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From Traditional to Novel Adsorbents: Do Specific Water Matrix Effects Impact PFAS Treatment?

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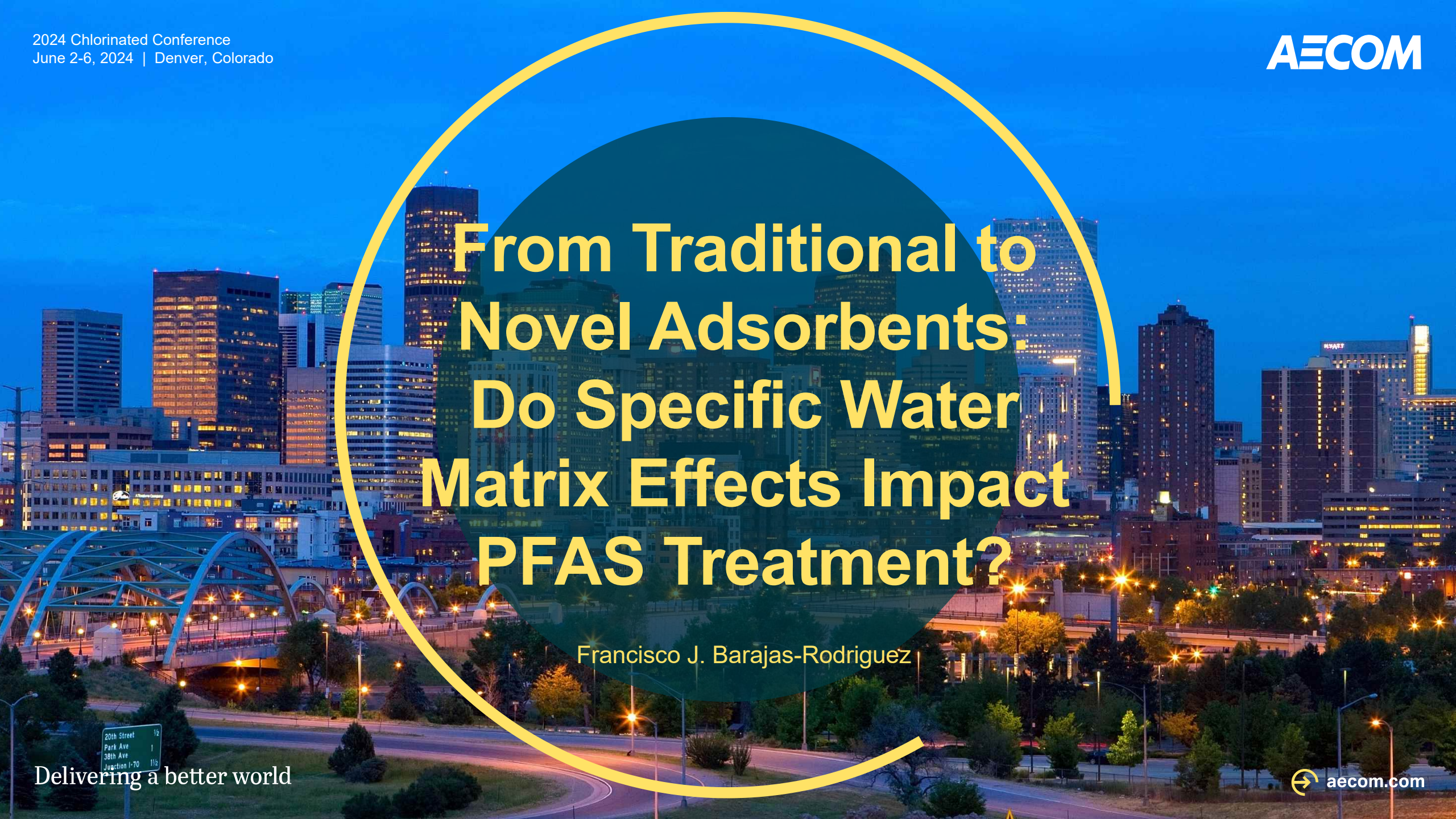

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Agenda

- 01 Introduction and Study Goals
- 03 Technical Approach
- 04 Results
- 05 Conclusions

Acknowledgments

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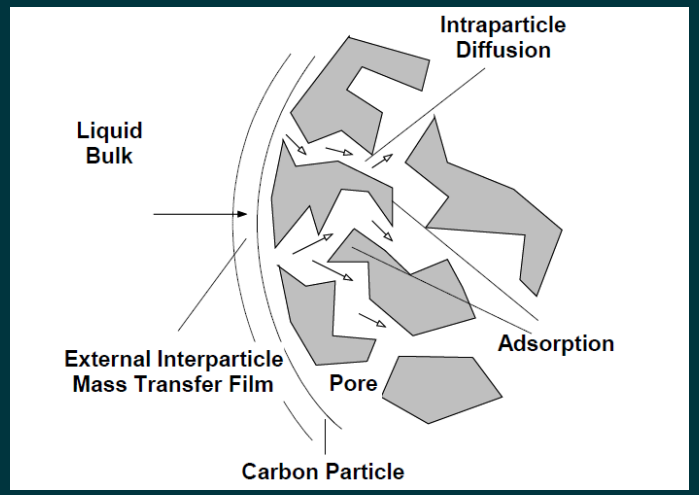
01

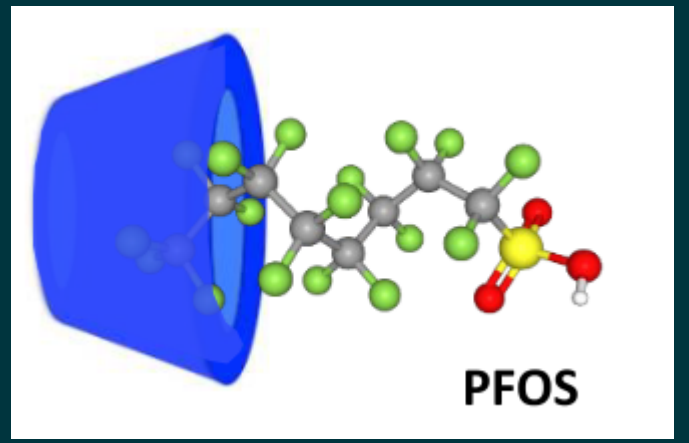
Introduction

Introduction

- PFAS removal from water via adsorption
- Traditional adsorbents
  - Granular Activated Carbon (GAC), Ion Exchange Resins (IXR)
- Novel adsorbents
  - Cyclodextrins, modified bentonites
- Adsorbent selection
  - Costs and implementability
  - Specific water matrix interactions → effect on specific throughput
- Importance of treatability testing



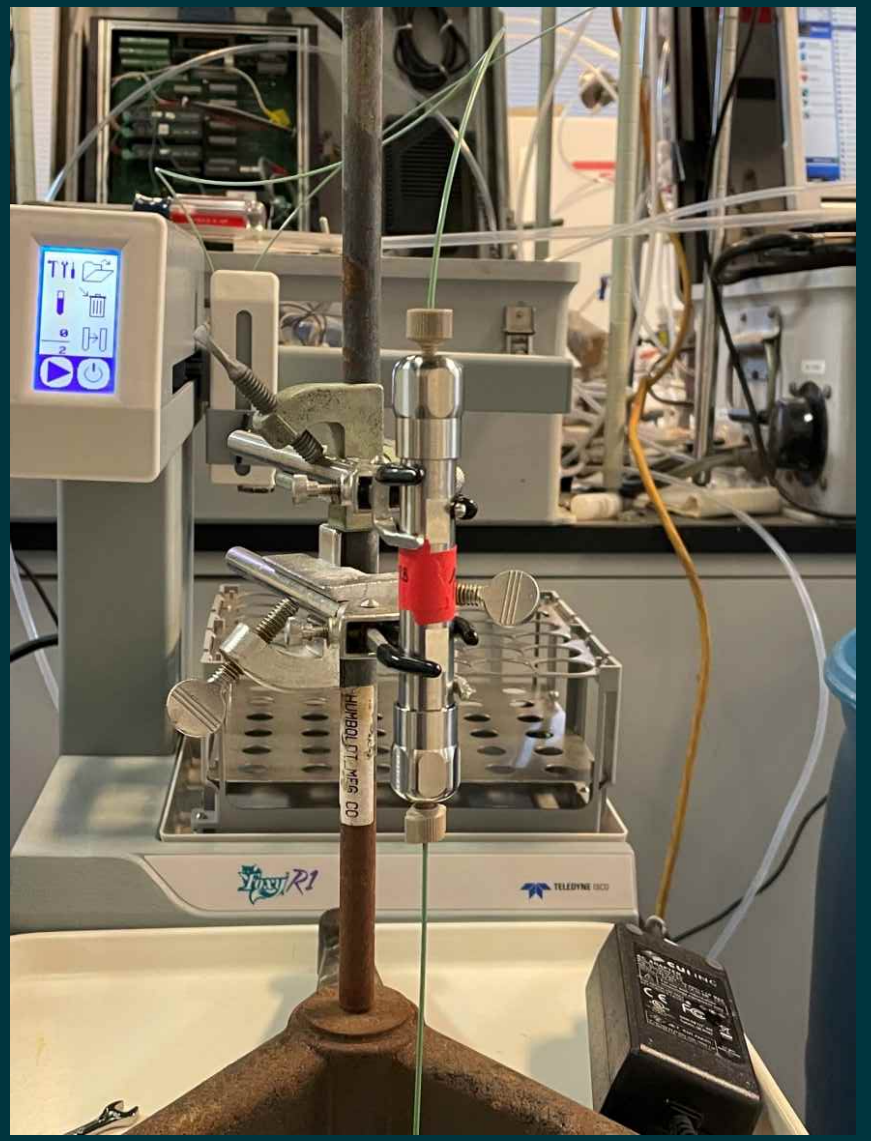
GAC Adsorption
Armenante (1991)



Cyclodextrin Adsorption
Ling (2021)

Study Goals

- Compile empirical data for PFAS adsorption from multiple treatability studies
- Compare adsorption capacities from different medias derived from batch isotherm tests
- Compare longevity from different medias from rapid small-scale column tests (RSSCTs)
- Gain insights on PFAS treatability by traditional and novel adsorbents in different water matrices with varied PFAS and total organic carbon (TOC) concentrations.



Introduction – Case Studies

- Five case studies, evaluating:
  - Three GACs
  - Three single use IXRs and one regenerable IXR
  - Commercial cyclodextrin
  - Surface modified bentonite clay
- Studies 1 and 2
  - High PFAS concentration in groundwater.
- Study 3
  - PFAS removal by the non-commercial cyclodextrin in wastewater.
- Study 4
  - PFAS removal in groundwater for drinking water purposes.
- Study 5
  - Seven adsorbents in two water matrices, untreated groundwater and air-stripped groundwater, from Hanscom Air Force Base (AFB).

02

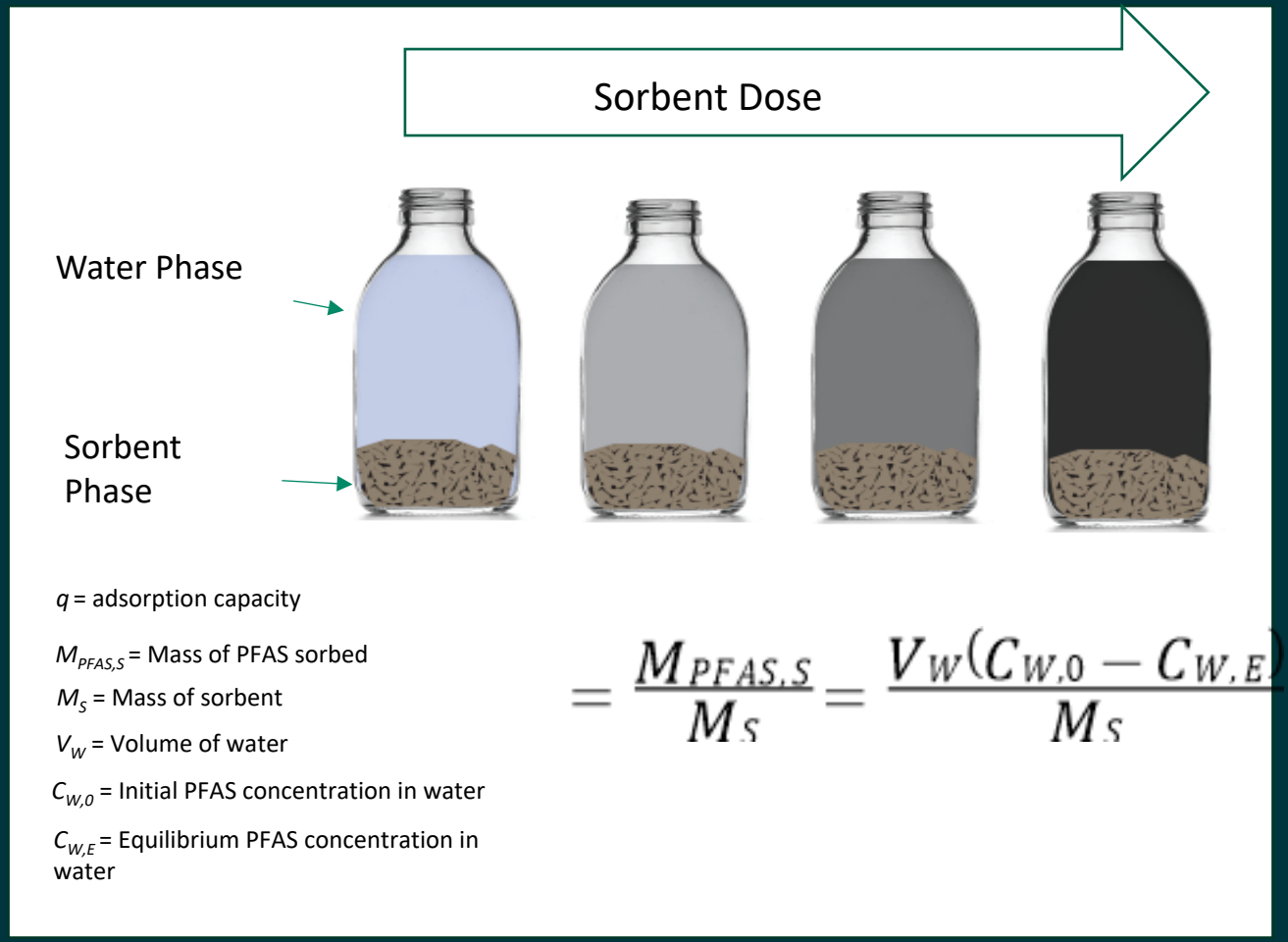
Technical Approach

Technical Approach – Case Studies

Study	Water Matrix	Adsorbents Tested	Tests Conducted	Application	Total PFAS (ng/L)	TOC (mg/L)
1	Groundwater	GAC (1) and IXR (4)	Isotherms and RSSCTs	Remediation	45,000	1.99
2	Groundwater	GAC (2), IXR (4) NA (2)	Isotherms and RSSCTs	Remediation	15,000 - 19,000	11
3	Municipal Pretreated Wastewater	GAC (1) and NA (1)	RSSCTs	Research Wastewater	500	400
4	Groundwater	GAC (2) and IXR (2)	RSSCTs	Drinking Water	42 - 220	0.85 - 1.90
5	Groundwater and Air-Stripped Groundwater	GAC (3), IXRs (2), and NA(2)	RSSCTs	Remediation	162-242	1.8 - 18

Technical Approach – Batch Isotherms

- Batch isotherm tests for two water matrices with low (Study 1) and high (Study 2) TOC
- Contact time of 48 hours
- Evaluate adsorption capacity under equilibrium condition
- Vary sorbent to contaminant ratio
  - Varied sorbent doses



Schematics of experimental set up for batch isotherm tests

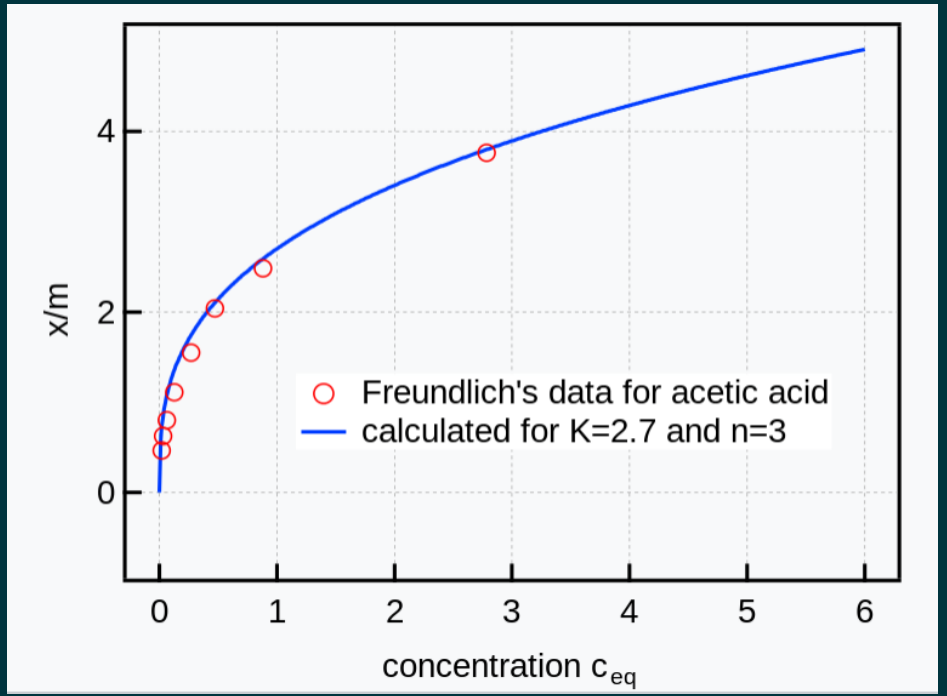
Technical Approach – Batch Isotherms

- Fit data to Freundlich to predict adsorption capacities under multiple initial or influent concentrations
- Freundlich parameters
  - n= system heterogeneity factor, usually > 1.
  - K = adsorption capacity factor, higher K → higher adsorption capacities

Nonlinear form $q_e = KC^{1/n}$

Linear form $\log(q_e) = \log K + \frac{1}{n}\log C$

q_e = adsorption capacity
C = equilibrium concentration



Example of an isotherm curve following the Freundlich model showing parameters K and n for acetic acid. Freundlich, Herbert (1907). " Über die Adsorption in Lösungen." Zeitschrift für Physikalische Chemie – Stöchiometrie und Verwandschaftslehre. 57 (4), 385–470

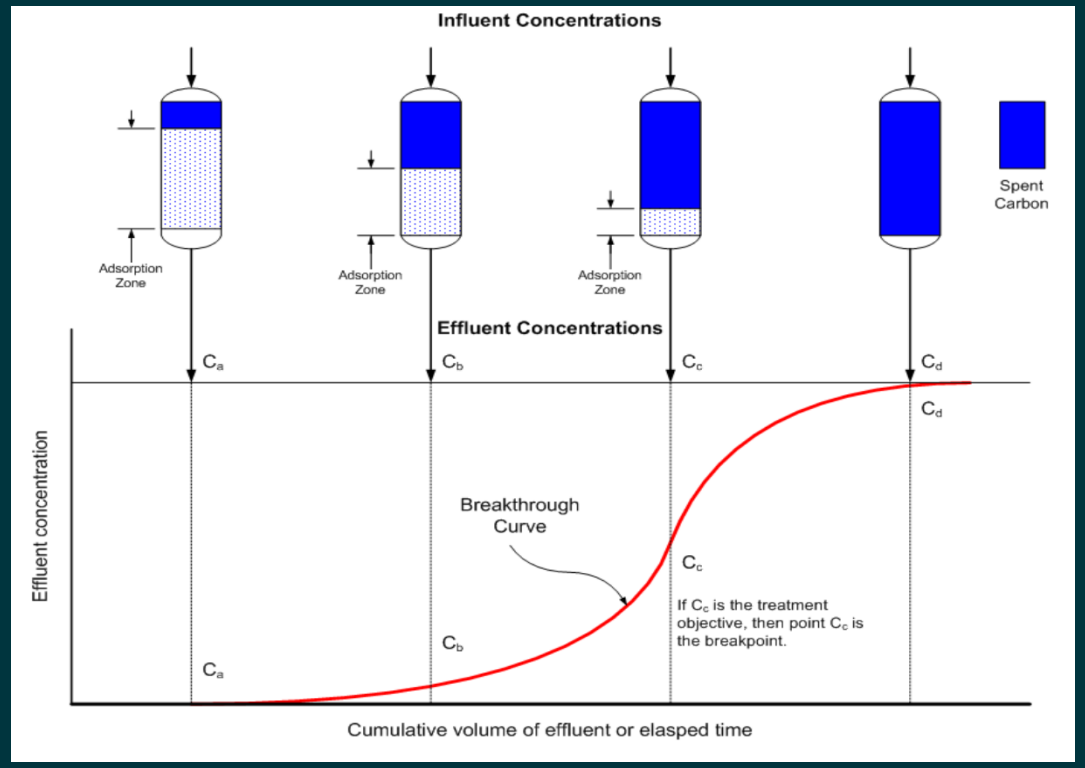
Technical Approach – RSSCTs

- Evaluate PFAS removal under flow-through conditions
- Small columns simulate thousands of bed volumes in days
- Scaling approach per ASTM D6586 method
- Obtain specific throughput → volume of water treated per mass of sorbent media

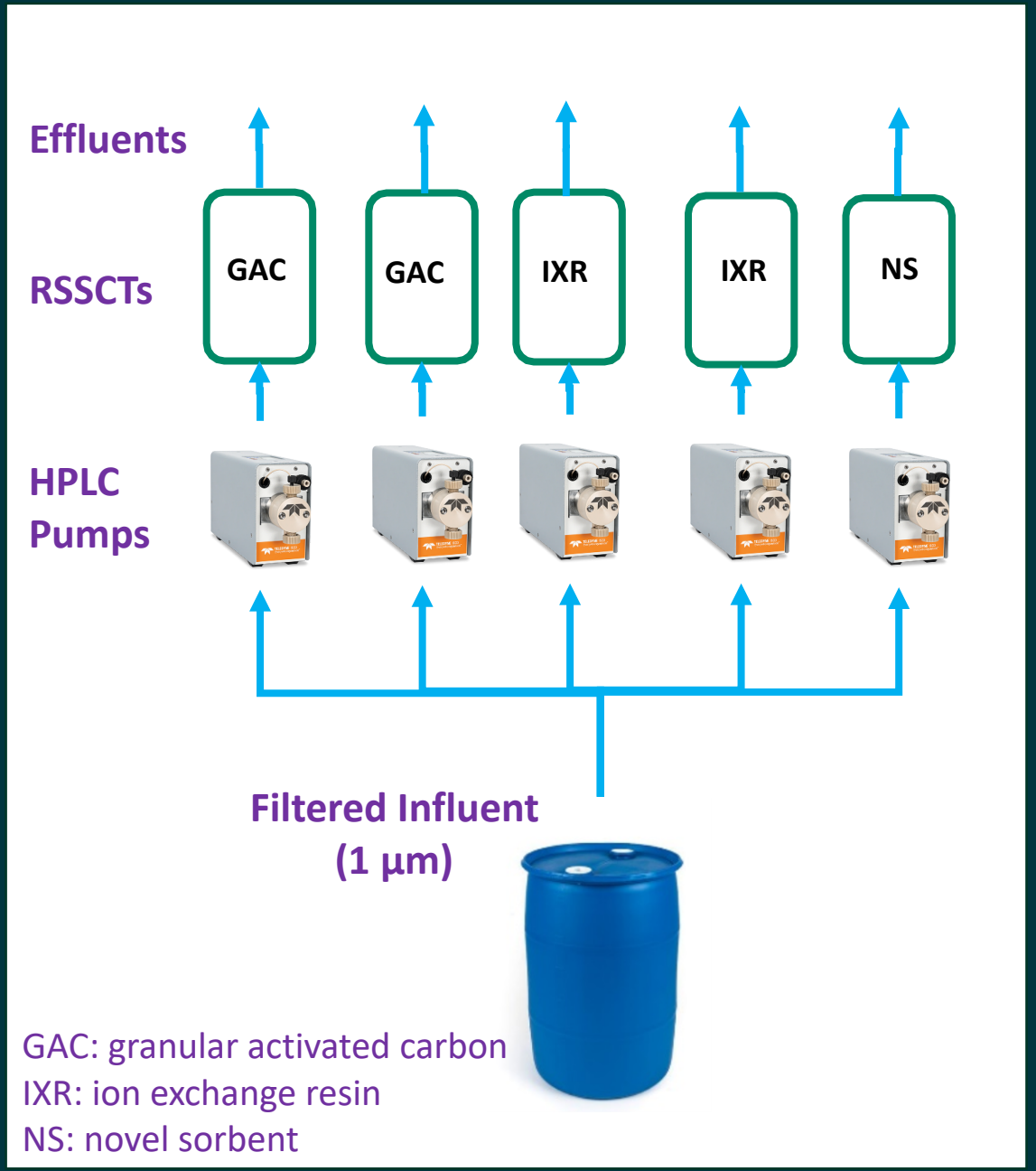
RSSCT apparatus for Case Study 5, Hanscom Air Force Base Treatability Study.

Technical Approach – RSSCTs

- Evaluate breakthroughs simultaneously
- Test > 100,000 bed volumes



https://www.thewastewaterblog.com/activated-carbon



GAC: granular activated carbon
IXR: ion exchange resin
NS: novel sorbent

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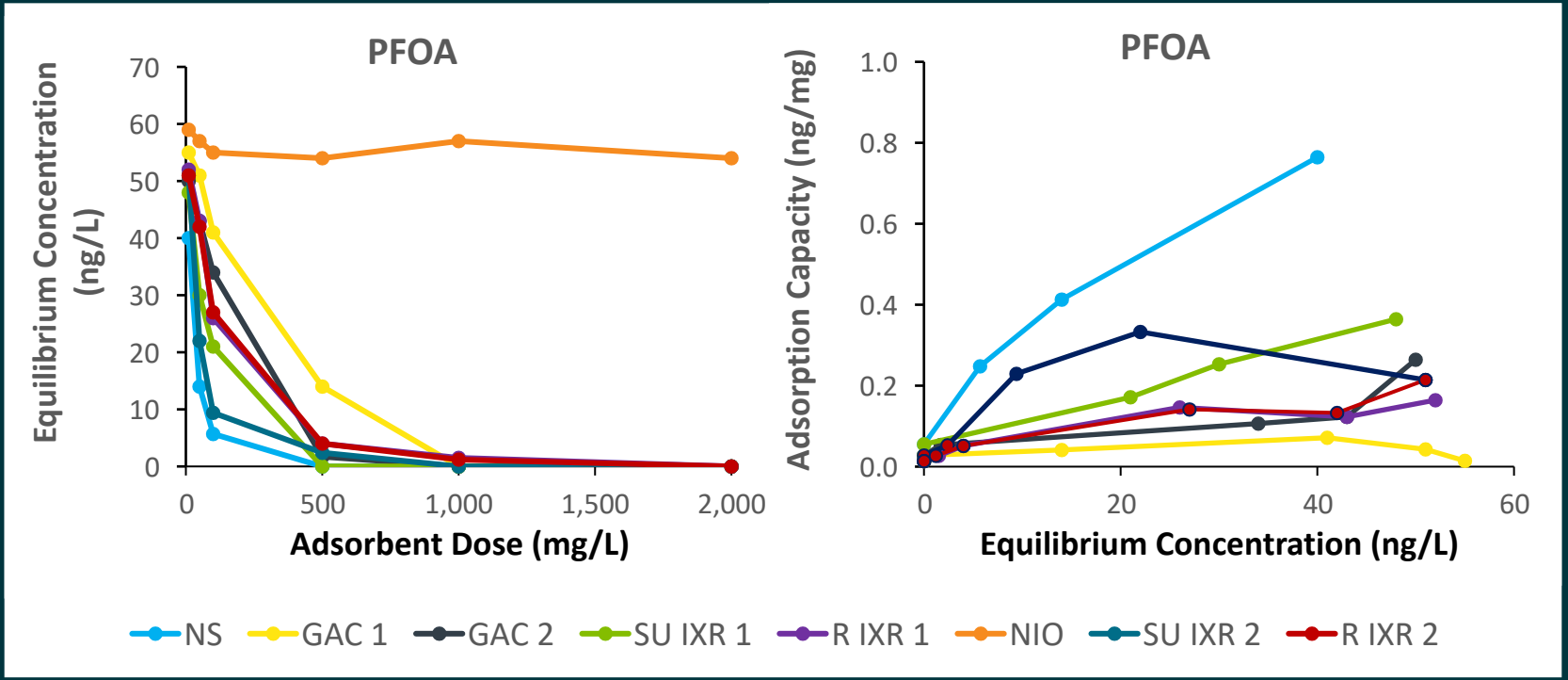
Results – Batch Isotherms

- Highest adsorption capacities : cyclodextrin and modified bentonite clay
- GAC → lowest adsorption capacities
- Maximum adsorption capacity → initial PFAS concentration; consider Freundlich parameters
- Cyclodextrin not affected by TOC (Study 2)



Batch isotherm dose response (left) and adsorption capacity (right) for PFOA with adsorbents tested during Study 2.

Results – Batch Isotherms

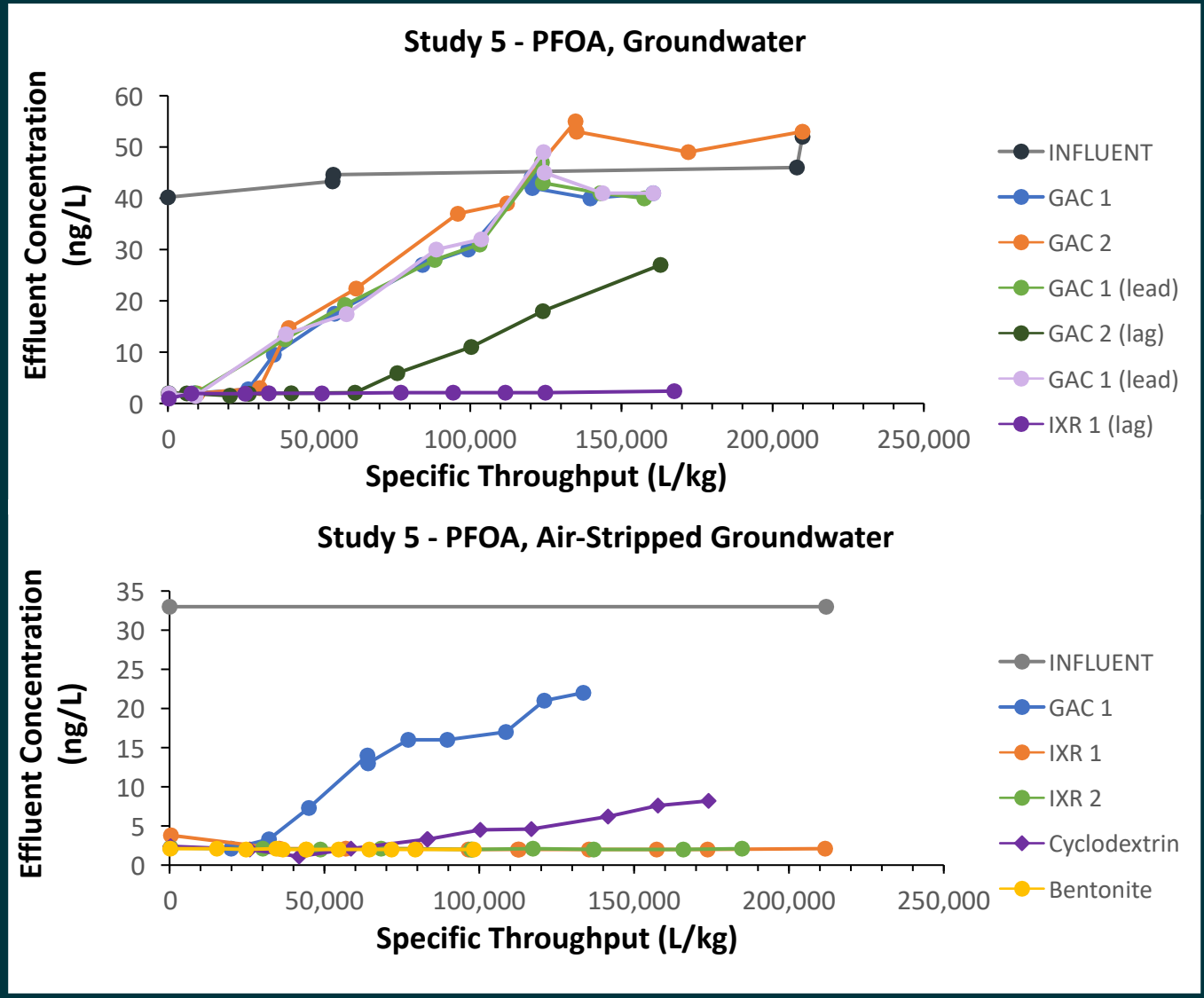
- Adsorption capacities and Freundlich parameters are different among water matrices, mainly due to different TOC
- This highlights the importance of bench-scale tests

Study	GAC 1	GAC 2	SU IXR 1	R IXR 2	SU IXR 1	R IXR 2	Cyclodextrin
Maximum Adsorption Capacities for PFOA (ng/mg)							
1	25.40	NA	32.60	NA	36.20	10.20	NA
2	0.07	0.26	0.36	0.16	0.33	0.21	0.76
Freundlich Parameter K							
1	1.04	NA	0.71	NA	0.85	0.54	NA
2	0.02	0.024	0.028	0.019	0.024	0.019	0.031
Freundlich Parameter n							
1	2.72	NA	1.99	NA	2.18	3.18	NA
2	3.71	1.93	1.52	1.69	1.34	1.65	1.04

GAC is granular activated carbon; R IXR is regenerable ion exchange resin, SU IXR is single use ion exchange resin, NS: novel sorbent (cyclodextrin), and NIO is nano-scale iron oxide.

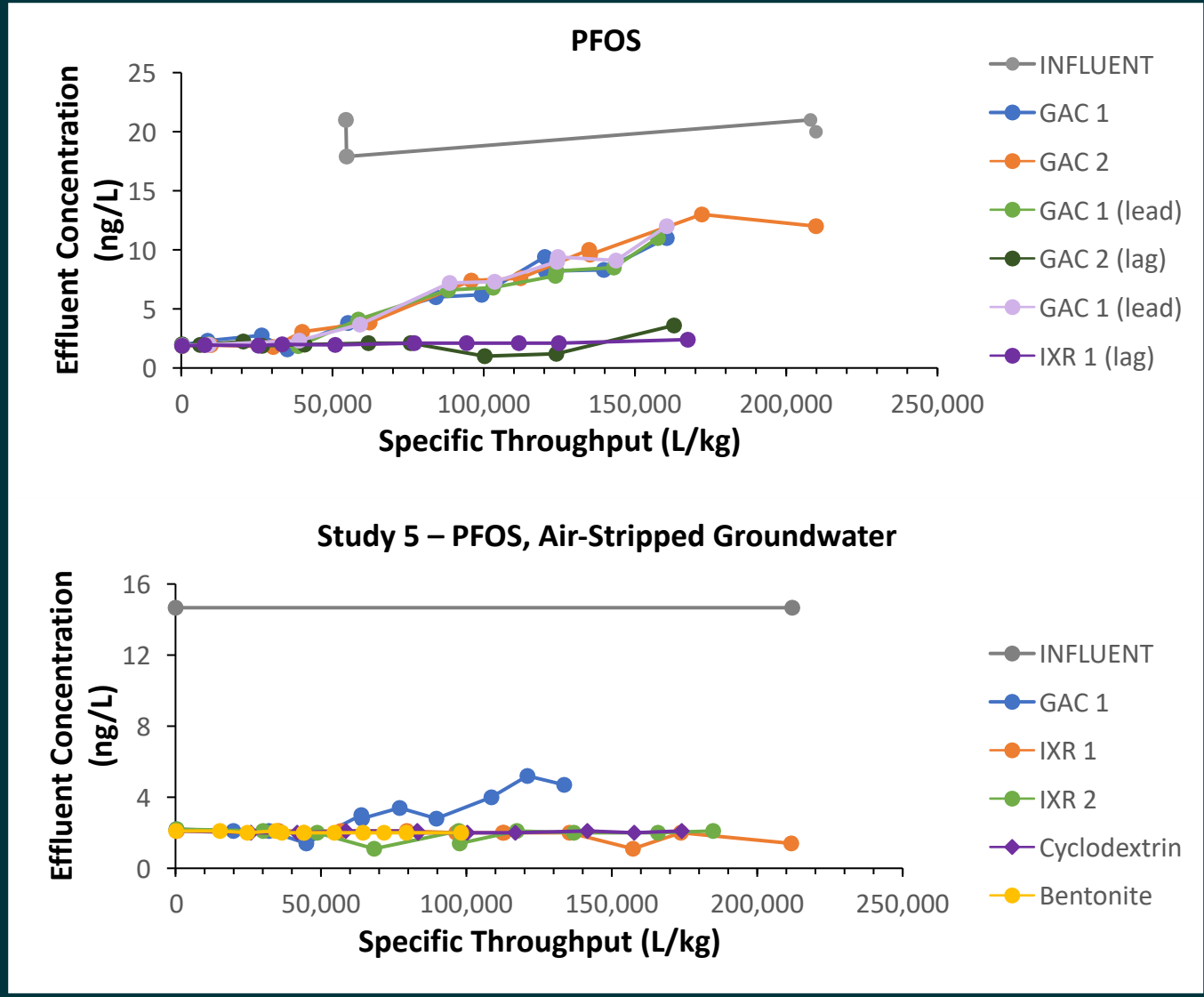
Results – RSSCTs Study 5 PFOA

- Determined breakthroughs for effluent samples
- Specific throughput = liters of water treated per Kg of media
- IXRs outperform GACs and cyclodextrin
- Bentonite performance similar to IXRs
- Cyclodextrin is kinetically limited, needs longer contact time



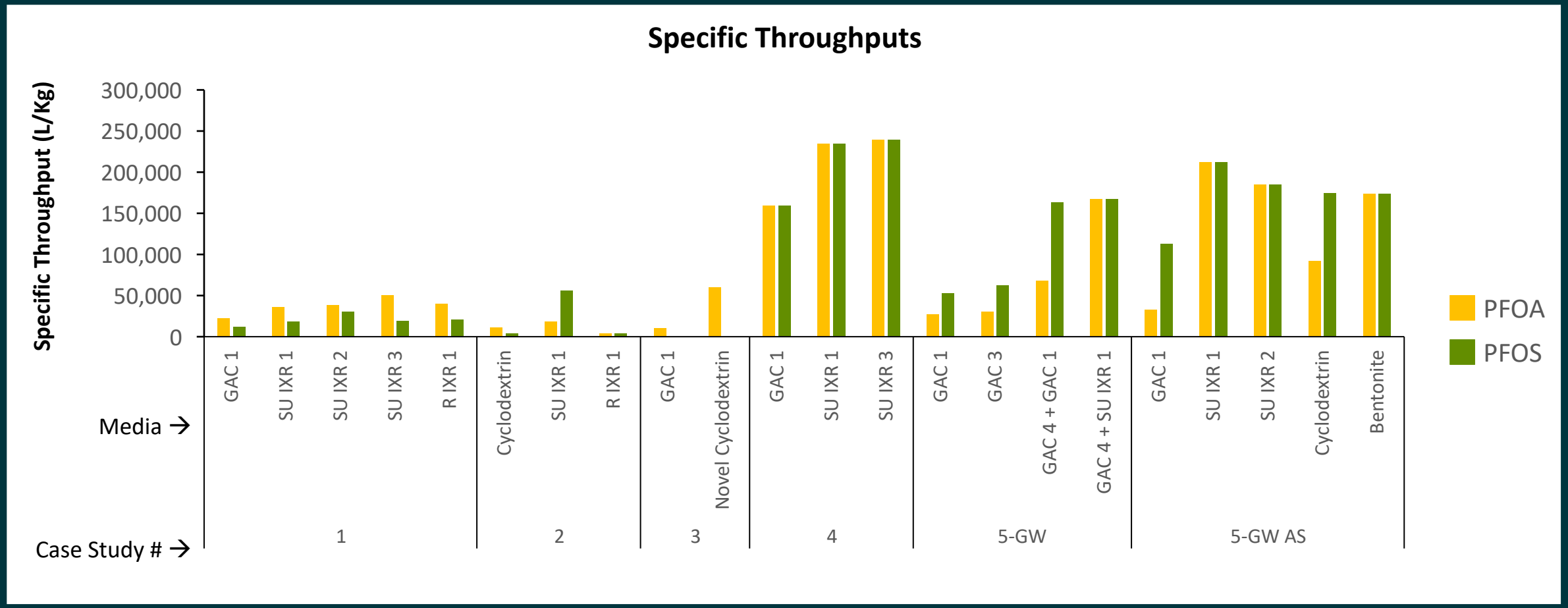
Results – RSSCTs Study 5 PFOS

- Better removal than PFOA
- GACs still underperformed vs other sorbents
- GAC pretreatment works as well as air stripping
- High specific throughputs



Results – RSSCTs

- Specific throughputs vary by water matrix due to PFAS and TOC influent concentration



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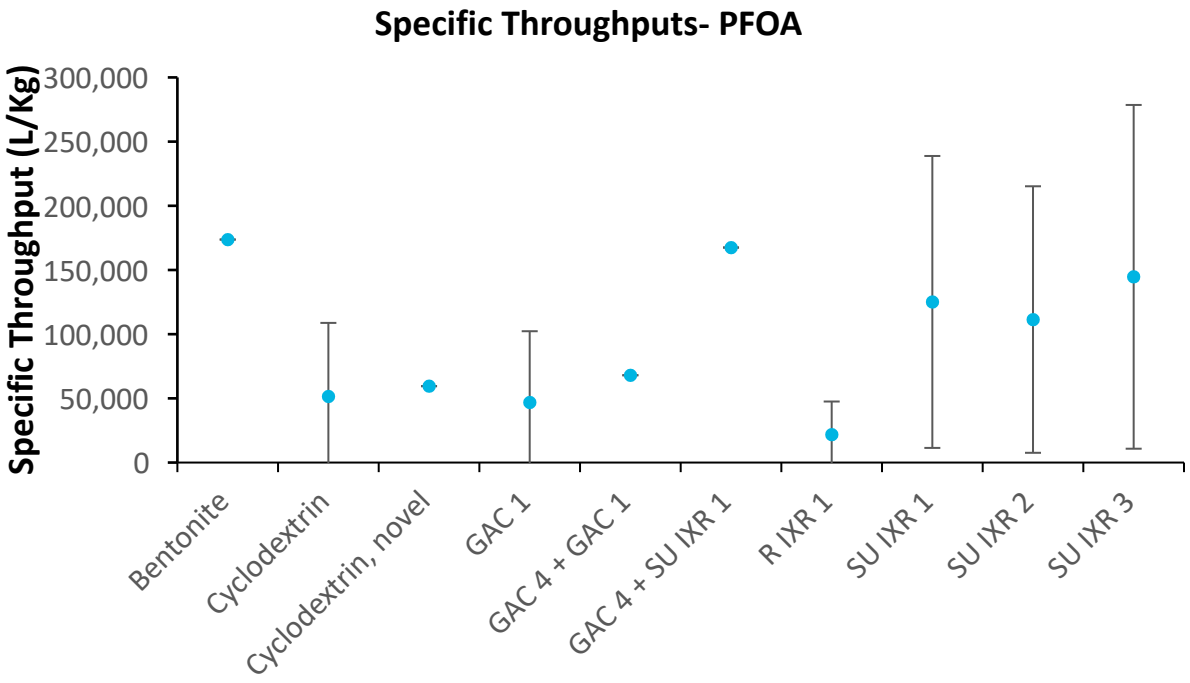

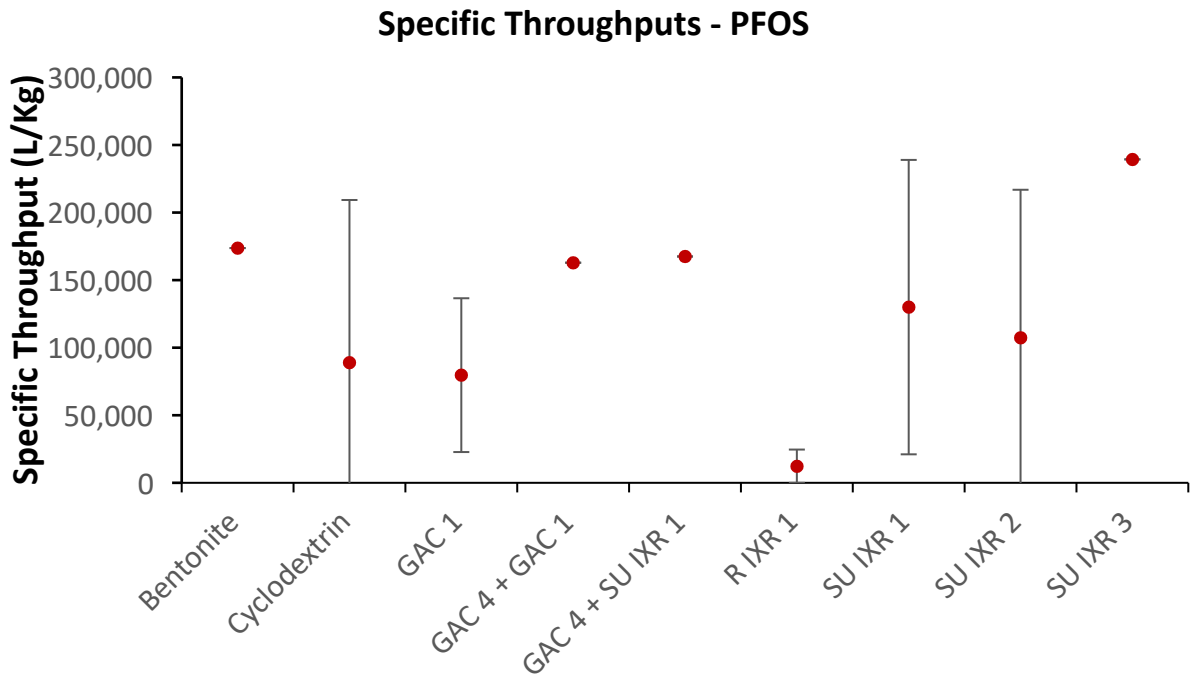

04

Conclusions

Conclusions

- Experimental data obtained from bench-scale treatability studies across multiple projects.
- adsorption capacity or media longevity (specific throughput) can vary widely depending on the water matrix, TOC content, and PFAS initial/influent concentrations
- **Batch Isotherms** showed low adsorption capacities for GAC, moderate adsorption capacities for IXR, and high adsorption capacities for the cyclodextrin

Conclusions

- **RSSCTs**
  - Low specific throughputs for GACs
  - High specific throughputs for IXRs in Studies 4 and 5
  - High specific throughput for novel adsorbents (cyclodextrin and bentonite in Study 5)
  - Media longevity is highly dependent on water matrix, PFAS influent concentration, and TOC
- Study 5
  - Pre-treatment with either GAC or air-stripping revealed high specific throughputs for the media dedicated for PFAS removal
- TOC affects performance of media like GAC, and to a lesser degree, IXR
- Novel adsorbents are not affected by TOC in terms of competitive inhibition
- Consider practical implementation factors (prone to clogging) and costs

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THANK YOU!

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