City of Vancouver Bench- and Pilot-Scale Evaluations for PFAS Mitigation

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Vancouver Water System

- 3rd largest utility in state, serves about 277,000 people, 78,000 metered connections
- Supplied by three regional groundwater aquifers
- Includes 9 Wellfields (water stations), 40 wells, 50 booster pumps, and 1,100 miles of pipes
- ADD of 27 MGD
- 25% of service area outside City limits

Responding to PFAS

City milestones

2013
City UCMR3 PFAS sampling below reporting limit

2020 & 2021
City PFAS sampling low levels detected.
City begins taking action on PFAS

Ongoing
City researching PFAS sources and treatment options

State and federal milestones

2016
EPA sets new PFOS & PFOA Health Advisory Levels (70 ppt)
WA begins developing PFAS Chemical Action Plan

2017-2018
WA begins drinking water rulemaking and restricts PFAS in firefighting foam and food packaging

2021
WA finalizes PFAS State Action Levels

2024
EPA sets regulations for PFAS

Water Production Station Locations

Project Overview

Establish Project Objectives

- Review existing data
- Establish WQ goals
- Technology selection for further testing

Bench-Scale Testing

- Rapid Small-Scale Column Testing (RSSCT)
- Tested two source waters
- Tested seven different media

Pilot-Scale Testing

- Four pilot columns
- Four media tested
- Tested WS4 source water
- One full year of piloting

Final Technology Review

- Review relative performance of GAC and IX media tested

Review of State (SALs) and Federal (MCLs) Levels

PFAS Compound	USEPA HAL: 2016 to 2022 (ng/L)	State of WA SALs: As of 2021 (ng/L)	USEPA HALs: As of 2022 (ng/L)	USEPA Proposed MCLG: As of 2023 (ng/L)	USEPA Proposed MCLs: As of 2023 (ng/L)
Perfluorooctanoic acid (PFOA)	Combined HAL = 70	10	0.004	Zero	4.0
Perfluorooctanesulfonic acid (PFOS)		15	0.02	Zero	4.0
Perfluoro-n-nonanoic acid (PFNA)	N/A	9	N/A	1.0 (unitless) Hazard Index	1.0 (unitless) Hazard Index
Perfluorohexanesulfonic acid (PFHxS)	N/A	65	N/A		
Perfluorobutanesulfonic acid (PFBS)	N/A	345	2,000		
Hexafluoropropylene oxide dimer acid (HFPO-DA)	N/A	N/A	10		

PFAS Compounds Found in City Wells in 2020 and 2021

PFAS Compound	CAS#	Carboxylic or Sulfonic Acid?	Carbon Chain Length	Avg. Conc. in Wells (ng/L)	Max. Conc. in Wells (ng/L)
Perfluorobutanesulfonic acid (PFBS)	375-73-5	Sulfonic	4	3.6	6.9
Perfluorohexanoic acid (PFHxA)	307-24-4	Carboxylic	6	2.3	7.8
Perfluorohexanesulfonic acid (PFHxS)	355-46-4	Sulfonic	6	3.6	7.1
Perfluoroheptanoic acid (PFHpA)	375-85-9	Carboxylic	7	0.76	3.1
Perfluorooctanoic acid (PFOA)	1763-23-1	Carboxylic	8	4.7	14
Perfluorooctanesulfonic acid (PFOS)	335-67-1	Sulfonic	8	10	25
Perfluoro-n-nonanoic acid (PFNA)	375-95-1	Carboxylic	9	0.36	0.93

Bench-Scale RSSCT Trials

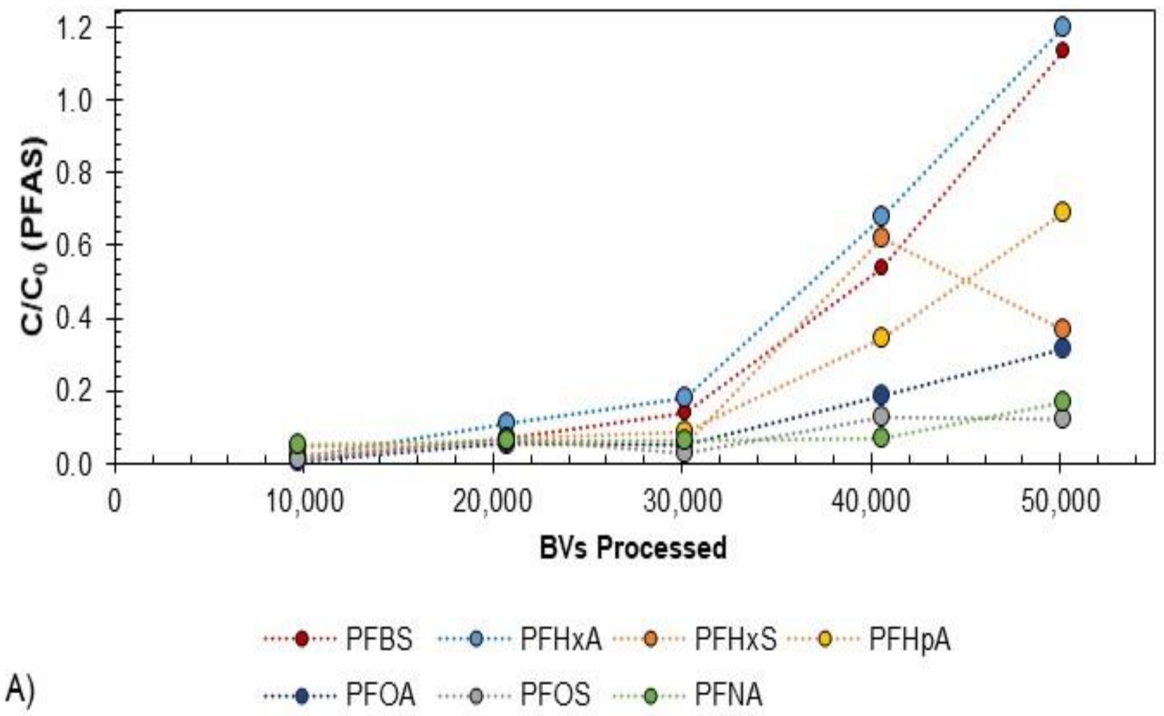
Media No.	Name	Vendor	Media Type
1	Filtrasorb 400	Calgon	Bituminous GAC
2	UltraCarb 1240LD10	Evoqua	Sub-bituminous GAC
3	CalRes 2304	Calgon	Strong Base Anion
4	AmberLite PSR2 Plus	Evoqua	Strong Base Anion
5	APR-2	Evoqua	Strong Base Anion
6	Purofine PFA694E	Purolite	Strong Base Anion
7	Fluoro-Sorb 200	Evoqua	Proprietary Adsorbent

Bench-Scale RSSCT

- Two source waters tested: raw water from WS4 and WS15
- Testing conducted at WS4
- PFAS compounds spiked to ~3 times System Maximum
  - Help ensure that breakthrough occurs in timeframe of short, bench-scale studies (particularly for IX resins)
  - Intent is to look at the relative performance of media
  - Pilot-scale testing later with ambient PFAS concentrations

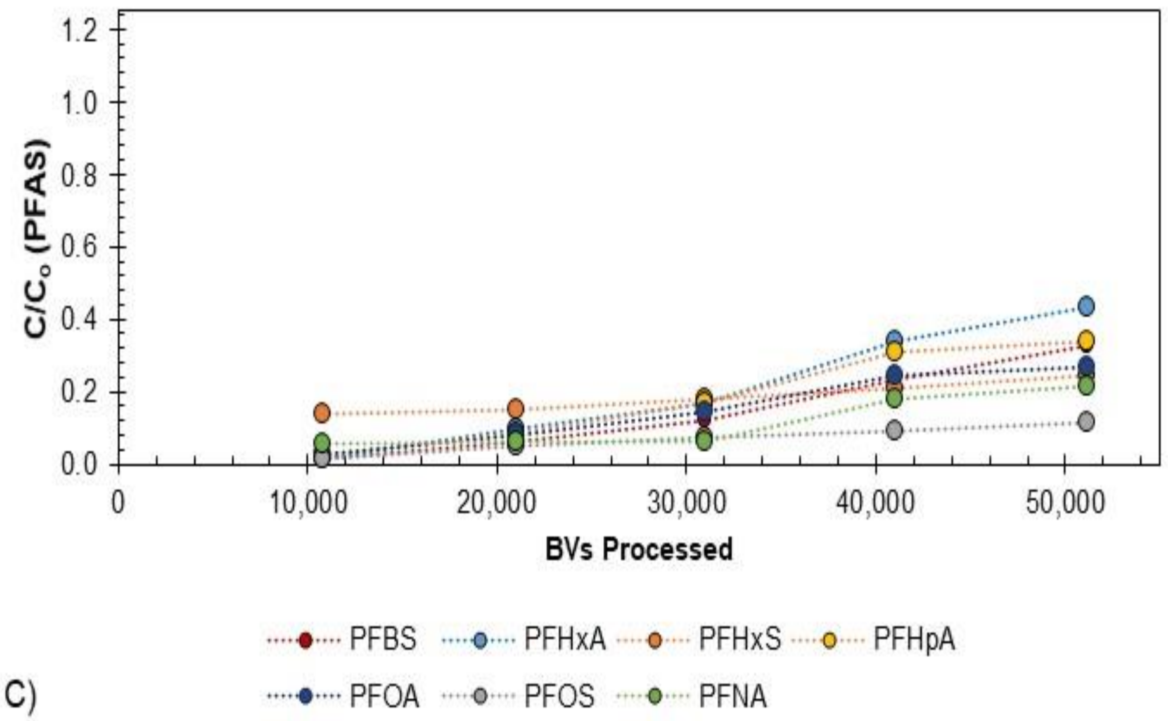
Bench-Scale RSSCT (GAC)

UC1240LD – WS4



A)

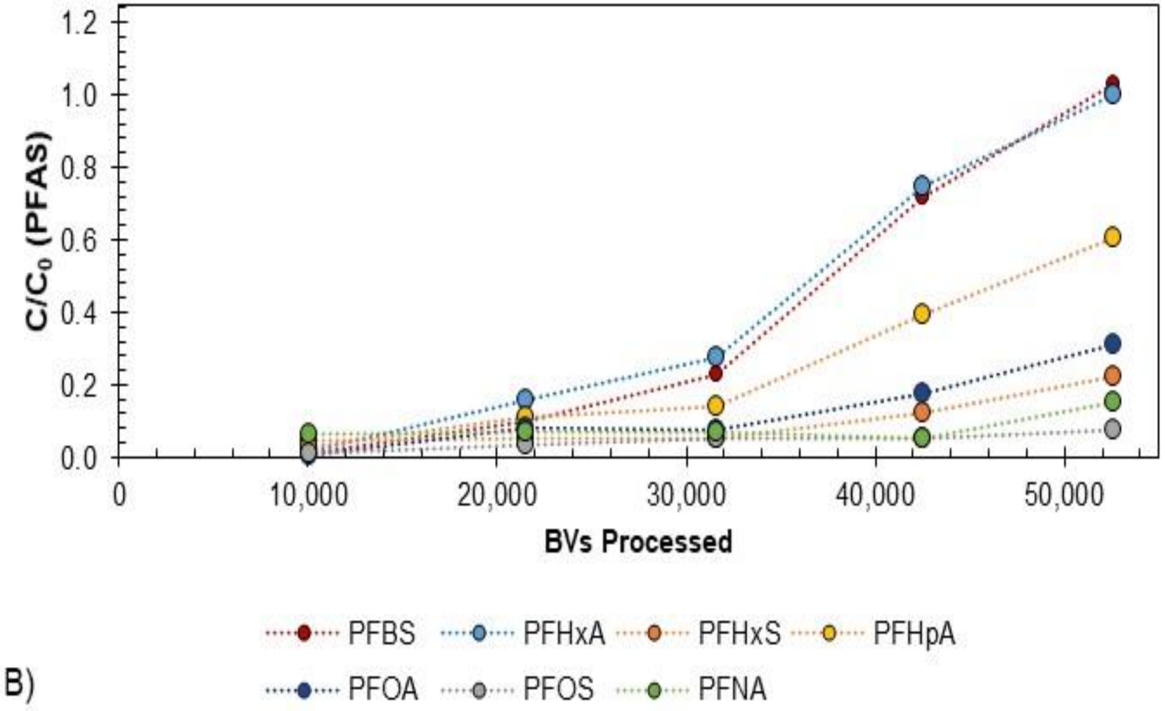
F400 – WS4



C)

Bench-Scale RSSCT (GAC)

UC1240LD – WS15



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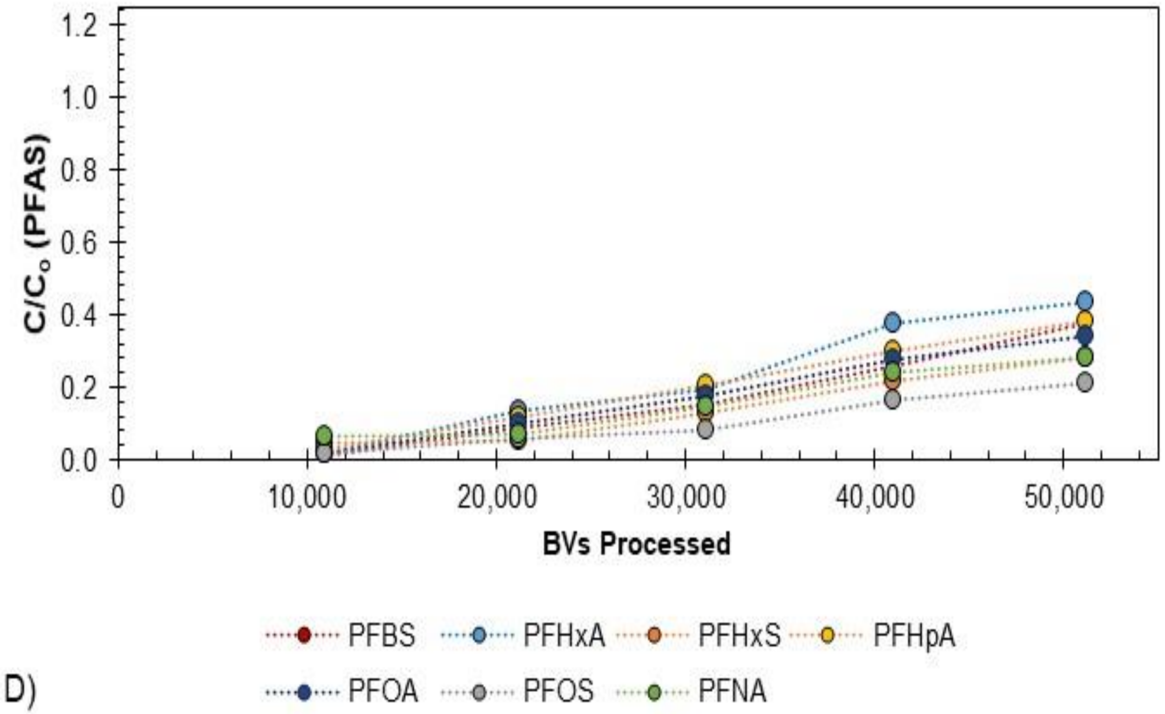
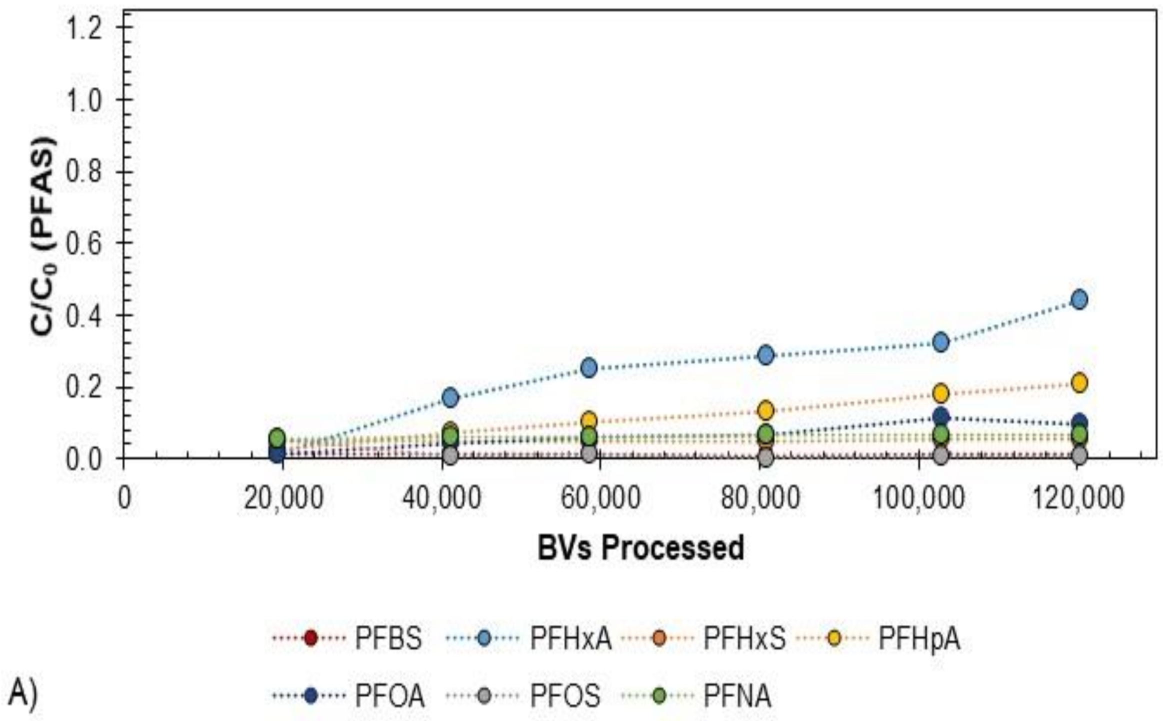
F400 – WS15



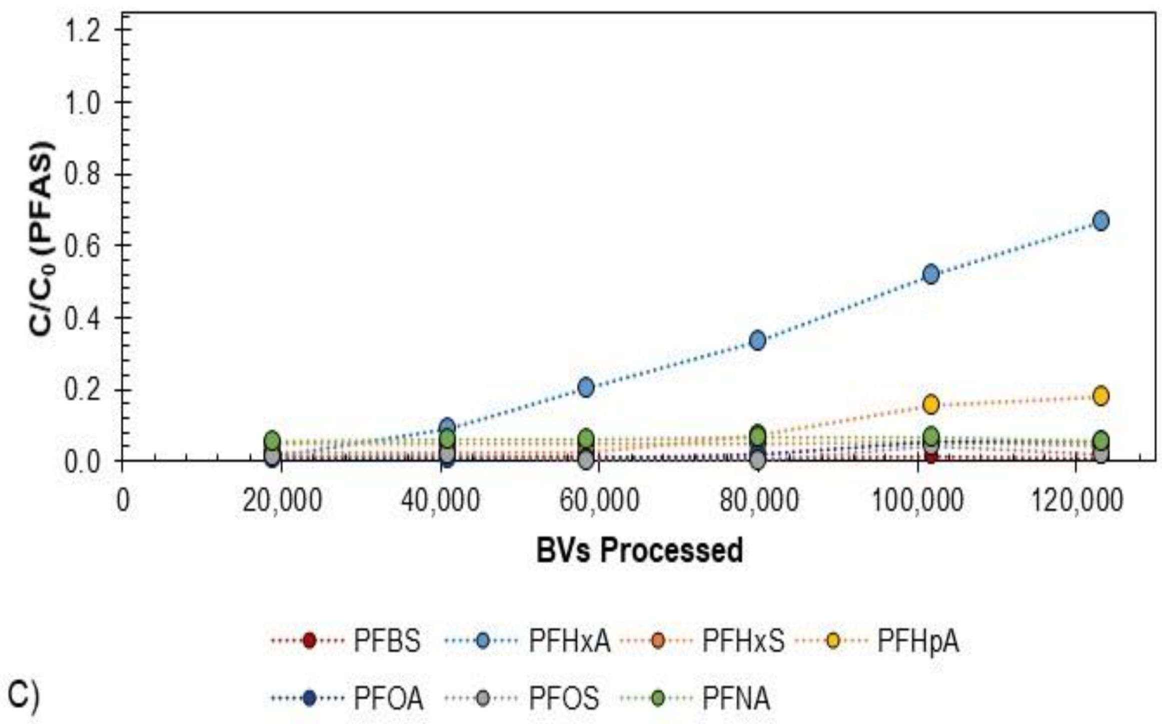
D)

Bench-Scale RSSCT (IX)

PSR2+ – WS4

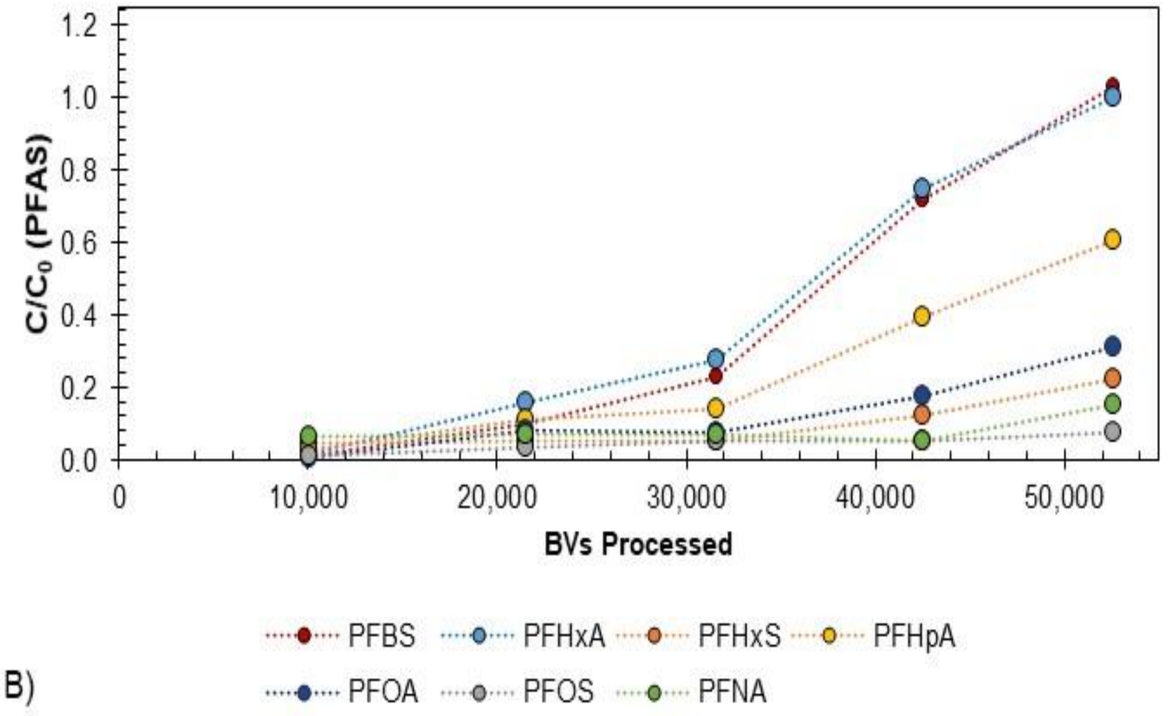


PFA4694E – WS4

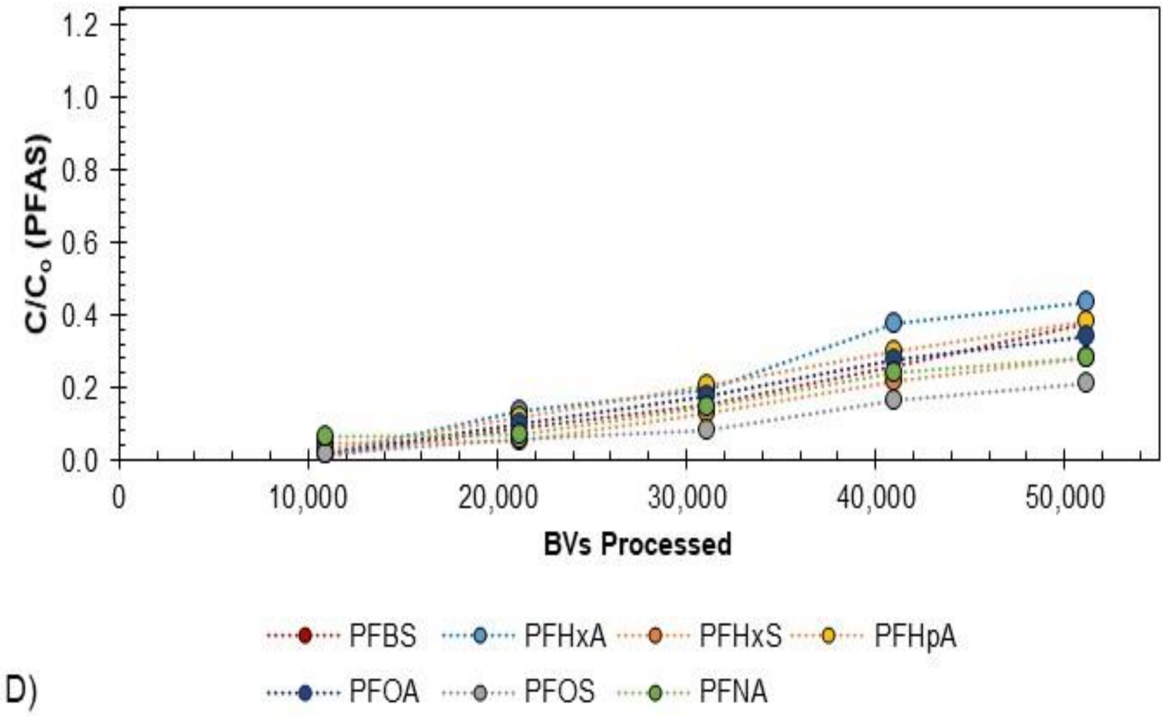


Bench-Scale RSSCT (IX)

PSR2+ – WS15

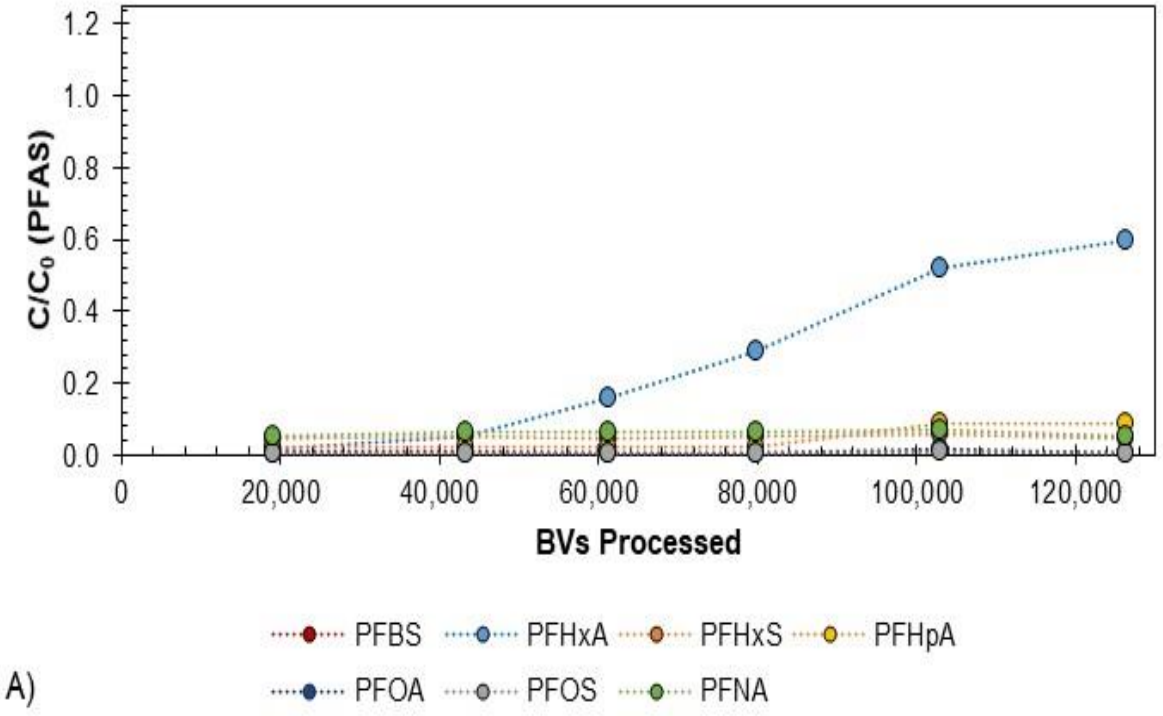


PFA4694E – WS15

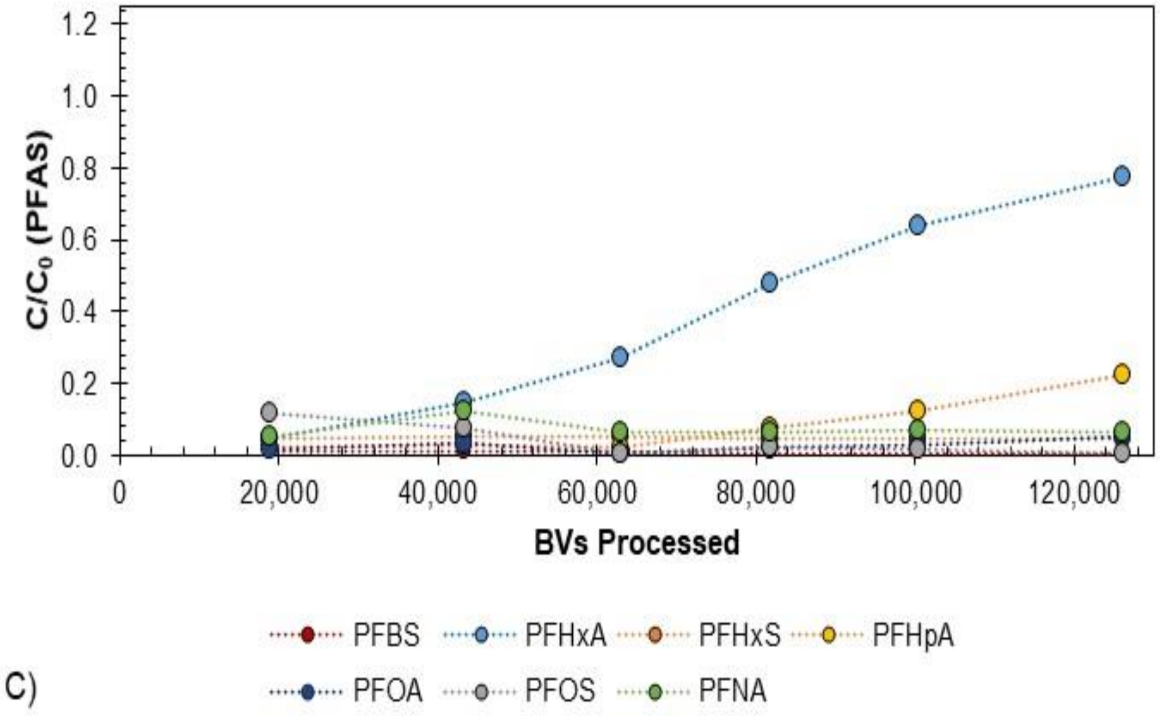


Bench-Scale RSSCT (IX)

APR2 – WS4

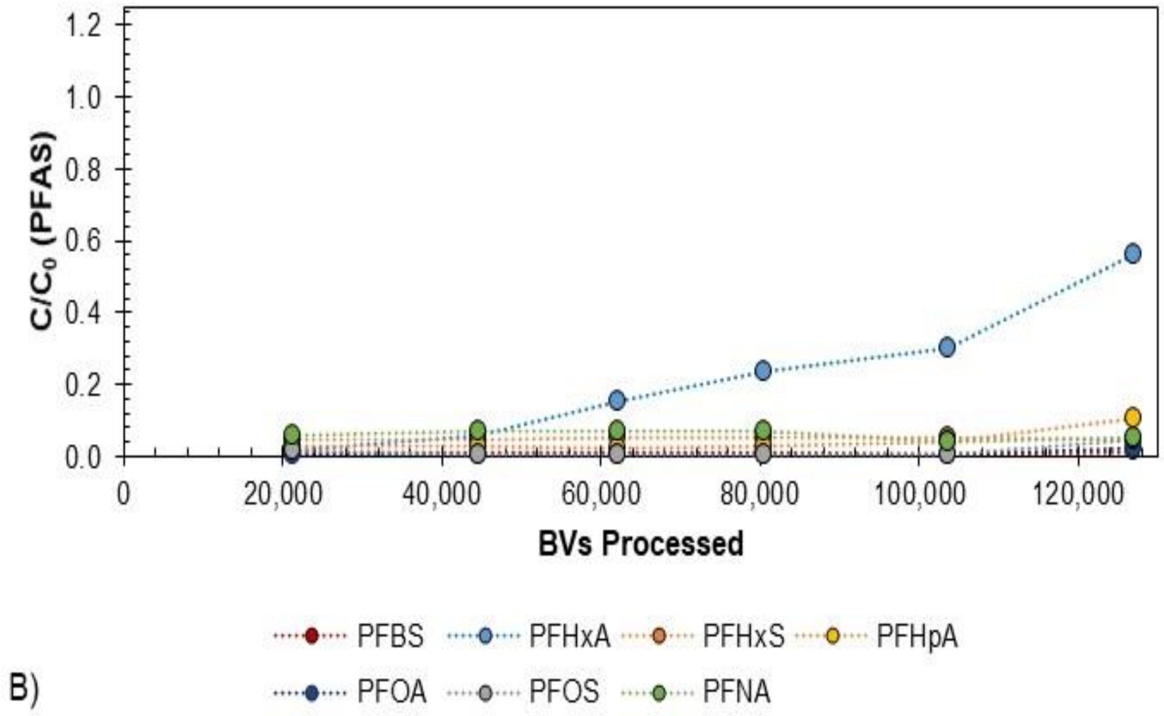


CR2304 – WS4

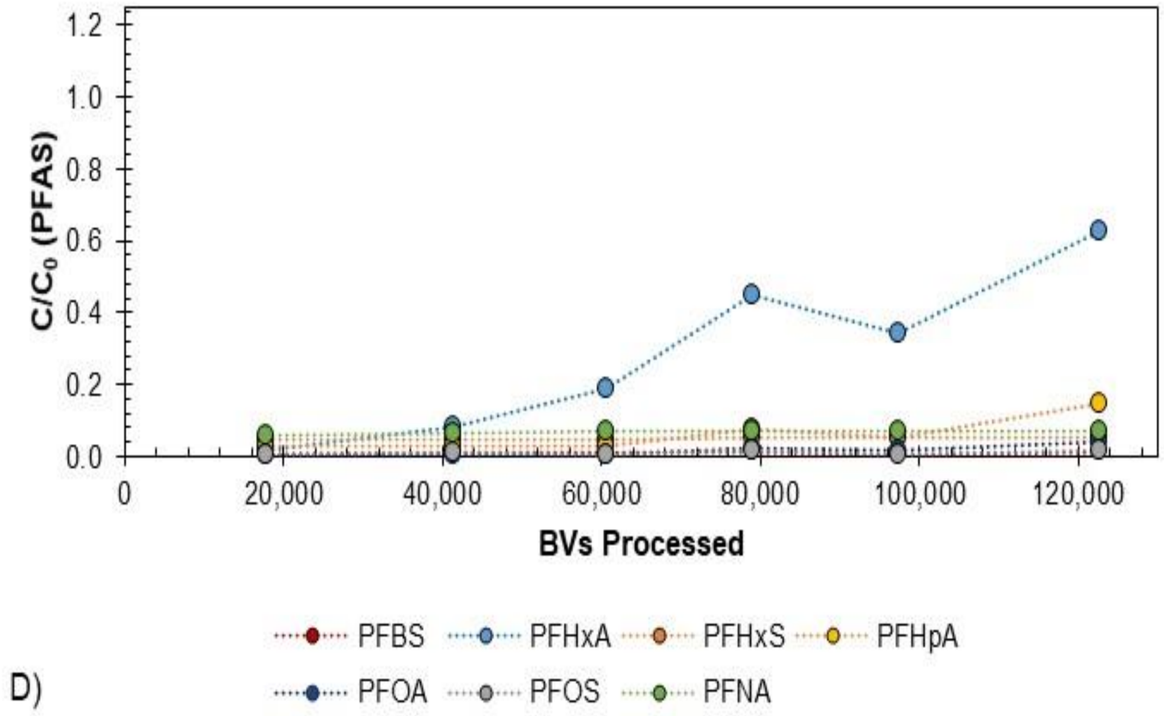


Bench-Scale RSSCT (IX)

APR2 – WS15

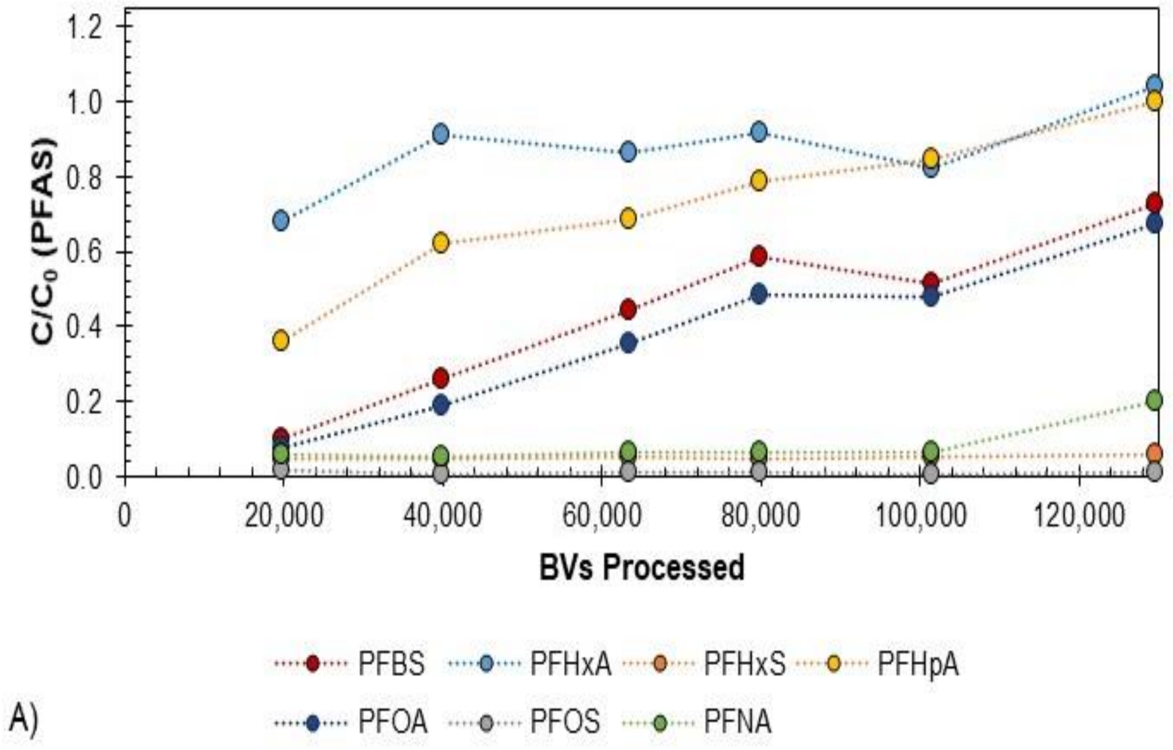


CR2304 – WS15

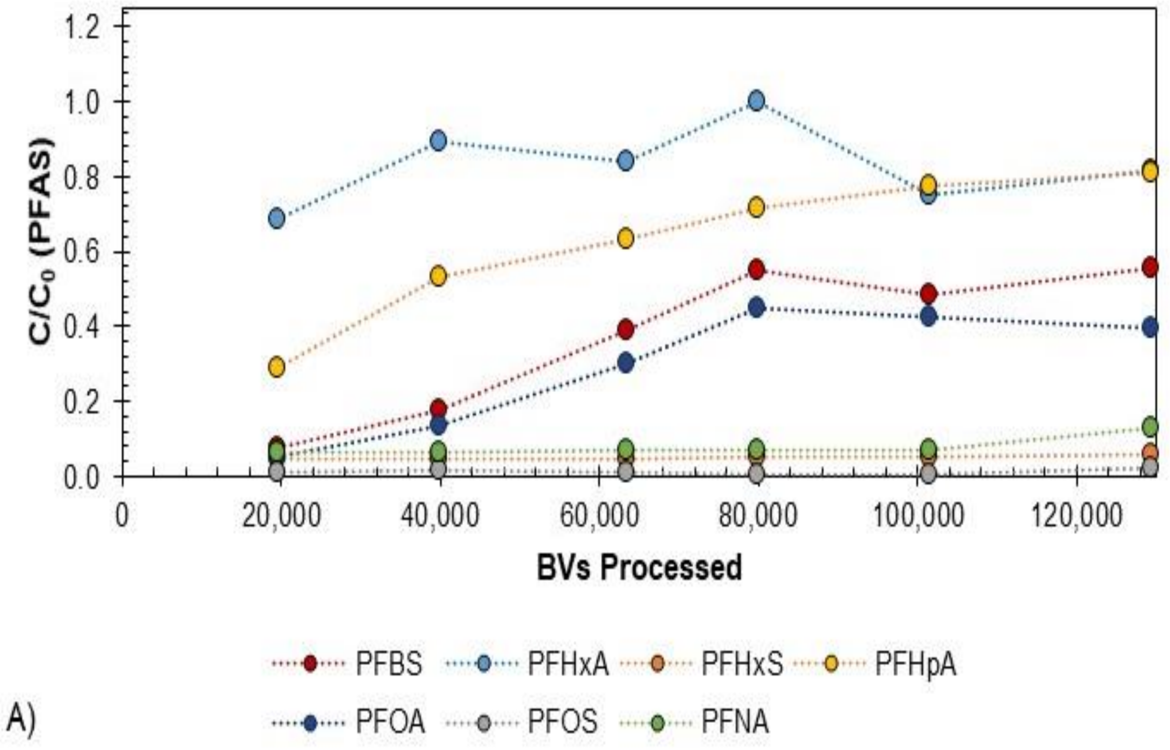


Bench-Scale RSSCT (Fluoro-Sorb)

FS200 – WS4

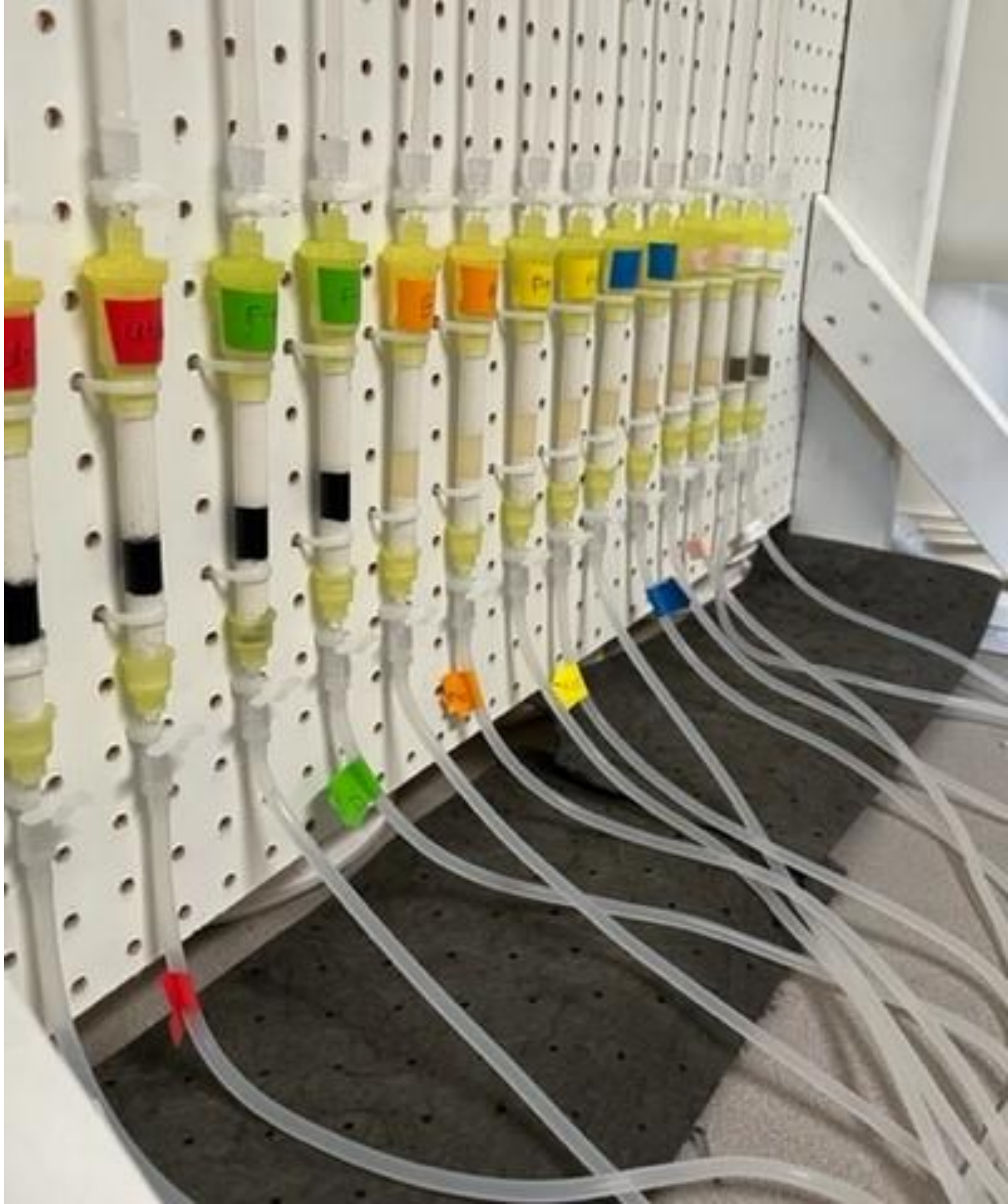


FS200 – WS15



Bench-Scale RSSCT Conclusions

- GAC: F400 > UC1240LD
- IX: APR2 > PFA4694E > CR2304 > PSR2+
- Fluoro-Sorb 200: poor performance with low molecular weight PFAS; PFOA also poorly retained
- Media Selection for Pilot Testing:
  - Calgon F400
  - Evoqua APR2
  - Purolite PFA4694E
  - Calgon CR2304



Pilot-Scale Design

- Source water: WS4 (post-aeration for logistical reasons)
- Pretreatment: 0.5-µm filtered (needed for IX columns)
- Column diameter: 4”
- EBCT: 5.4 min (GAC), 1.5 min (IX)
- Depth: 70” (GAC), 30” (IX)
- HLR: 8.0 GPM/ft^2 (GAC), 12.6 GPM/ft^2 (IX)

Pilot-Scale Sampling

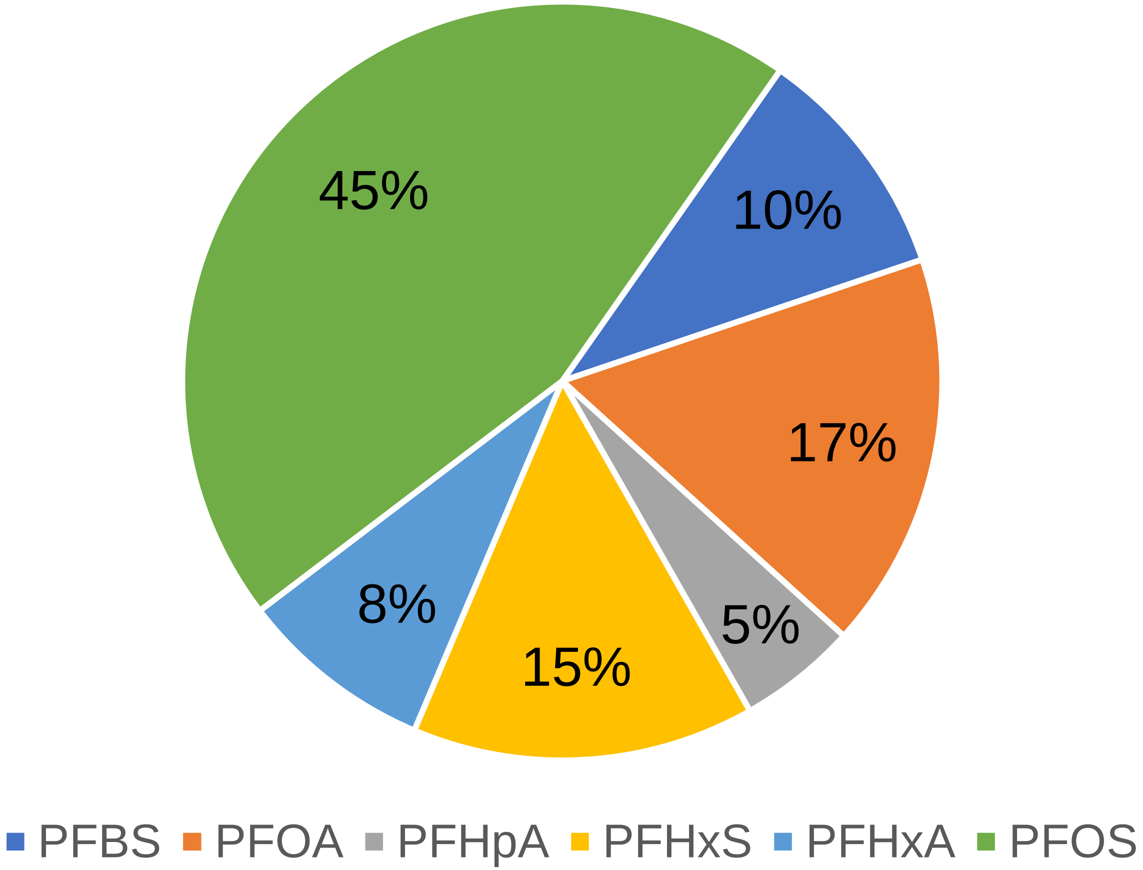
Parameter	Analytical Method	Frequency
On-Site Measurements		
Pressure	Pressure Transmitters	Daily
Inst. Flow Rate	Flow Meters	Daily
Total Flow Rate	Flow Meters	Daily
pH	SM4500H+B	Weekly
Temperature	USEPA 170.1	Weekly
Alkalinity	SM2330B	Weekly
Conductivity	SM2510B	Weekly
Turbidity	USEPA 180.1	Weekly
BSK Measurements		
PFAS	USEPA 537.1	Weekly
TOC	SM5310B	Weekly
DOC	SM5310B	Weekly

Pilot-Scale Sampling

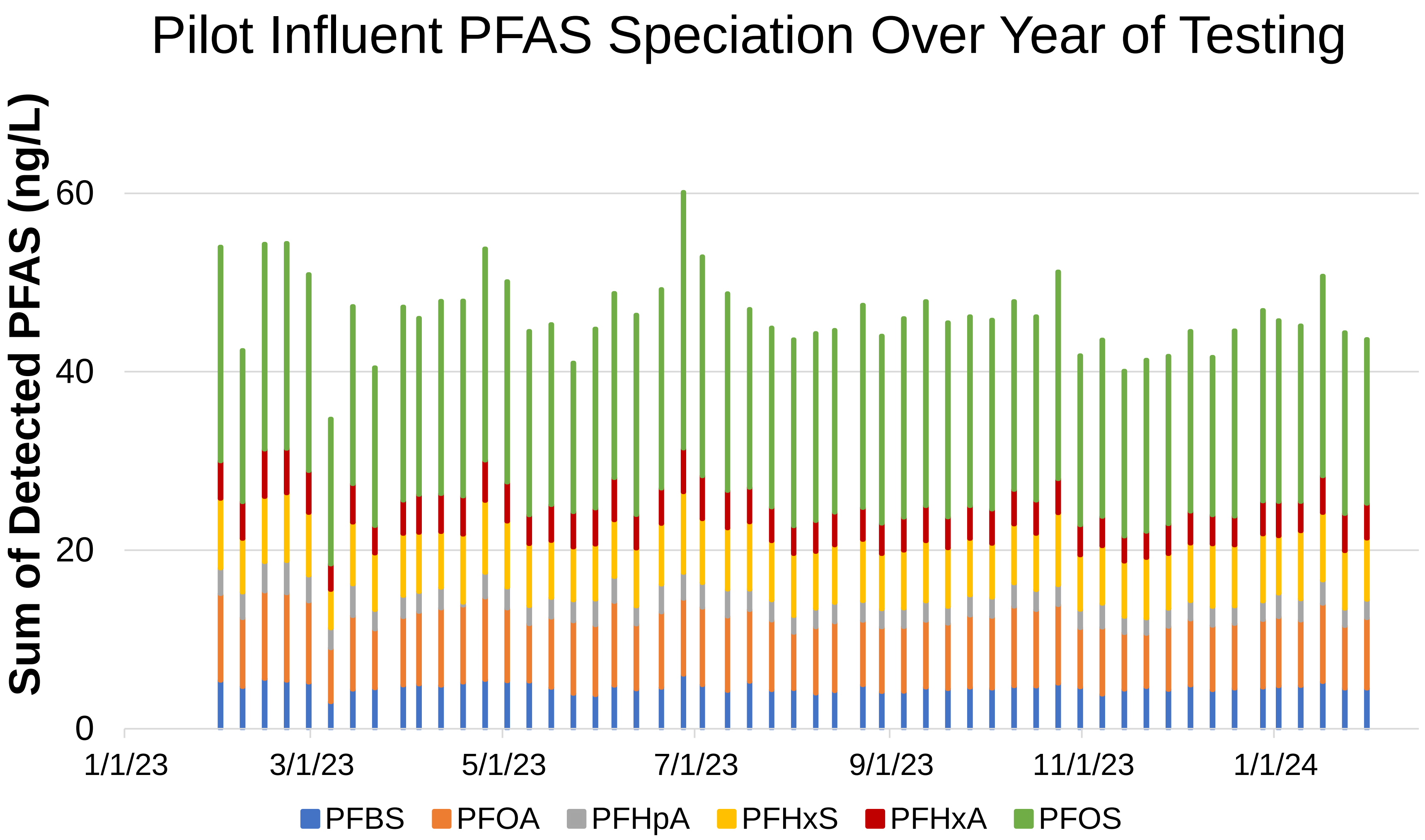
Parameter	Analytical Method	Frequency
BSK Measurements		
Hardness	SM2340B	Quarterly
Arsenic	USEPA 1632	Quarterly
Chloride	USEPA 300.0	Quarterly
Sulfate	USEPA 300.0	Quarterly
Fluoride	USEPA 300.0	Quarterly
Nitrate	USEPA 353.2	Quarterly
Calcium	USEPA 200.7	Quarterly
Magnesium	USEPA 200.7	Quarterly
Potassium	USEPA 200.7	Quarterly
Sodium	USEPA 200.7	Quarterly
TDS	SM2540C	Quarterly
Total Iron	USEPA 200.7	Quarterly
Dissolved Iron	USEPA 200.7	Quarterly
Total Manganese	USEPA 200.7	Quarterly
Dissolved Manganese	USEPA 200.7	Quarterly

Pilot-Scale Results

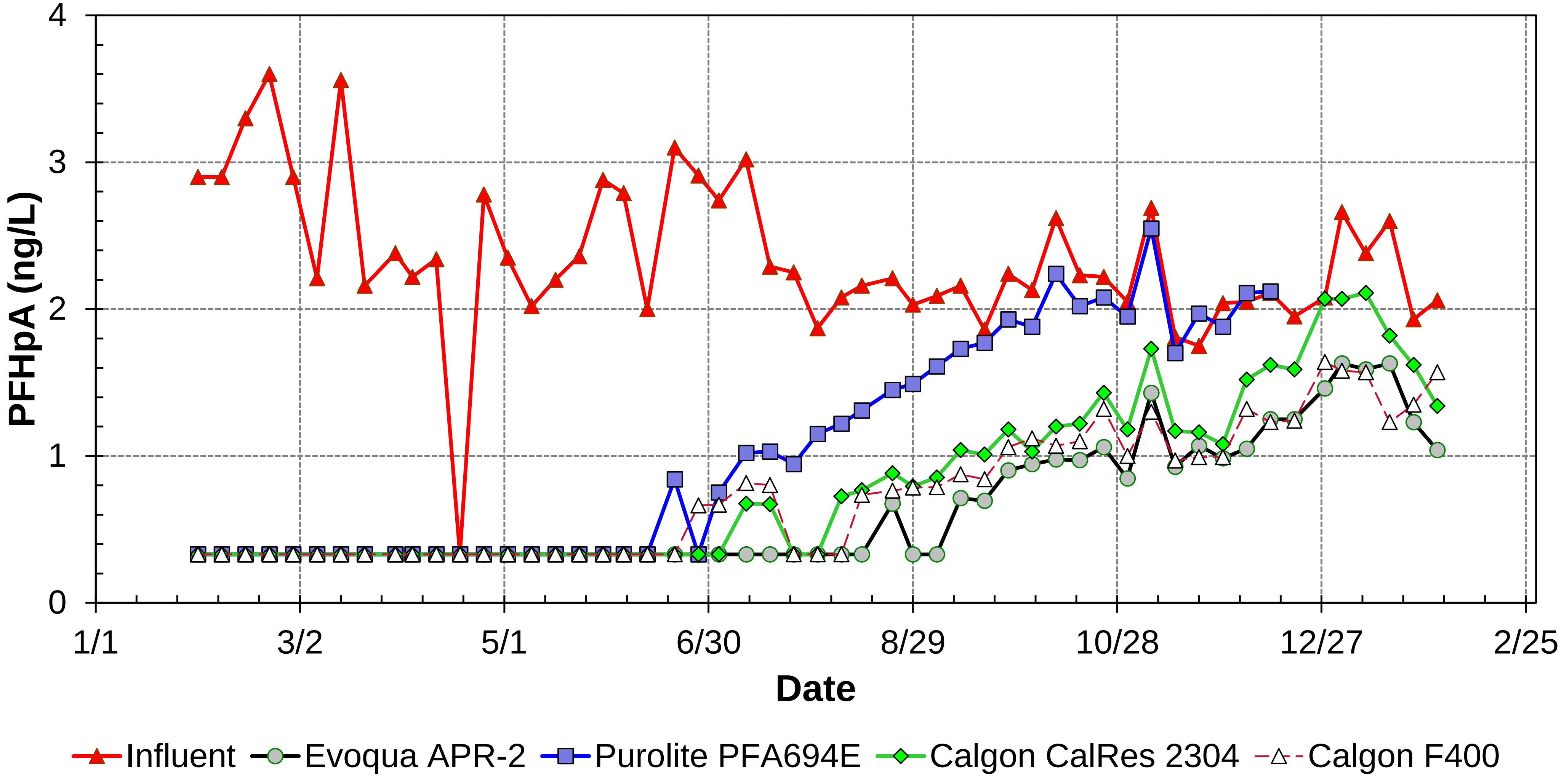
Average Pilot Influent PFAS Speciation



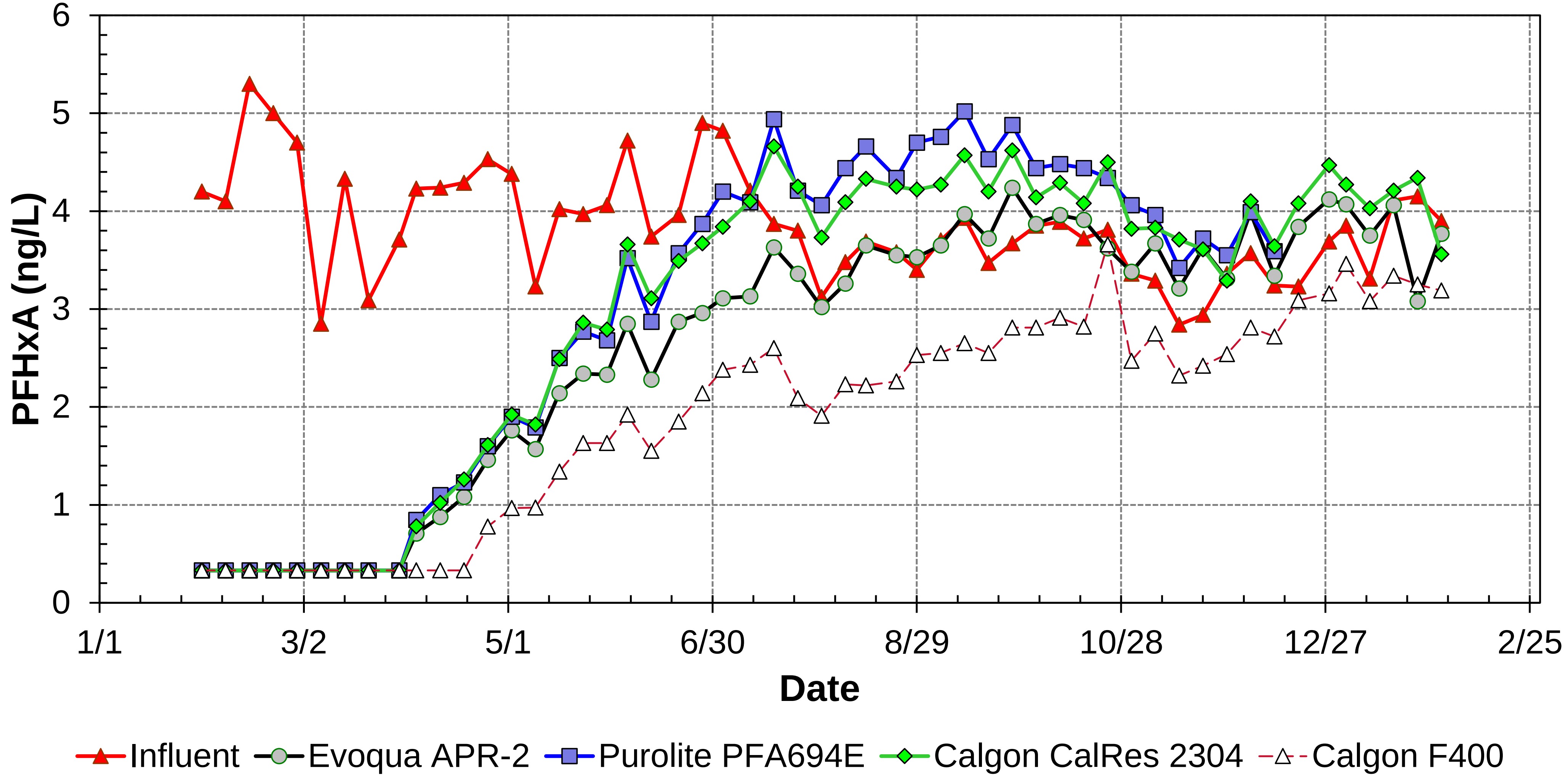
Pilot-Scale Results



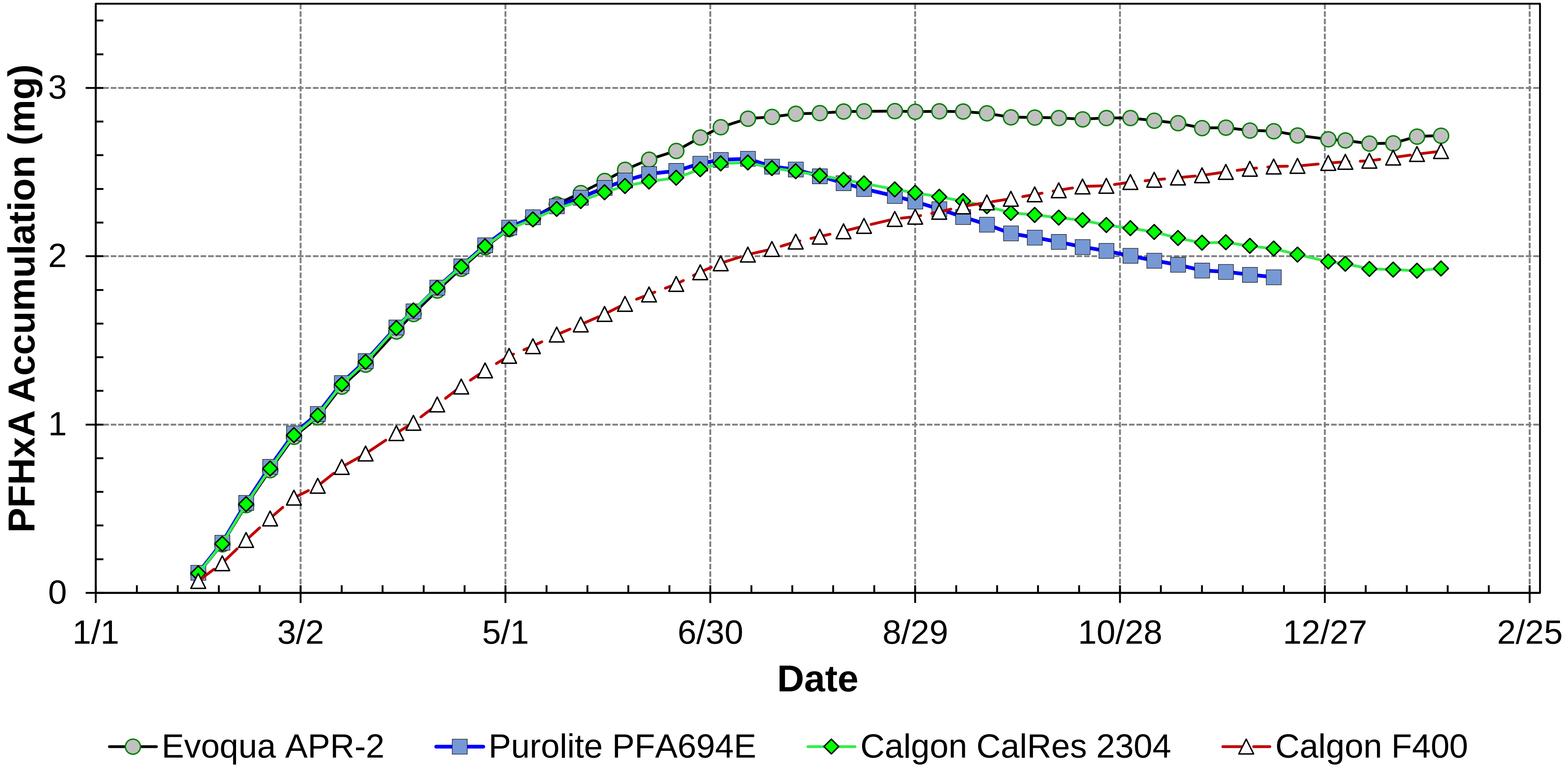
Pilot-Scale Results (PFHpA)



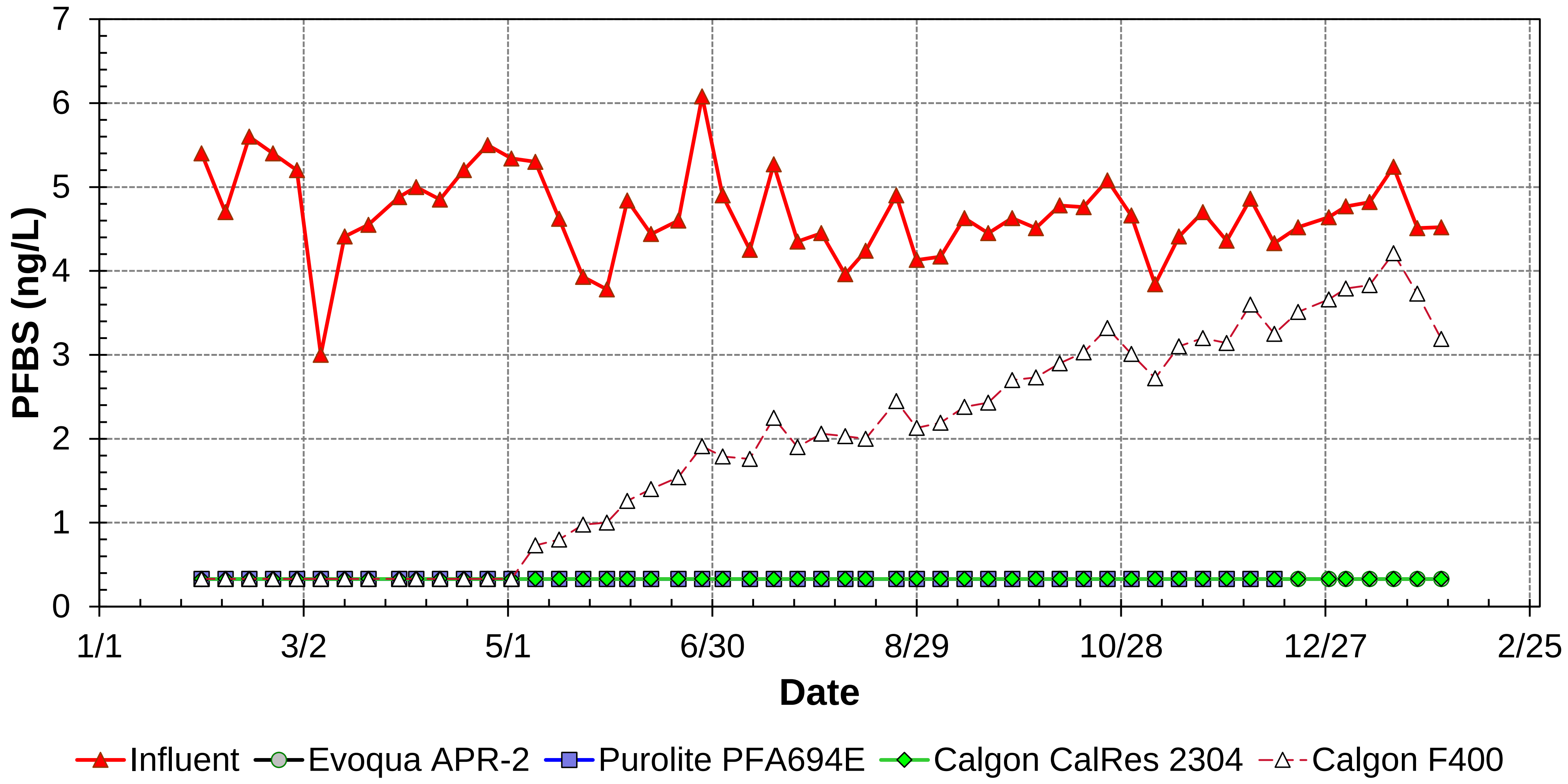
Pilot-Scale Results (PFHxA)



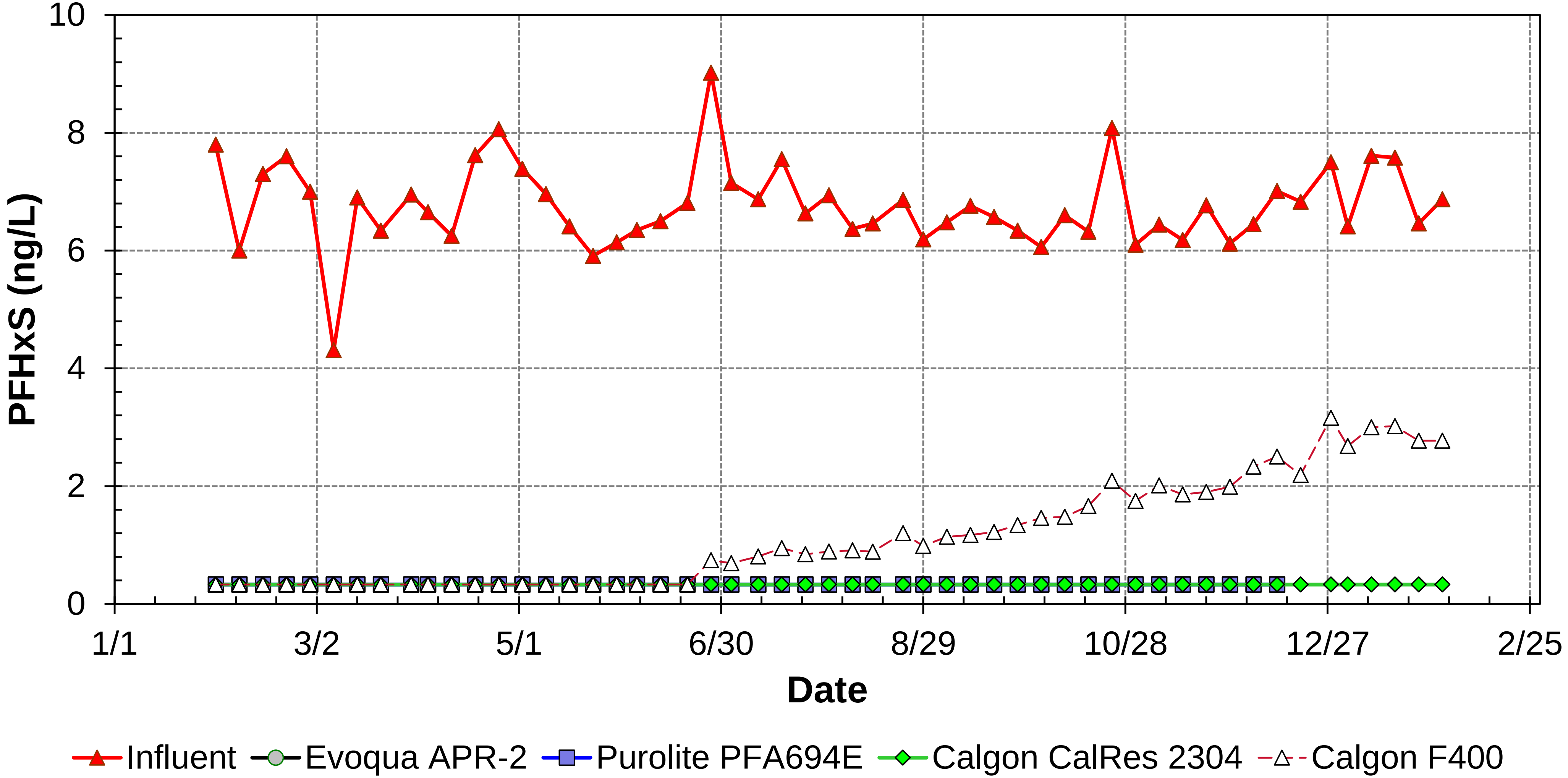
Pilot-Scale Results (PFHxA)



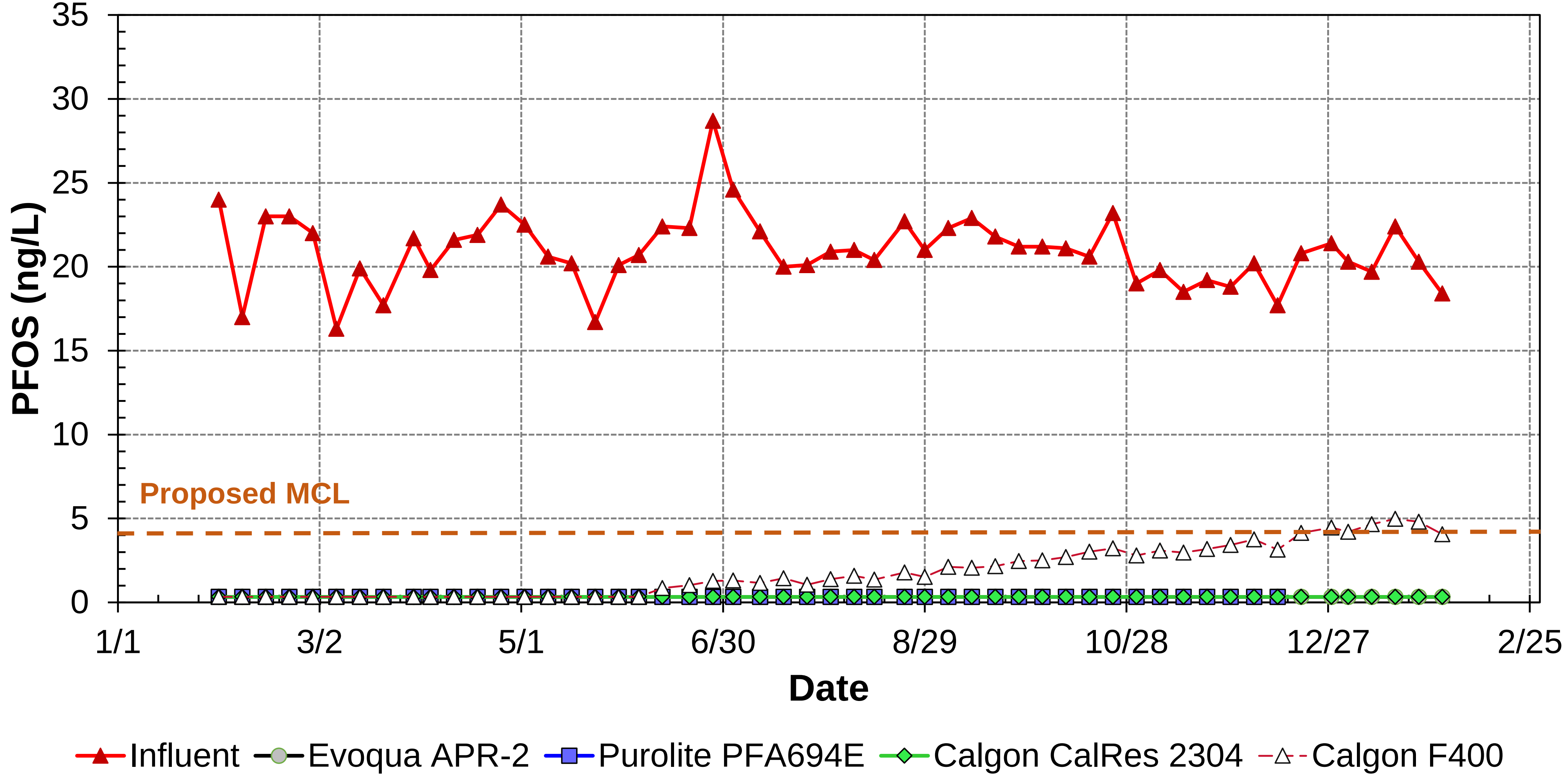
Pilot-Scale Results (PFBS)



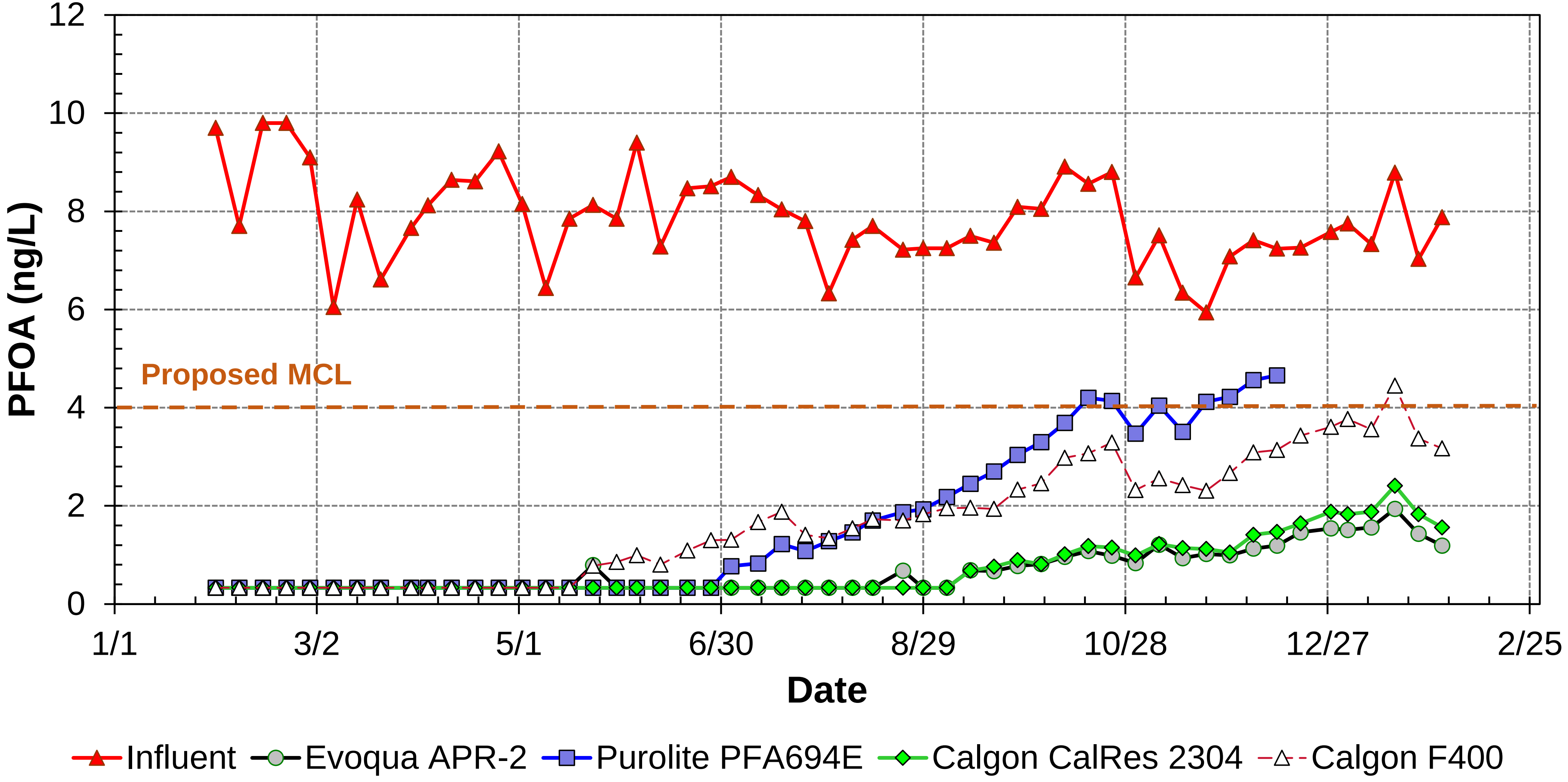
Pilot-Scale Results (PFHxS)



Pilot-Scale Results (PFOS)



Pilot-Scale Results (PFOA)



Pilot-Scale Results (Hazard Index)

$$\mathrm{HI} = \frac{\mathrm{HFPO-DA}}{10} + \frac{\mathrm{PFBS}}{2000} + \frac{\mathrm{PFNA}}{10} + \frac{\mathrm{PFHxS}}{9}$$

- HFPO-DA: not detected in wells
- PFBS: averaged 4.7 ng/L in ***influent*** over study
- PFNA: has only been detected below Reporting Limits
- PFHxS: averaged 6.8 ng/L in ***influent*** over study

Source Water	Calculated HI
Average Influent	0.75
Final Effluent (IX columns)	0.00
Final Effluent (GAC)	0.0016

CONCLUSION:

PFOA and PFOS will dictate media replacement. HI not predicted to be a problem under WQ conditions

Pilot-Scale Results: 20-Year Lifecycle Cost Estimates*

	Column 1 (APR-2)	Column 2 (PFA694E)	Column 3 (CR2304)	Column 4 (F400)	Column 4 (F400) – Reactivated**
Billion gallons to changeout	3.1	1.4	2.5	1.3	1.3
Years to first changeout	7.3	3.3	6.6	4.4	4.4
Media pricing per cubic foot	$ 511	$ 401	$ 524	$ 70	$ 58
No. vessels (entire system)	14	14	16	20	20
Vessel pricing (entire system)	$ 3,400,000	$ 3,450,000	$ 3,200,000	$ 4,600,000	$ 4,600,000
Media pricing (entire system)	$ 3,030,000	$ 2,380,000	$ 3,550,000	$ 1,860,000	$ 1,540,000
TOTAL (20-years)	$ 10,400,000	$ 14,900,000	$ 12,100,000	$ 11,400,000	$ 10,300,000
TOTAL (yearly)	$ 521,000	$ 745,000	$ 607,000	$ 571,000	$ 513,000
TOTAL (monthly)	$ 43,000	$ 62,000	$ 51,000	$ 48,000	$ 43,000
TOTAL (monthly, per customer)	$ 0.16	$ 0.23	$ 0.19	$ 0.18	$ 0.16

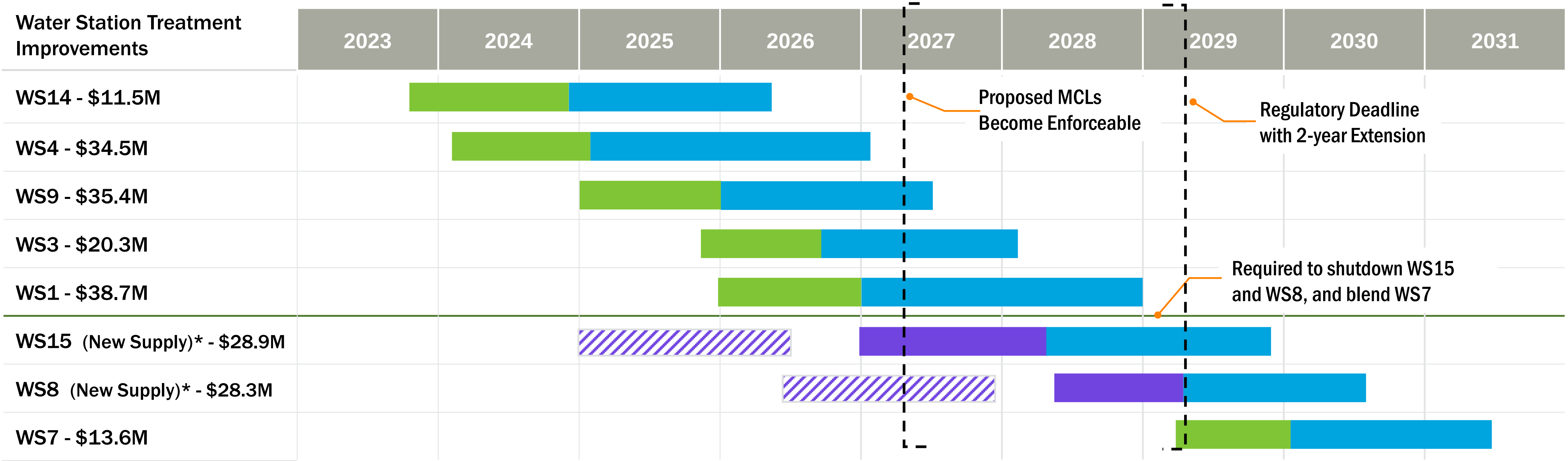
*Estimates based on PFOA breakthrough data and include pricing for Media and Vessels

**Estimates from Virgin GAC performance in pilot column

Bench-Scale and Pilot-Scale Testing SUMMARY

- **IX Resins**: APR2 can CR2304 were the best performing media in the pilot study (per volume of water treated)
- **GAC Media**: Bench-scale testing illustrated that the F400 performed significantly better than UC1240LD
- **Cost Analysis**: Under current market pricing, APR2 was more cost-effective than the other IX resins, but comparable to the F400 GAC
- **Pilot Operation**: Over year of operation, columns did not experience noticeable headloss or significant fouling. Backwashing wasn’t necessary with GAC
- **OVERALL**: Water quality at WS4 would be amenable to either IX or GAC, both for effectiveness of PFAS removal and operational considerations

PFAS Mitigation Implementation Schedule



LEGEND: PFAS Treatment Design | Construction | Potential New SGA Well(s) Development | Iron/Manganese Treatment Design or PFAS Treatment Design

- - - Proposed MCL timeline and regulatory deadline is subject to change based on finalization of the National Drinking Water Standard for PFAS.

* Site is a potential candidate for development of a new well supply from the deep aquifer, dependent on on-going water rights evaluation. WS15 is highly likely for SGA development.

Upcoming City Milestones

- Finalize WS 14 design (GAC)
- WS 4 design (GAC or IX??)
- RFQ late 2024 for WS 9
- Pursue sources of PFAS in groundwater
- Funding strategy
- Cost recovery/Settlements
- Ongoing customer outreach and education