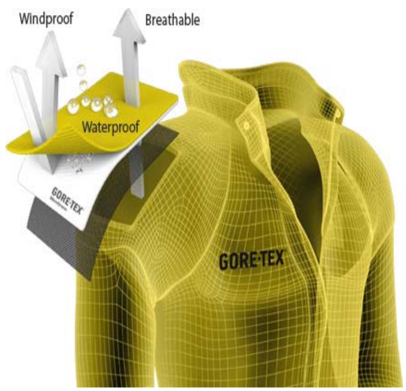
# PFAS U: A compilation of ex-situ treatment projects at Colorado School of Mines

Conner Murray, Charlie Liu, R. Eric Marshall, Tzahi Cath, Chris Bellona
Department of Civil and Environmental Engineering
Colorado School of Mines

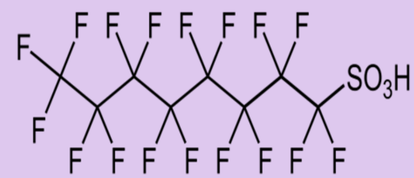
# Perfluoro and polyfluoroalkyl substances (PFAS) present in many household products



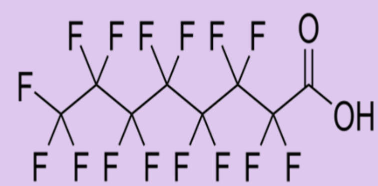




Thousands of PFAS, but PFOA and PFOS most commonly mentioned



Perfluorooctane sulfonate (**PFOS**)

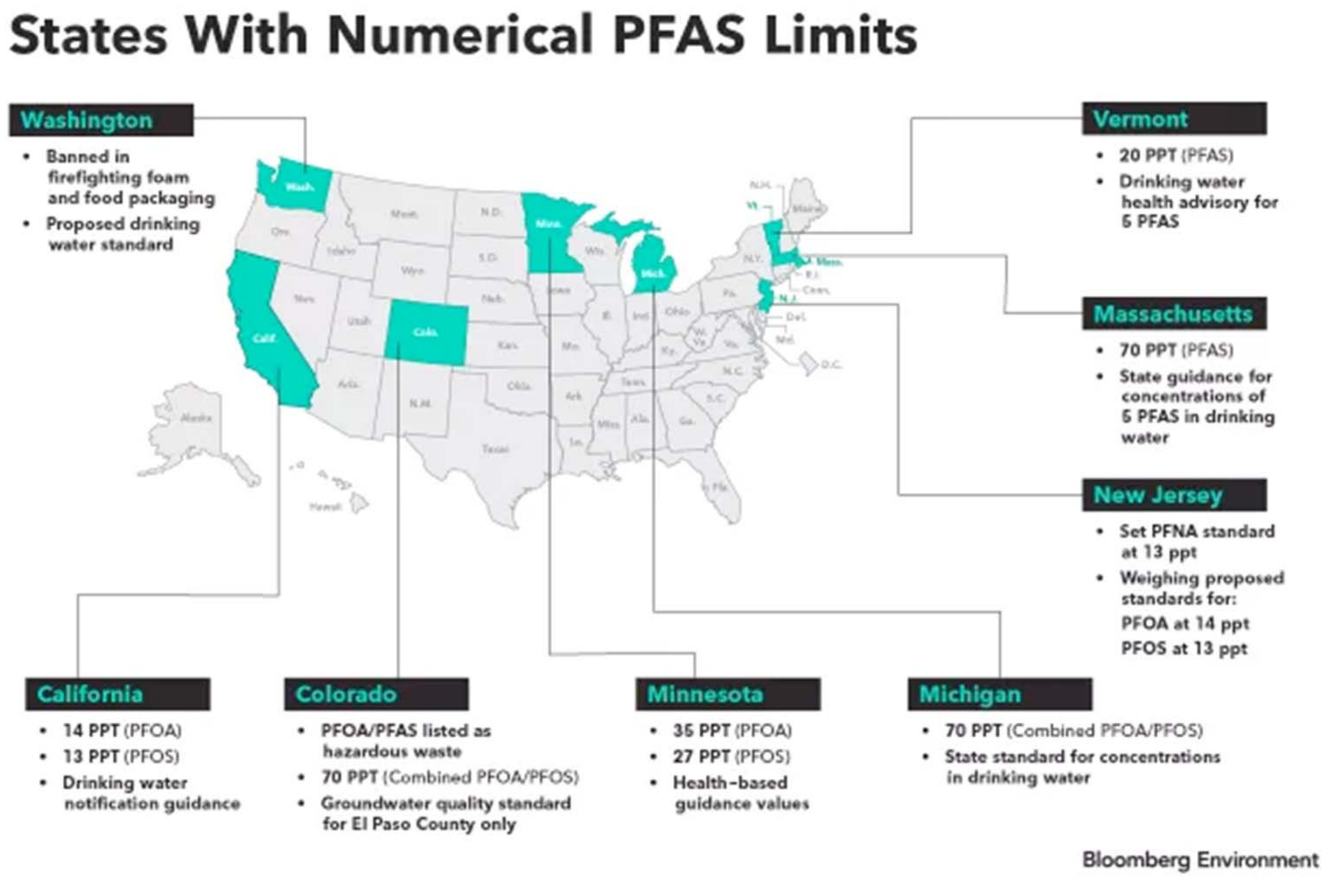


Perfluorooctanoic acid (**PFOA**)

# A major source of contamination is historical use of AFFF (Aqueous Film-Forming Foam)

- **AFFF** = mixture of fluorochemical and hydrocarbon surfactants used to rapidly extinguish fuel fires
- Extensive releases from air bases and airports due to use in fire training exercises

## In 2016 EPA issued stringent lifetime health advisory levels (HALs)

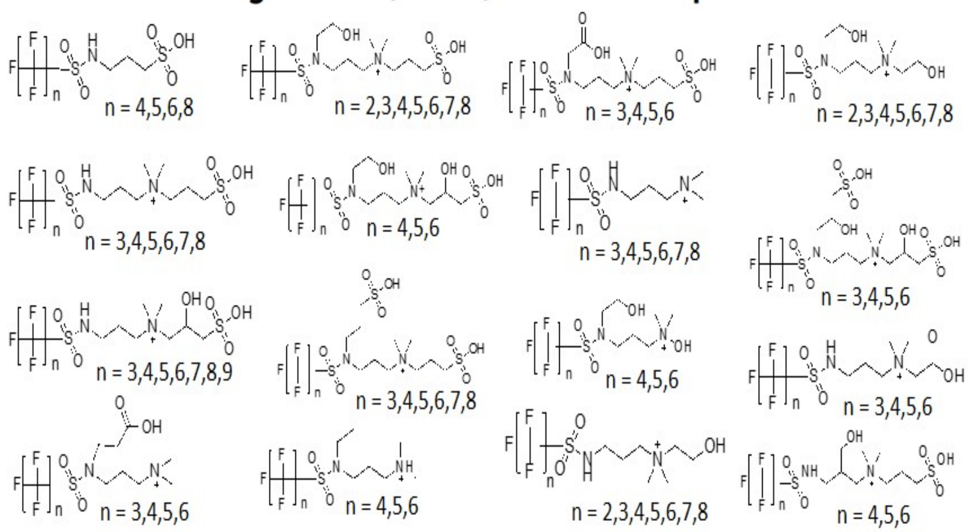


# PFAS are lot more complex than just PFOS and PFOA

Environmental Science & Technology
Article

Krista A. Barzen-Hanson,[†] Simon C. Roberts,[∇,‡] Sarah Choyke,[§] Karl Oetjen,[‡] Alan McAlees,[‖] Nicole Riddell,[‖] Robert McCrindle,[⊥] P. Lee Ferguson,[§] Christopher P. Higgins,[*,‡] and Jennifer A. Field[*,#]

**Discovery of 40 Classes of Per- and Polyfluoroalkyl Substances in Historical Aqueous Film-Forming Foams (AFFFs) and AFFF-Impacted Groundwater**



# Why are PFAS such a problem?

- Highly persistent
  - carbon-fluorine bond
  - hydrophobic and oleophobic
  - structural variability
- Low Concentrations
  - Often ng/L ranges = 1 grain of sand in a swimming pool

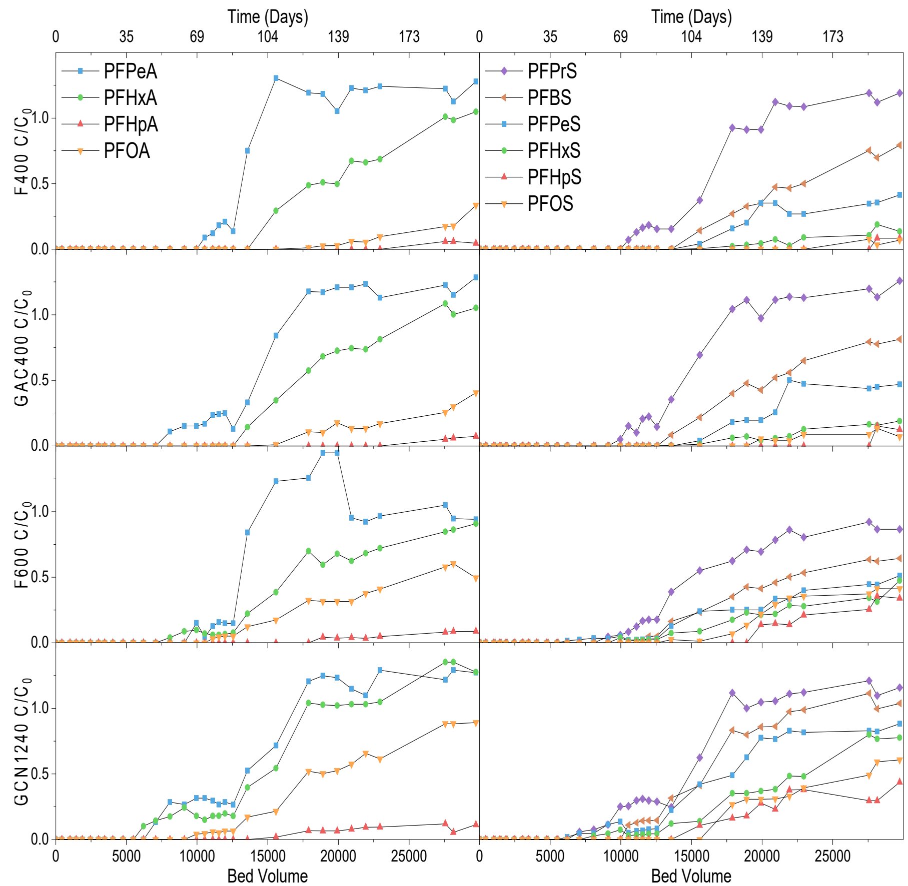
- Common Treatment Approaches:
  - Granular Activated Carbon (GAC)
  - Ion-Exchange Resin (IX)
  - High Pressure Membranes (NF&RO)

- Emerging Technologies:
  - Super-fine powder activated carbon
  - Novel adsorbents (organoclays, polymers)
  - Destructive technologies

# Past, Current, and Future PFAS Studies

| Project Title | Sponsor | Technologies | Water Type(s) |
|---|---|---|---|
| Pilot-scale evaluation of adsorbents | City of Fountain, CO | GAC, IX, IX-regeneration | GW |
| NF/RO with UV-reductive concentrate treatment | AFCEC | NF, RO, UV-bisulfite | GW |
| FLUORO-SORB® adsorbents | CETCO | Modified clay, GAC, IX | GW |
| Sub-micron PAC with ceramic microfiltration | CSM/ESTCP | sPAC, Ceramic MF | GW, AFFF |
| Life-cycle comparison of ex-situ treatment technologies | ESTCP | GAC, IX, sPAC | GW, AFFF |
| Removal of short-chained PFAS | Water Research | GAC, IX, NF/RO | GW, SW |
| Sustainability of IX regeneration | SERDP | IX, IX Regeneration | GW, AFFF |

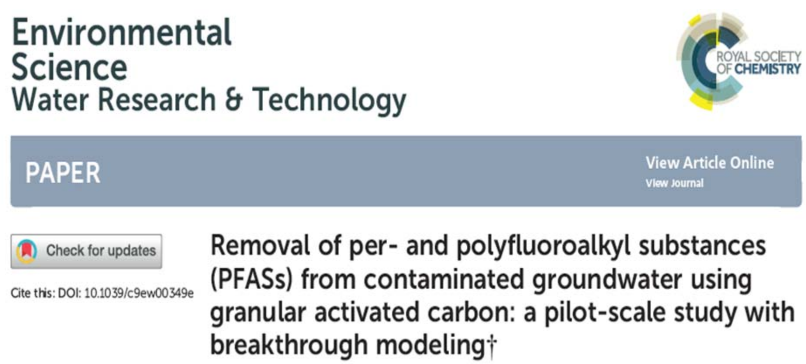
# GAC study: Fountain, Colorado



# GAC study: Fountain, Colorado

<u>Conclusions</u>:

- GAC product selection is extremely important
- Higher fraction of mesoporous structure improved GAC performance
- Short-chain PFAS breakthrough occurred relatively quickly
- PFOS and PFOA breakthrough around 30,000 bed volumes
- Best performing GAC (F400) installed at full-scale facility



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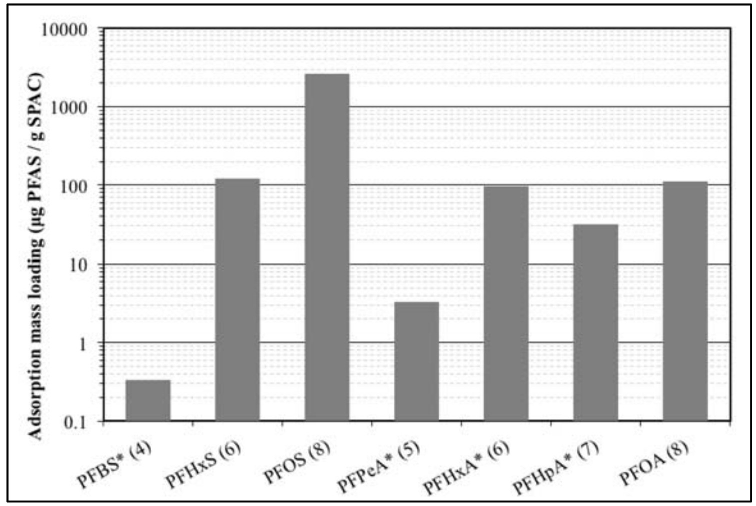
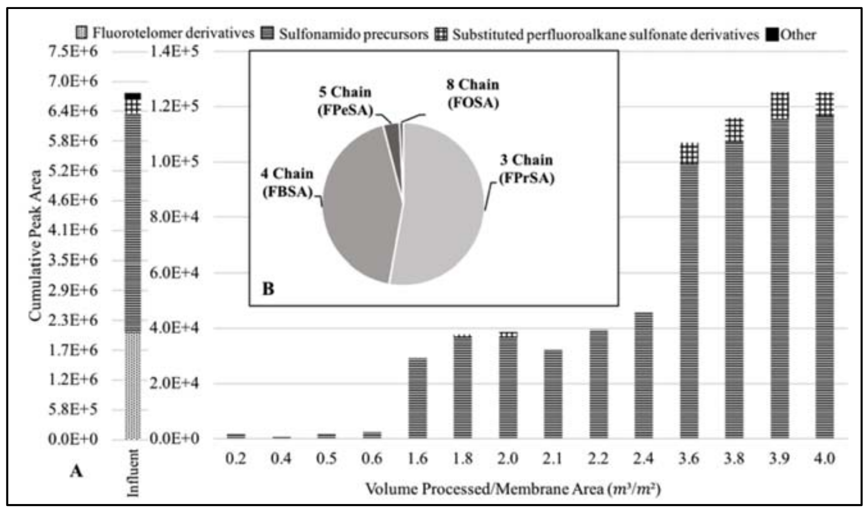
Removal of per- and polyfluoroalkyl substances (PFASs) from contaminated groundwater using granular activated carbon: a pilot-scale study with breakthrough modeling†

# SPAC /MF

50th Anniversary
AQUA-AEROBIC SYSTEMS, INC.
A Metawater Company
1969 – 2019

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Conclusions:

- SPAC has 480x higher capacity for PFAS compared to GAC
- Breakthrough followed similar trend as GAC with hort-chain PFAS breaking through more rapidly
- May be option for PFAS contaminated water requiring filtration
- Recently obtained DoD funding (ESTCP) to demonstrate technology

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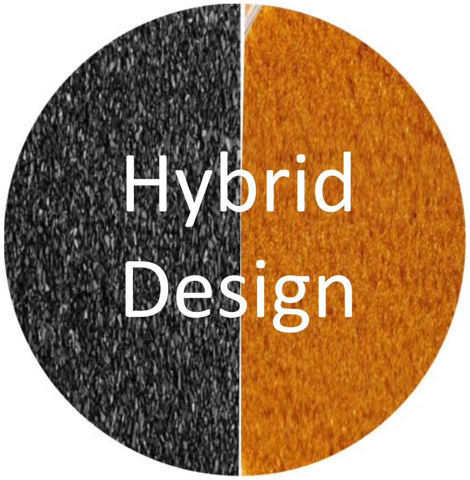
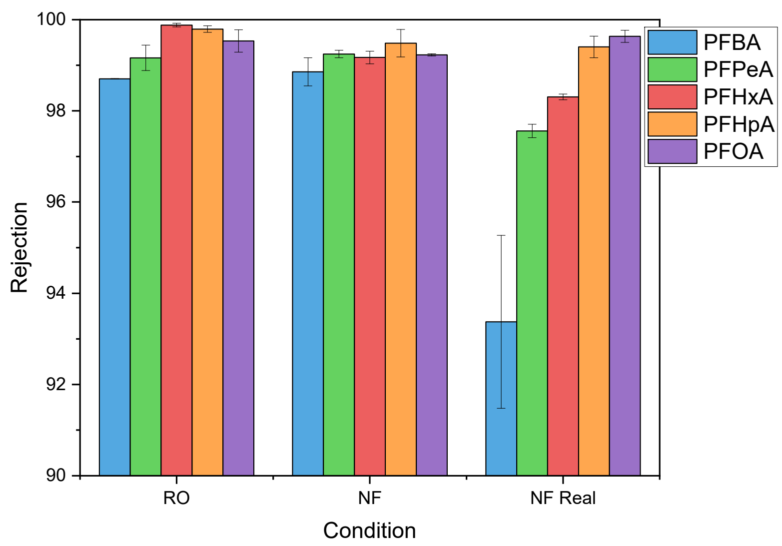
Removal of per- and polyfluoroalkyl substances using super-fine powder activated carbon and ceramic membrane filtration



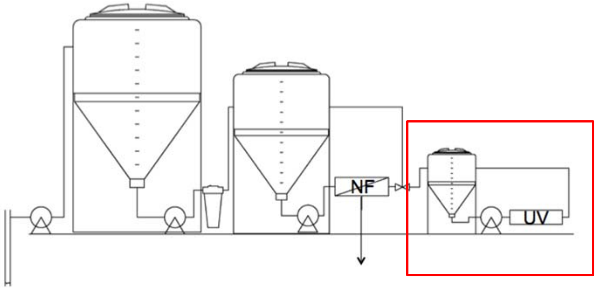

**Project Objectives**

1. Develop a robust testing system for adsorption of PFAS contaminated water
2. Better understand competitive adsorption relationships between water quality parameters
3. Assess PFAS adsorption potential and characterize new adsorbents
4. Evaluate hybrid treatment designs with GAC, IX resins and clay adsorbents.

# Nanofiltration (NF) or reverse osmosis (RO) with UV-bisulfite concentrate treatment



# Nanofiltration (NF) or reverse osmosis (RO) with UV-bisulfite concentrate treatment

# Nanofiltration (NF) or reverse osmosis (RO) with UV-bisulfite concentrate treatment

Conclusions:

- RO and NF membranes are robust barriers to a wide variety of PFAS
- UV-bisulfite treatment promising but requires long-term evaluation
- NF offers operating benefits over RO particularly for UV-bisulfite process
- Concentrate management is critical for NF/RO in PFAS treatment

# Treatment Selection

## Database Development

- Compiling affiliated project data for variety of treatment processes
- Searching literature
- Collaborating with USEPA efforts to produce similar tool

| | | | | |
|---|---|---|---|---|
| Sorption of perfluorinated compounds from contaminated water to activated carbon | 2010 | Bench Isotherm | 32 N6589900 E596499 | INTL |
| Q Yu et al (Water Research) | 2009 | Bench Isotherm | DI-Spike | N/A |
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| Ochoa-Herrera and Sierra-Alvarez (Chemosphere) | 2008 | Bench Isotherm | DI-Spike | N/A |
| Mines Liu IX | 2019 | Pilot | Fountain | CO |
| Mines Liu GAC | 2018 | Pilot | Fountain | CO |
| Mines Marshall CETCO | 2019 | Bench Column | Wurtsmith | MI |
| Mines Marshall GAC | 2019 | Bench Column | Wurtsmith | MI |
| Mines Liu UV Bisulfite | 2019 | Bench | Fountain | CO |
| Mines Murray SPAC | 2018 | Pilot | DI-Spike | CO |
| Mines Murray GAC | 2018 | Bench Column | Fountain | CO |
| Ochoa-Herrera and Sierra-Alvarez (Chemosphere) | 2008 | Bench Isotherm | DI-Spike | N/A |
| | | | | |
| More to come... | | | | |

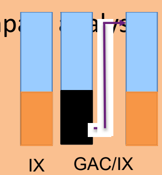
Short chain (PFBA, PFPeA, PFBS) | PFOS Technologies Comparison | PFOA Technologies Comparison | PFHxS Technologies Comparison | Sheet

## Scaling Treatability

- Evaluating scalability of lab-scale adsorption data
- RSSCT results comparison with lab- and pilot-scale data
- Development of a robust laboratory testing plan for generating data necessary for life cycle cost and impact analysis

## Treatment Scenario Testing

- Bench-mark testing of best treatment approaches under various treatment scenarios for treatment database
- Treatability data to be used for life




## LCA and Toolbox Development

- Develop cost and impact metrics for treatment processes and scenarios
- Integrate results into a toolbox format including treatability database

# What's next?

- PFAS problem is rapidly evolving
- Significant amount of research being conducted on PFAS removal – no silver bullet process
- Unless something magical happens – need cost effective (and sustainable?) solutions
- Moving into other water treatment arenas (e.g., industrial effluent, wastewater, landfill leachate)

# Questions and Contact Information

Conner Murray: ccmurray@mymail.mines.edu
Chris Bellona: cbellona@mymail.mines.edu

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