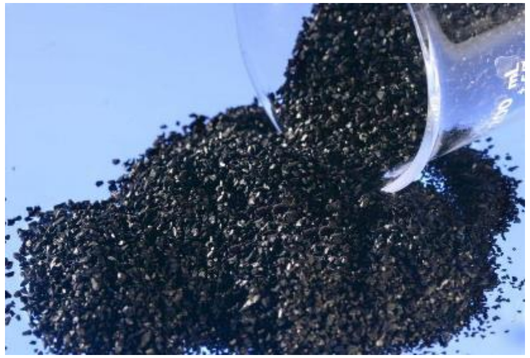


Perfluorooctanoic acid (PFOA)

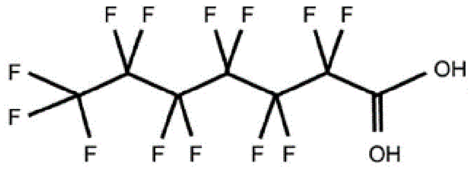


Perfluorooctanesulfonic acid (PFOS)

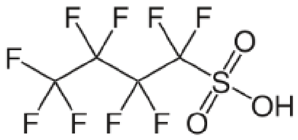




Perfluoroheptanoic acid (PFHpA)

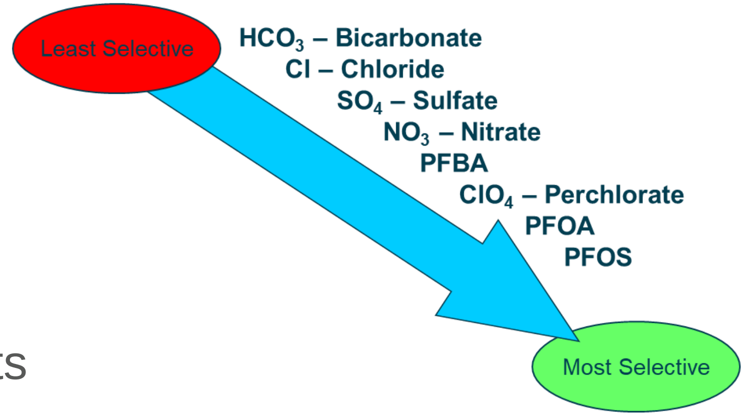


Perfluorobutanesulfonic acid (PFBS)



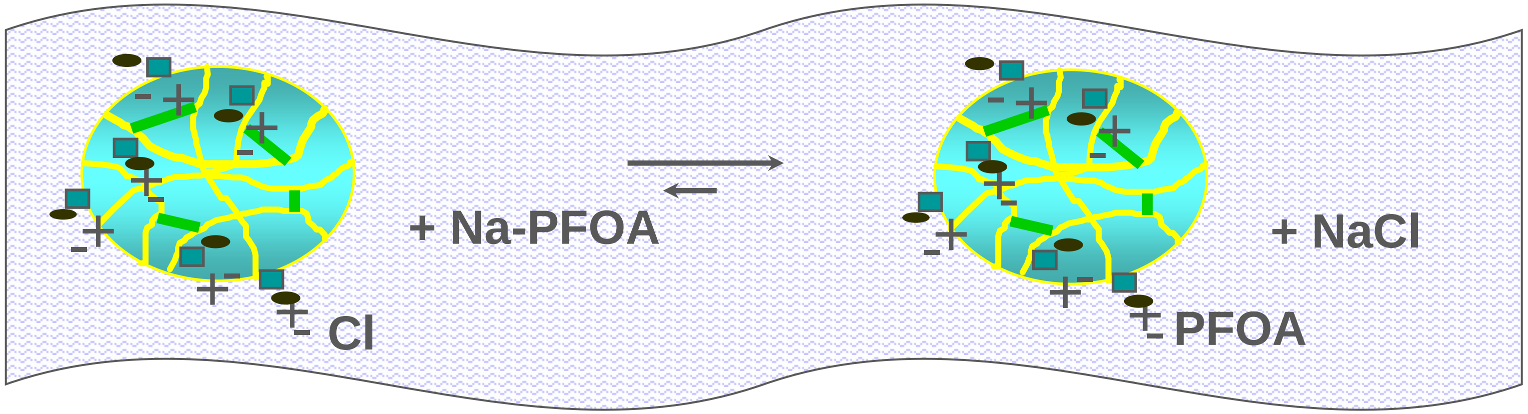
Design Considerations

1. Contaminant profile
2. Contaminant concentration
3. Competitive adsorption
4. Pretreatment Requirements
5. Water flow rate
6. Treatment Targets
7. Footprint requirements
8. Timing



Water Analysis

- Organic contaminants
- PFAS Compounds
- TOC, TDS, Hardness, Alkalinity
- TSS, pH, Nitrates, Sulfates, Chlorides, Iron, Manganese



Approach To Remediation and Emergency Response

Remediation

- Site Investigation
  - Source Determination
  - Plume Size
- Project Team Selection
  - Consultants
  - Contractors
  - Vendors
  - Labs
- Design Considerations?
  - Groundwater/Surface Water
  - Other Contaminants
  - Water Quality
  - Pilot/RSSCT

Emergency Response

- Containment
- Project Team
  - Treatment, Consulting, WDNR
- Testing and QA/QC

CASE STUDIES

Water Treatment at Construction Sites – Midwest Construction Project

- Water tested positive for PFAS, metals and other inorganics
- Solutions tapped directly at the well head
- Mitigating PFAS, arsenic, mercury, others
- Cleaned effluent discharged into municipal sewer

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WATER TECHNOLOGIES

Midwest Automotive Manufacturer

- After a fire had been extinguished with AFFF the client had to manage 500,000 gallons of impacted fire water

- Evoqua modeled a treatment scheme using GAC We also partnered with Frac Tank & Pump Supplier to manage the storage of treated water

- Water was successfully treated but the local POTW had initial push back due to 1.3 ppt of PFHxA.

- QA/QC review concluded it was lab error.

- Water Recycled for Fire Water Use

- Fire management plan now includes capturing of fire water for treatment.

Wrap-Up

Portfolio – Comprehensive Solutions

Unbiased Technology, Start to Finish

- Temporary mobile assets for rapid deployment providing treatment today
- Treatability studies – identifying the optimal technology train for each customer
- Permanent solutions
- Servicing network – 85% of the US pop. within 2 hours

EVOQUA
WATER TECHNOLOGIES

And Now….Time For Your Questions

Reach out to us:

Geoff Pellechia

Geoffrey.Pellechia@evoqua.com

(207) 272-7118

Dillon Gilbow

Dillon.Gilbow@evoqua.com

(847) 452-5522