Removal of PFAS in Groundwater: Practical lessons and forward-looking planning

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American Water Works Association
Pacific Northwest Section
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Discussion Topics

1. Treatment Facility Overview
2. Multiple Contaminants – who's driving the bus?
3. Monitoring split flow, parallel treatment through adsorbers in series
4. Estimating a non-linear future

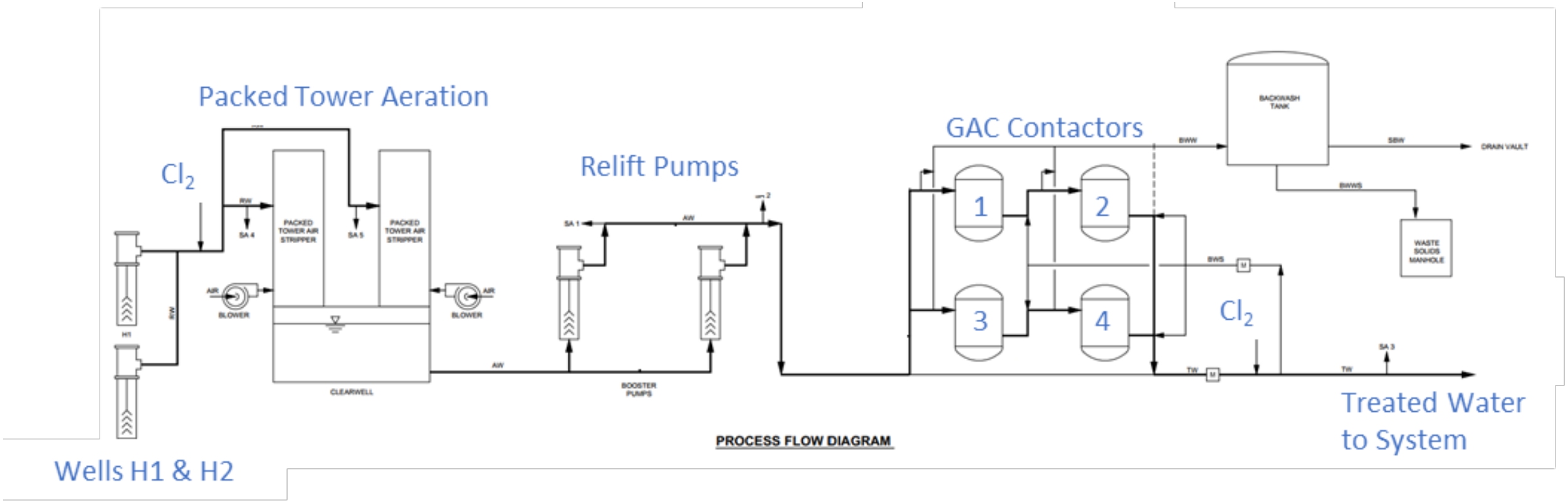
Ponders
(Wells H-1 & H-2)

Scotts
(Wells G-1 & G-2)

The Treatment Plants


Backwash
Tank
TRAIN 2
TRAIN 1
4
3
2
1
STRIPPING
TOWERS
(PCE & TCE)

Ponders Corner Process Flow Diagram



Source: Kennedy Jenks, 2019

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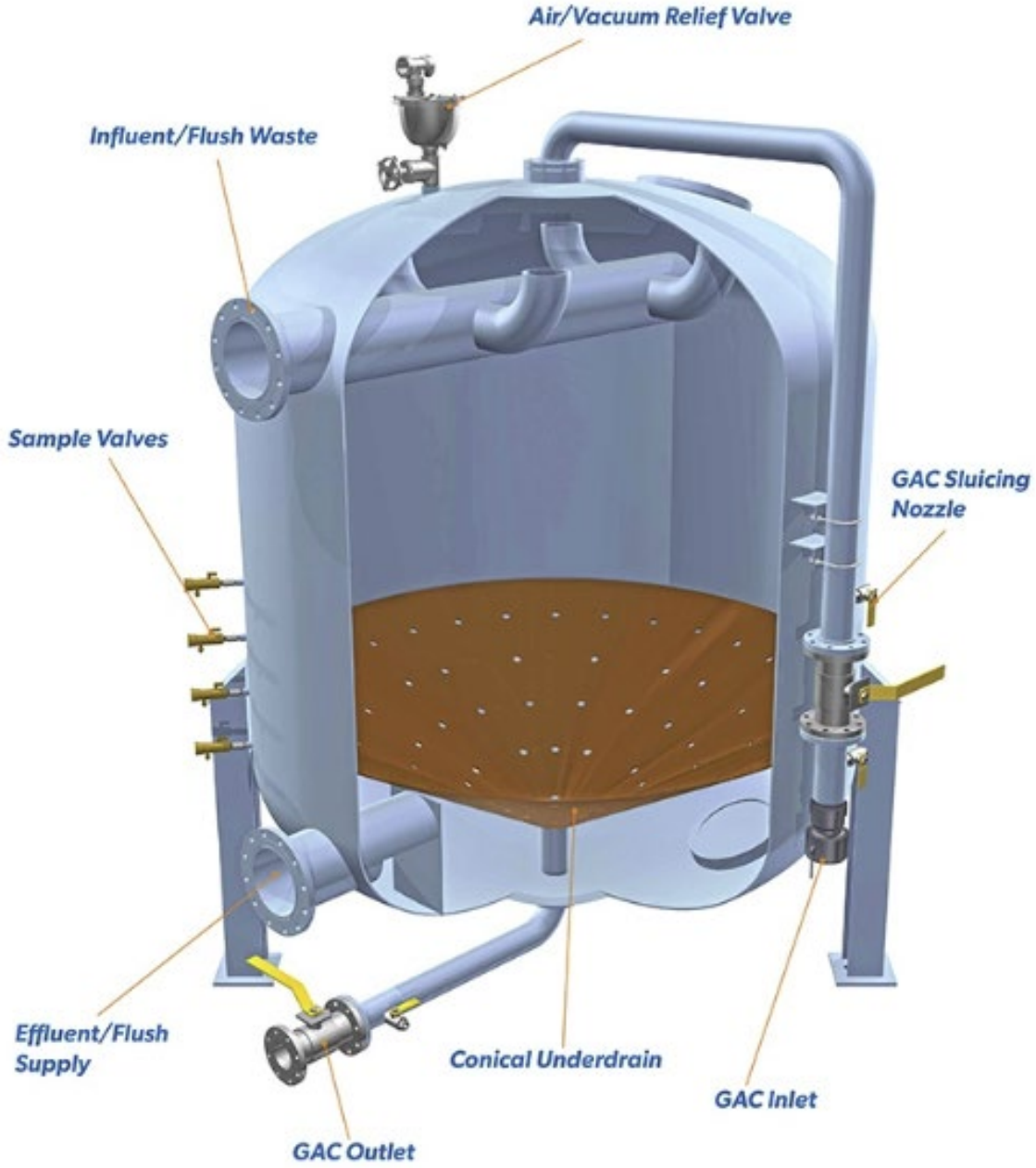
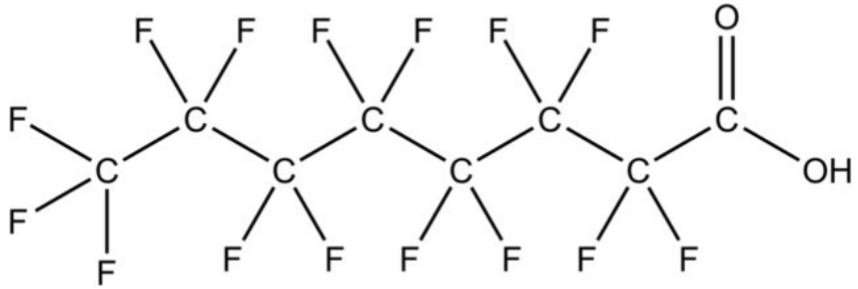
Ponders Corner Water Treatment Plant

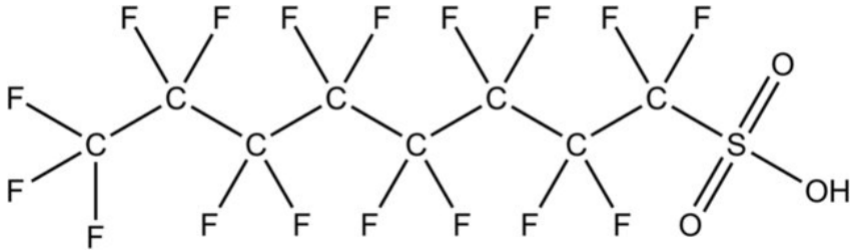
Pressure Vessel Cutaway



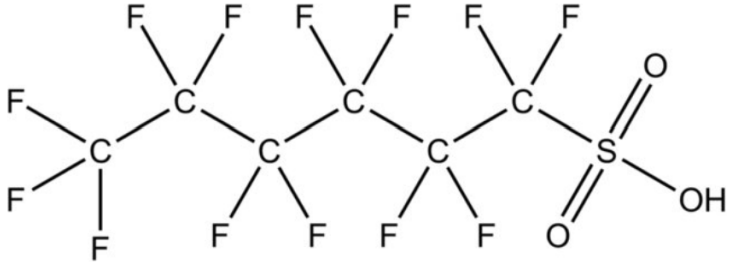
Source: WestTech, Inc https://www.westech-inc.com/products/granular-activated-carbon-contactors



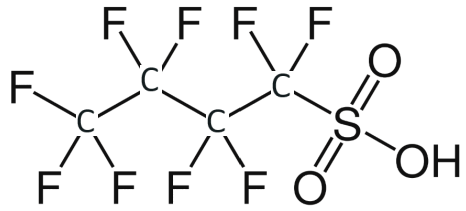
Perfluorooctanoic acid (PFOA – C8)



Perfluorooctane sulphonate (PFOS – C8)



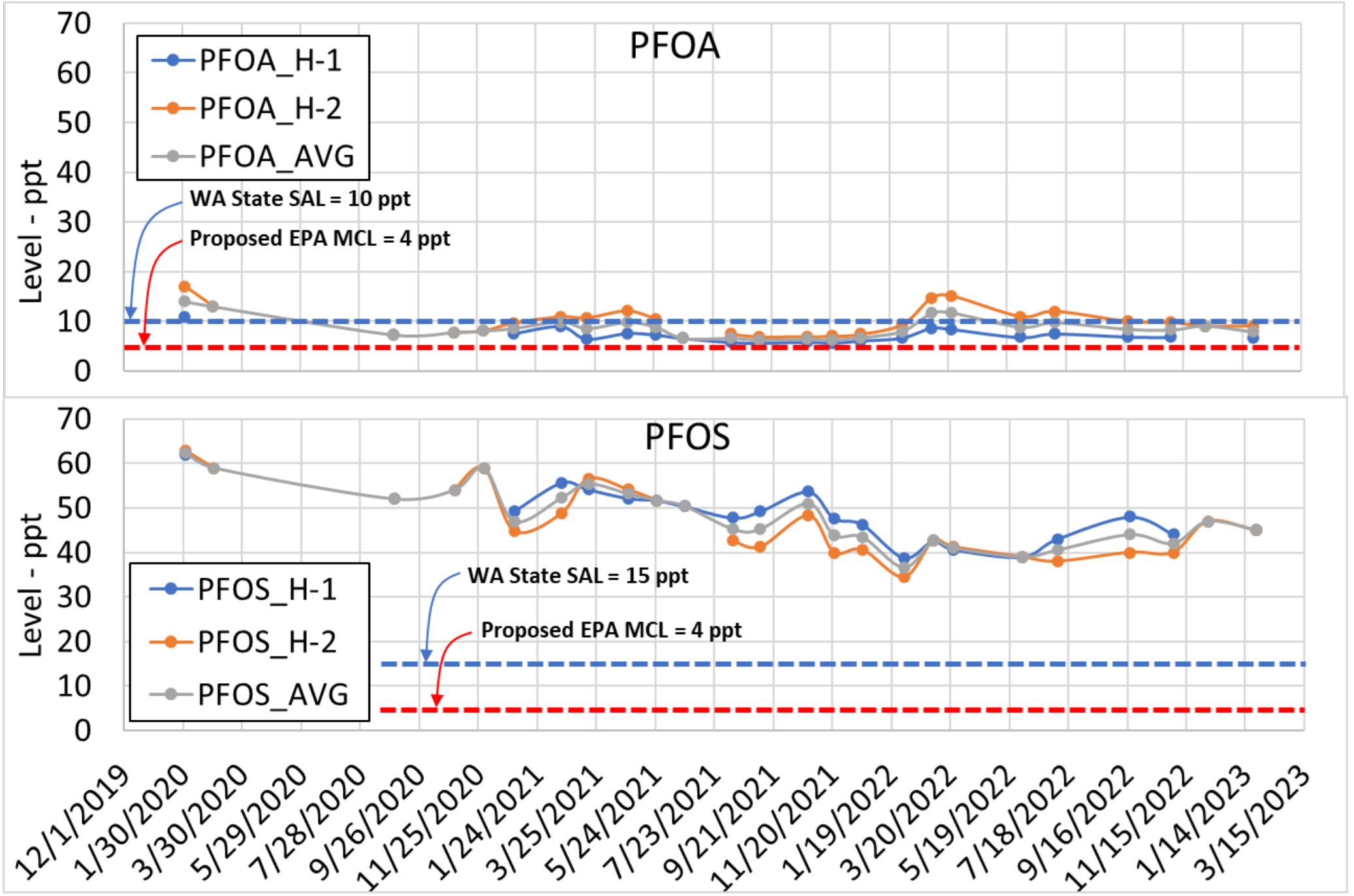
Perfluorohexane sulphonic acid (PFHxS – C6)



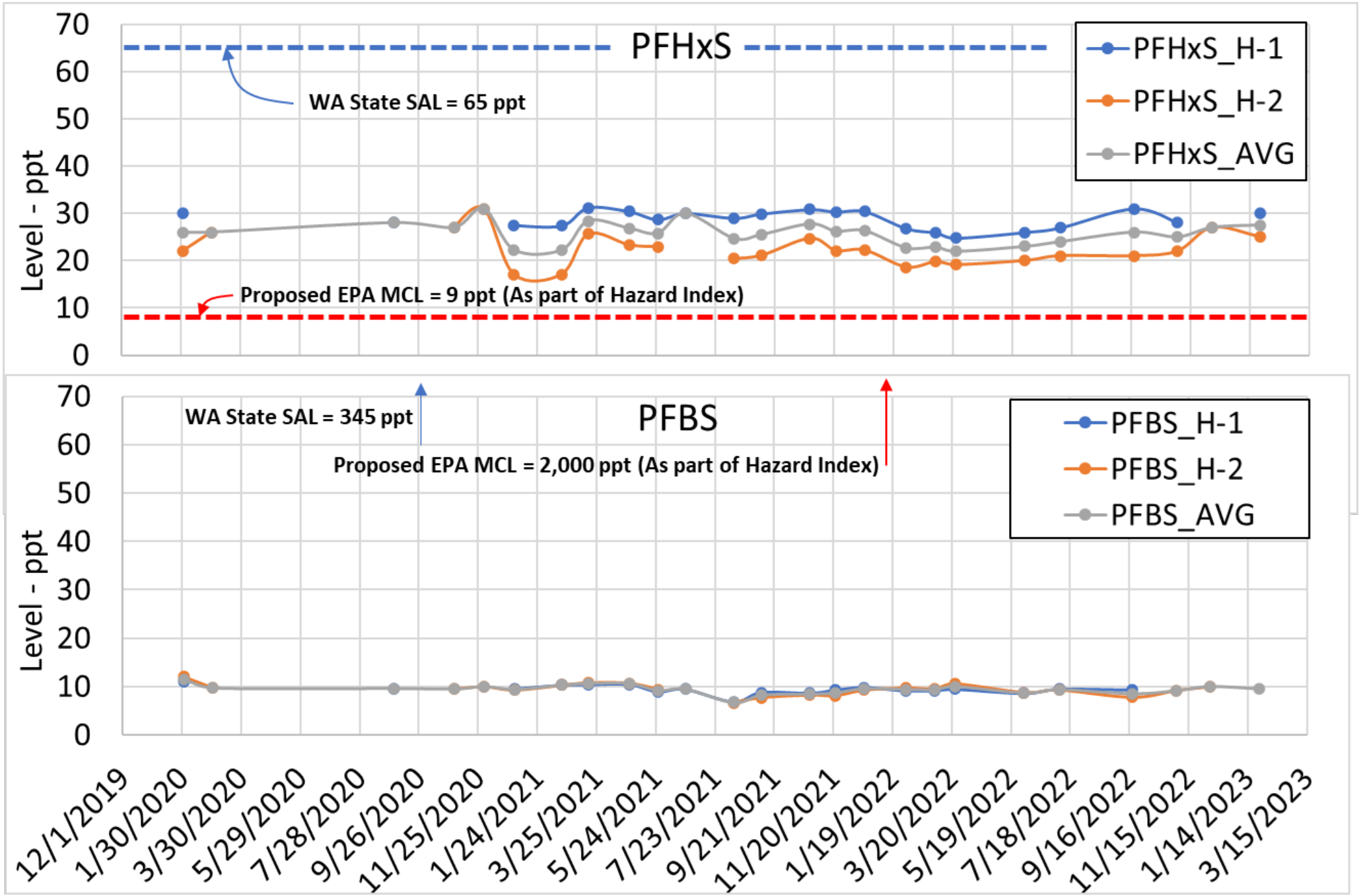
Perfluorobutane sulfonic acid (PFBS – C4)

PFAS

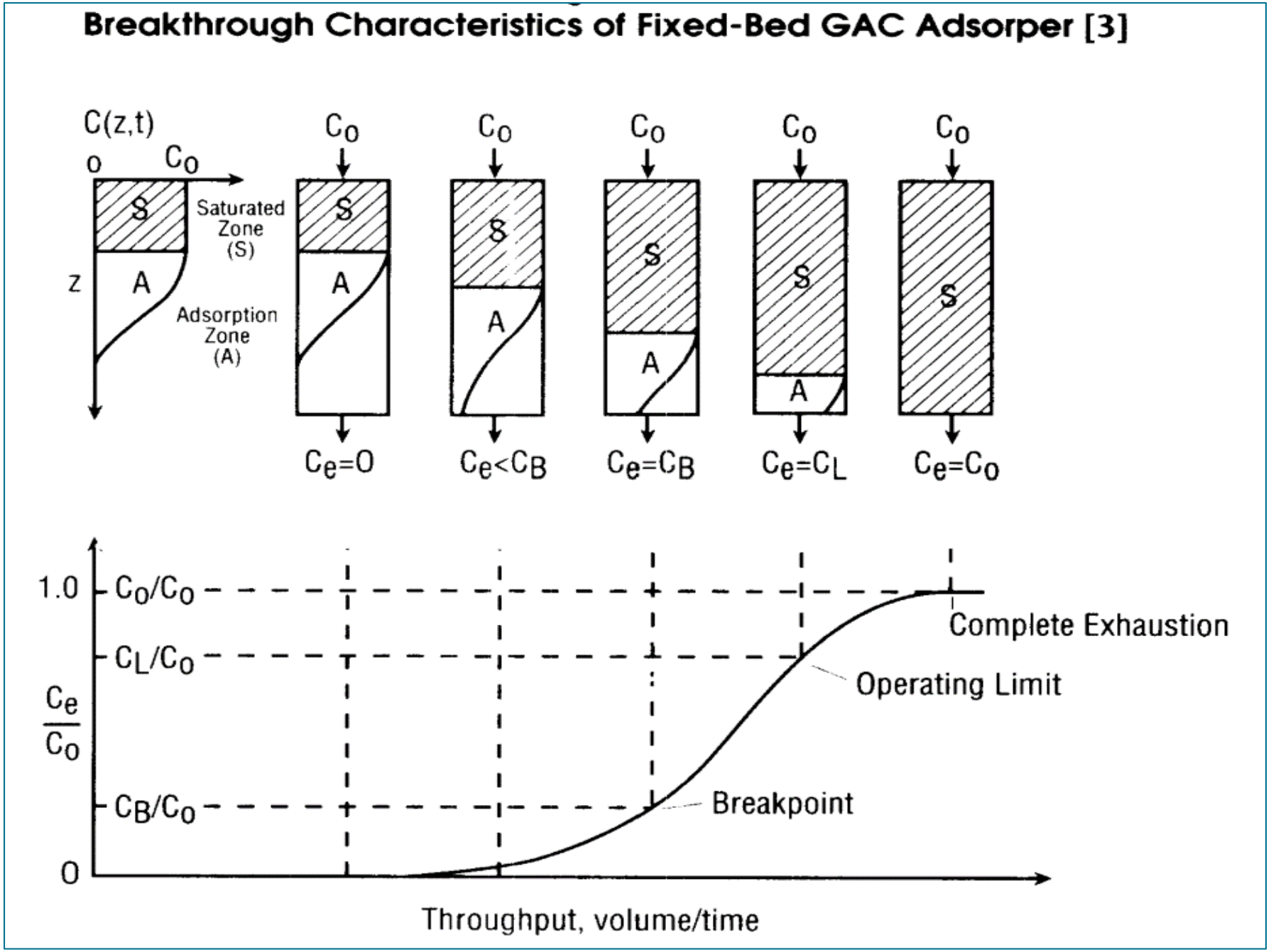
Ponders Raw Water PFAS Levels



Ponders Raw Water PFAS Levels



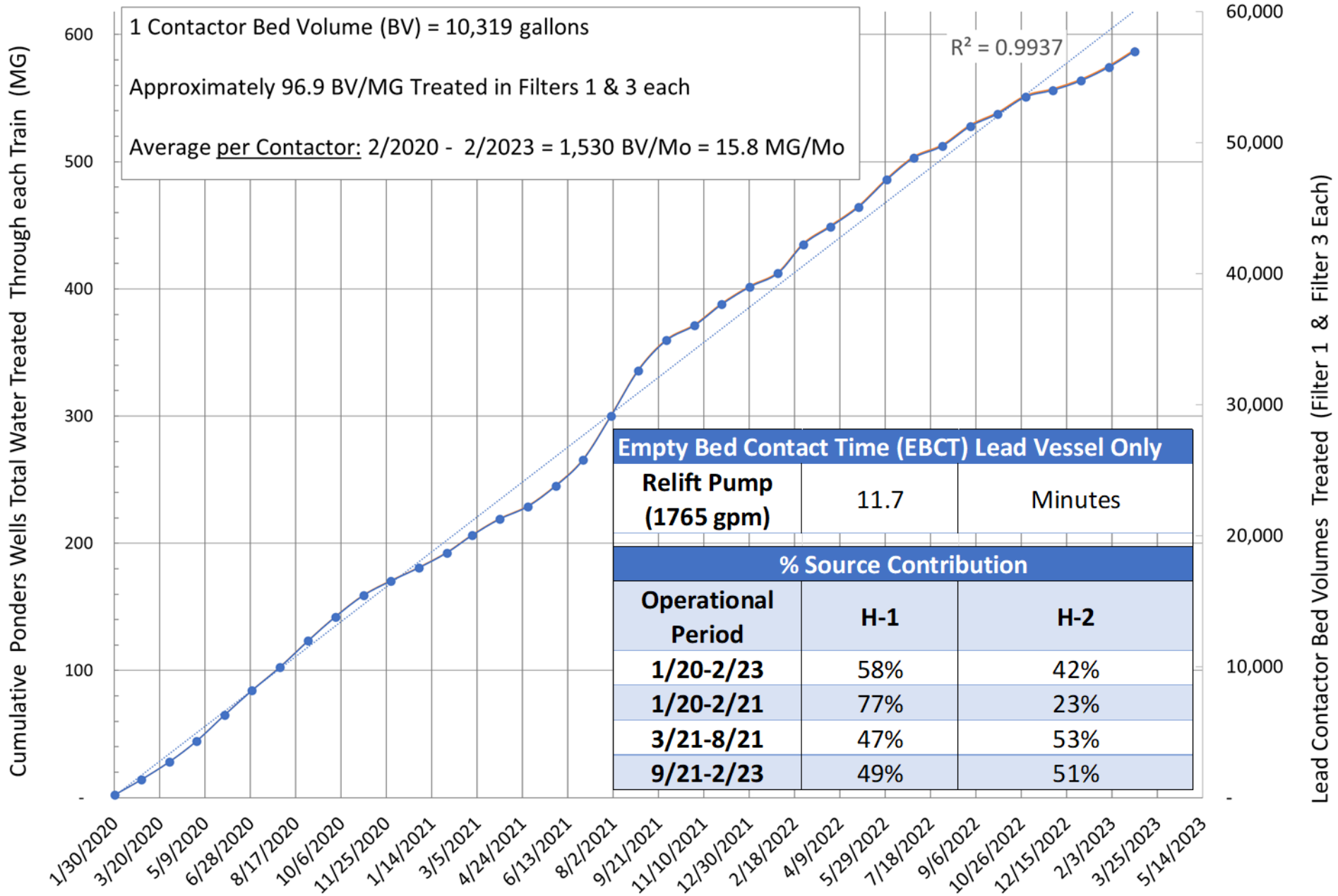
Classic Breakthrough Curve



Source: Weber, 1984

Process Monitoring Approach

Tracking Process Flow: Time and Bed Volumes



Empty Bed Contact Time (EBCT) Lead Vessel Only		
Relift Pump (1765 gpm)	11.7	Minutes

% Source Contribution		
Operational Period	**H-1**	**H-2**
1/20-2/23	58%	42%
1/20-2/21	77%	23%
3/21-8/21	47%	53%
9/21-2/23	49%	51%

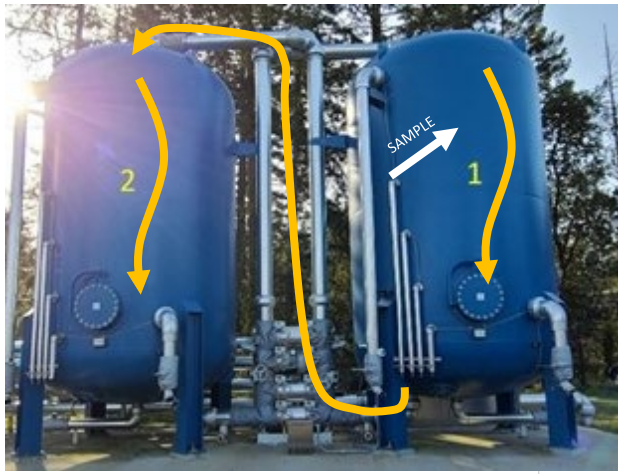
Process Sampling Regime

- Part of a system-wide monitoring program
- Must demonstrate compliance
  - Utility Policy Direction
- Track "progress" of multiple contaminants
- Balance data visibility with Cost

GAC Contactor Monitoring Data: PFOS All Results in ng/L = parts per trillion (ppt)									
		TRAIN 2 - FILTER 3				TRAIN 2 - FILTER 4			
Date	PFOS Source	Top (25%)	Middle (50%)	Bottom (75 %)	100%	Top (25%	Middle (50%)	Bottom (75 %)	100%
20-Feb	62.5	0							
20-Mar	60.8								
20-Sep	52.0	4.3							
20-Nov	54.0				0	0			0
20-Dec	59.0	6.4			0				
21-Jan	47.0		0	0					
21-Feb	52.3			0		0			
21-Mar	55.4			0		0			
21-Apr	53.2			0				0	
21-May	51.7			0				0	
21-Jun	50.4			0				0	
21-Aug	45.3					0		0	
21-Sep	45.2	33.2	14.3	3.9		0		0	
21-Oct	51.0	25.8	9.0	2.3				0	
21-Nov	43.9			0					
21-Dec / **22-Feb**	43.5					0		0	
22-Feb	36.6					0		0	
Mar 3-22	42.7		14.1	4.2		0		0	
Mar 23-22	41.0			3.4		0		0	
22-Jun	39.0	31.0	16.0	6.2		0	0	0	
22-Jul	40.5					0			
22-Sep	44.0	27.0	13.0	4.9		0	0	0	
22-Nov	42.0		6.0	5.5		0		0	
22-Dec	47.0					0		0	
23-Jan	45.0		17.0	6.1		0		0	

Date	PFHxS Raw	The following Tables show breakthrough in terms of allowable maximum level of PFHxS @ this treatment goal:									9	ppt	
2/1/2020	26.0												
3/1/2020	26.0	Date	F1 Top	F1-Top-Ce/Ca	Date	F1 Middle	-Middle-Ce/	Date	F1 Bottom	-Bottom-Ce/	Date	F2 Top	F2-Top-Ce/Ca
9/1/2020	28.0	9/1/2020	5.2	0.58	9/8/2021	13.5	1.50	9/8/2021	4.8	0.54	2/1/2022	0.0	0.00
11/1/2020	27.0	12/1/2020	5.4	0.60	11/22/2021	10.6	1.18	11/22/2021	3.3	0.37	3/3/2022	2.9	0.32
12/1/2020	31.0	9/8/2021	17.7	1.97	2/1/2022	10.6	1.18	2/1/2022	3.8	0.42	3/23/2022	2.5	0.28
1/1/2021	22.3	11/22/2021	14.4	1.60	6/1/2022	15.0	1.67	3/23/2022	5.0	0.55	6/1/2022	4.8	0.53
2/18/2021	22.3	2/1/2022	14.5	1.61	7/7/2022	15.0	1.67	6/1/2022	8.1	0.90	7/7/2022	5.1	0.57
3/17/2021	28.4	6/1/2022	19.0	2.11	12/7/2022	13.0	1.44	7/7/2022	8.4	0.93	9/19/2022	4.8	0.53
4/27/2021	26.9										11/2/2022	5.5	0.61
5/26/2021	25.8										12/7/2022	3.9	0.43
6/23/2021	30.0										1/25/2023	6.0	0.67
8/11/2021	24.7												
9/8/2021	25.5	Date	F3 Top	F3-Top-Ce/Ca	Date	F3 Middle	-Middle-Ce/	Date	F3 Bottom	-Bottom-Ce/	Date	F4 Top	F4-Top-Ce/Ca
10/27/2021	27.8	9/1/2020	7.1	0.79	9/8/2021	16.4	1.82	5/26/2021	0.0	0.00	2/1/2022	0.0	0.00
11/22/2021	26.2	12/1/2020	9.9	1.10	10/27/2021	13.0	1.44	6/23/2021	2.4	0.26	3/3/2022	2.3	0.25
12/21/2021	26.3	9/8/2021	23.0	2.56	3/3/2022	16.1	1.79	9/8/2021	9.1	1.01	6/1/2022	4.0	0.44
2/1/2022	22.7	10/27/2021	21.9	2.43	6/1/2022	17.0	1.89	10/27/2021	6.8	0.75	7/7/2022	3.6	0.40
3/3/2022	22.9	9/19/2022	23.0	2.56	9/19/2022	17.0	1.89	3/3/2022	10.2	1.13	9/19/2022	3.5	0.39
3/23/2022	22.0				11/2/2022	19.0	2.11	3/23/2022	9.0	1.00	11/2/2022	4.2	0.47
6/1/2022	23.0				1/25/2023	20.0	2.22	6/1/2022	13.0	1.44	12/7/2022	2.8	0.31
7/7/2022	24.0							9/19/2022	11.0	1.22	1/25/2023	4.4	0.49
9/19/2022	26.0							11/2/2022	13.0	1.44			
11/2/2022	25.0							1/25/2023	14.0	1.56			
12/7/2022	27.0												
1/25/2023	27.5												

Brief Data Review



Ponders PFBS Chart

PFBS Concentration (ppt)

Raw PFBS
F1 Top
F3 Top

SOURCE RAW WATER
F3-TOP
F1-TOP

16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0

12/1/19
12/31/19
1/30/20
2/29/20
3/30/20
4/29/20
5/29/20
6/28/20
7/28/20
8/27/20
9/26/20
10/26/20
11/25/20
12/25/20
1/24/21
2/23/21
3/25/21
4/24/21
5/24/21
6/23/21
7/23/21
8/22/21
9/21/21
10/21/21
11/20/21
12/20/21
1/19/22
2/18/22
3/20/22
4/19/22
5/19/22
6/18/22
7/18/22
8/17/22
9/16/22
10/16/22
11/15/22
12/15/22
1/14/23
2/13/23
3/15/23
4/14/23

Lead Vessel in Train 2 (Filter 3)
Breaking through first 25% GAC faster
EBCT ≈ 3 mins (To Top Port)

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Ponders PFBS Chart

Raw PFBS
F1 Bottom
F3 Bottom

PFBS Concentration (ppt)

16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0

SOURCE RAW WATER

F3-BOTTOM

F1-BOTTOM

12/1/19
12/31/19
1/30/20
2/29/20
3/30/20
4/29/20
5/29/20
6/28/20
7/28/20
8/27/20
9/26/20
10/26/20
11/25/20
12/25/20
1/24/21
2/23/21
3/25/21
4/24/21
5/24/21
6/23/21
7/23/21
8/22/21
9/21/21
10/21/21
11/20/21
12/20/21
1/19/22
2/18/22
3/20/22
4/19/22
5/19/22
6/18/22
7/18/22
8/17/22
9/16/22
10/16/22
11/15/22
12/15/22
1/14/23
2/13/23
3/15/23
4/14/23

Lead Vessel in Train 2 (Filter 3) still Breaking through first 50% GAC faster
EBCT ≈ 9 mins (To Bottom Port)

Ponders PFBS Chart

PFBS Concentration (ppt)

Raw PFBS
F2 Top
F4 Top

SOURCE RAW WATER

F2-TOP
F4-TOP

Top Port in Lag Vessels show breakthrough similar in both **Trains**
EBCT ≈ 15 mins (To Top Port-Lag Filter)

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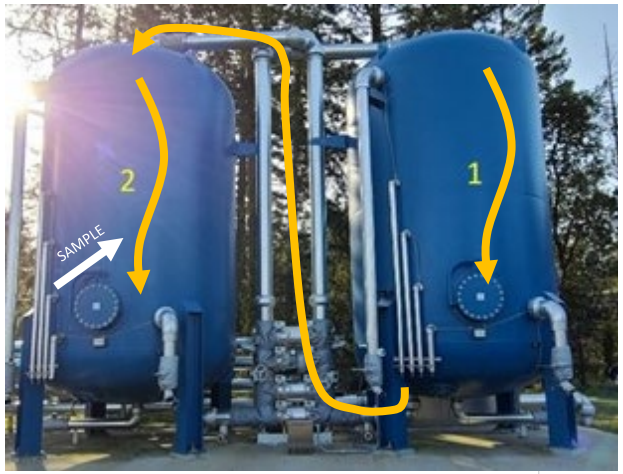


Ponders PFBS Chart

PFBS Concentration (ppt)

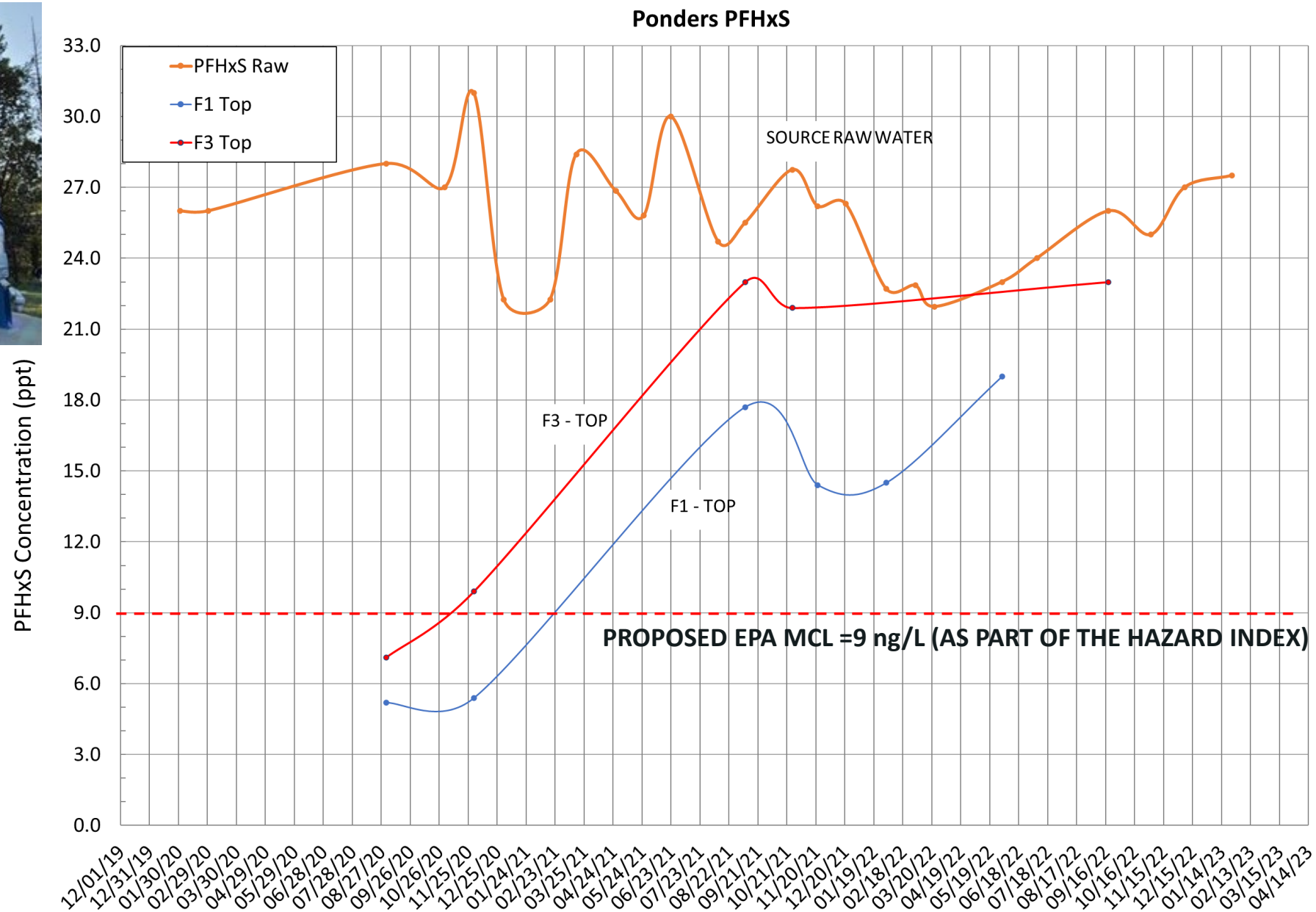
Raw PFBS
F2 Bottom
F4 Bottom

SOURCE RAW WATER

F2-BOTTOM

F4-BOTTOM

Bottom Port in Lag Vessels show
Train 1 now breaking through earlier
EBCT ≈ 20.5 mins



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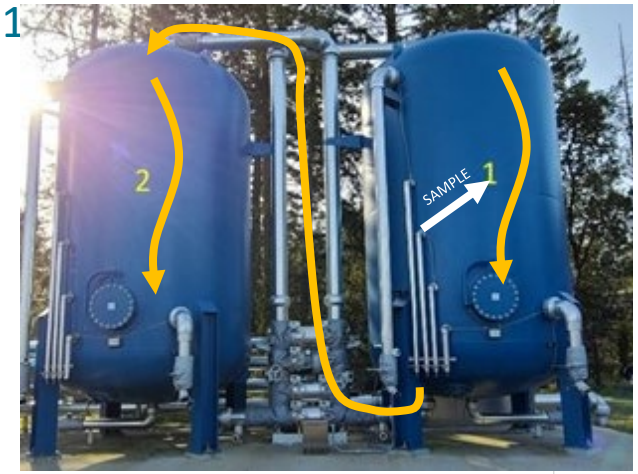

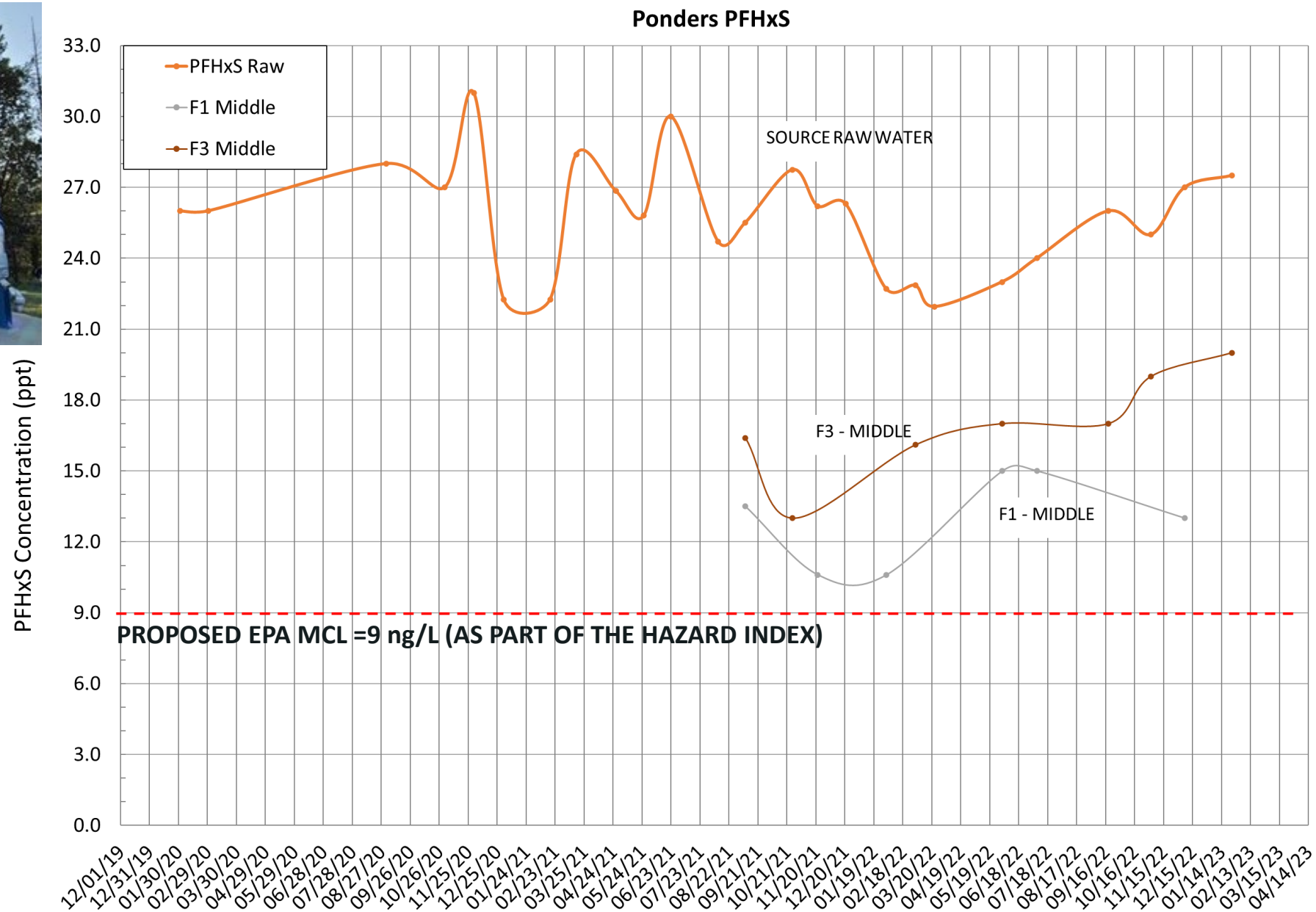

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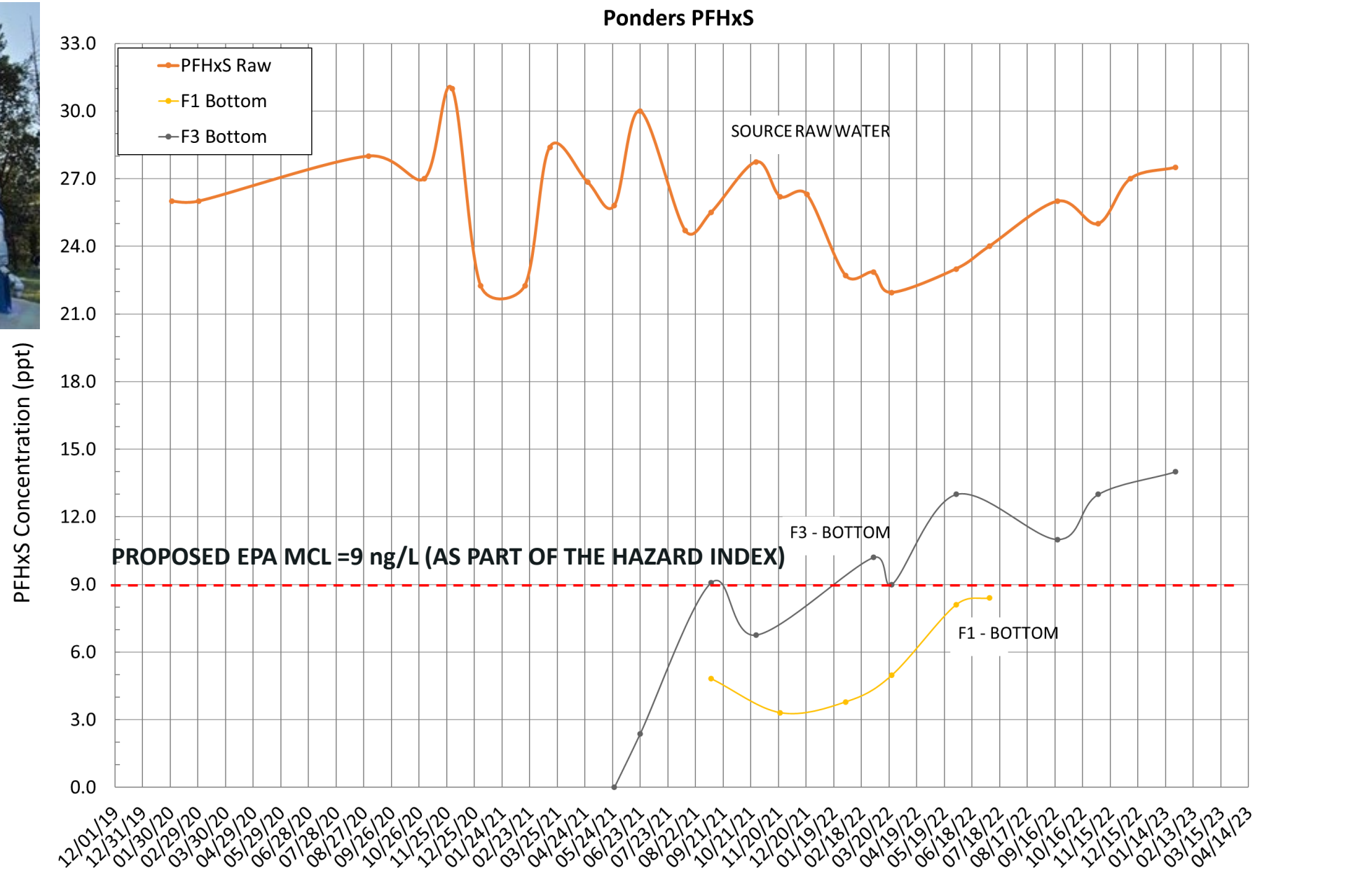

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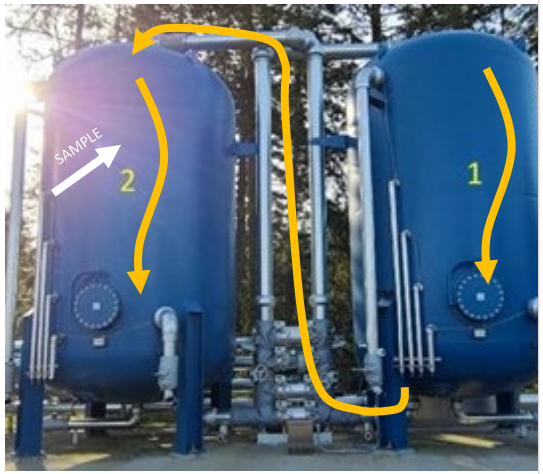

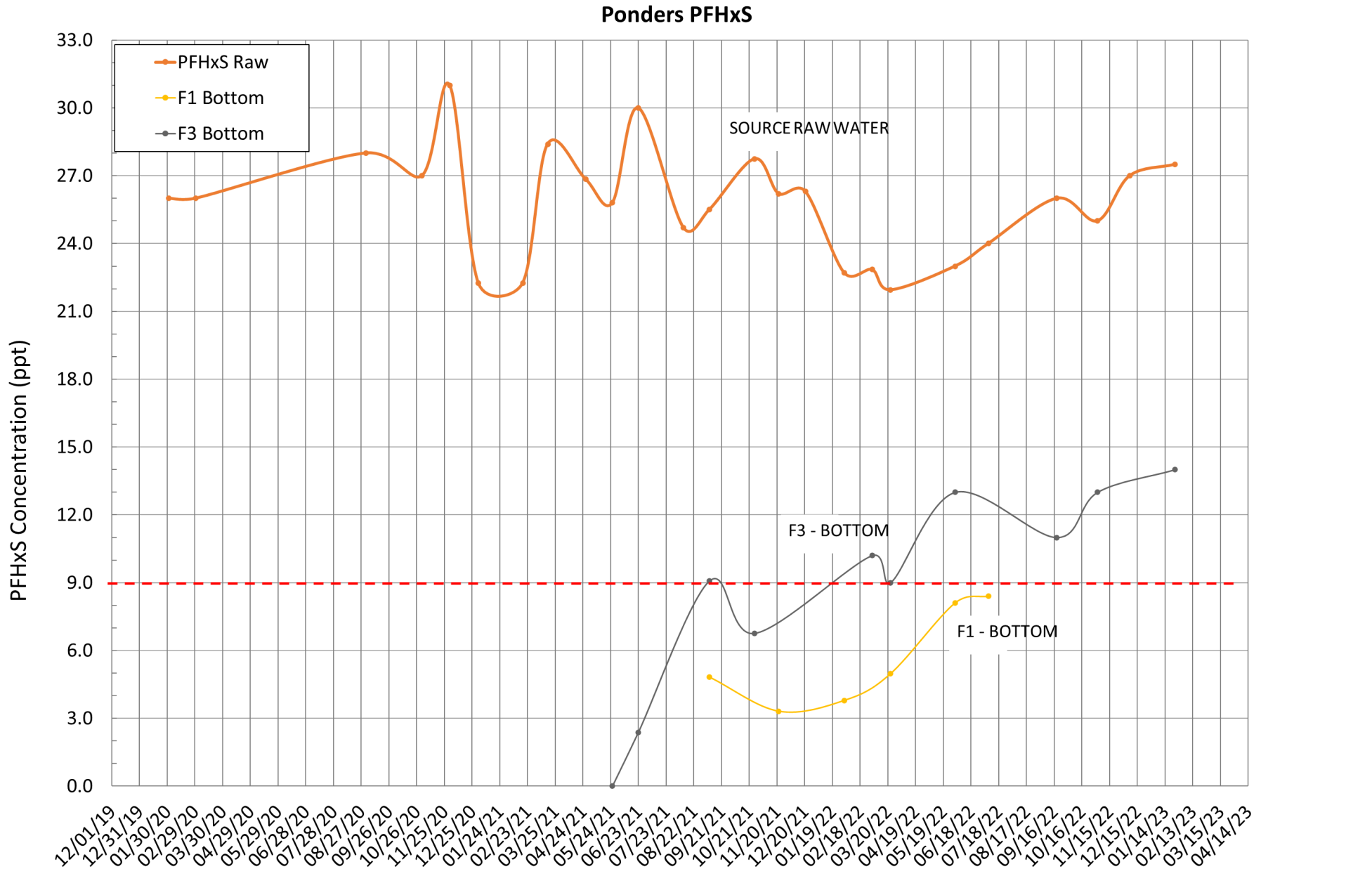

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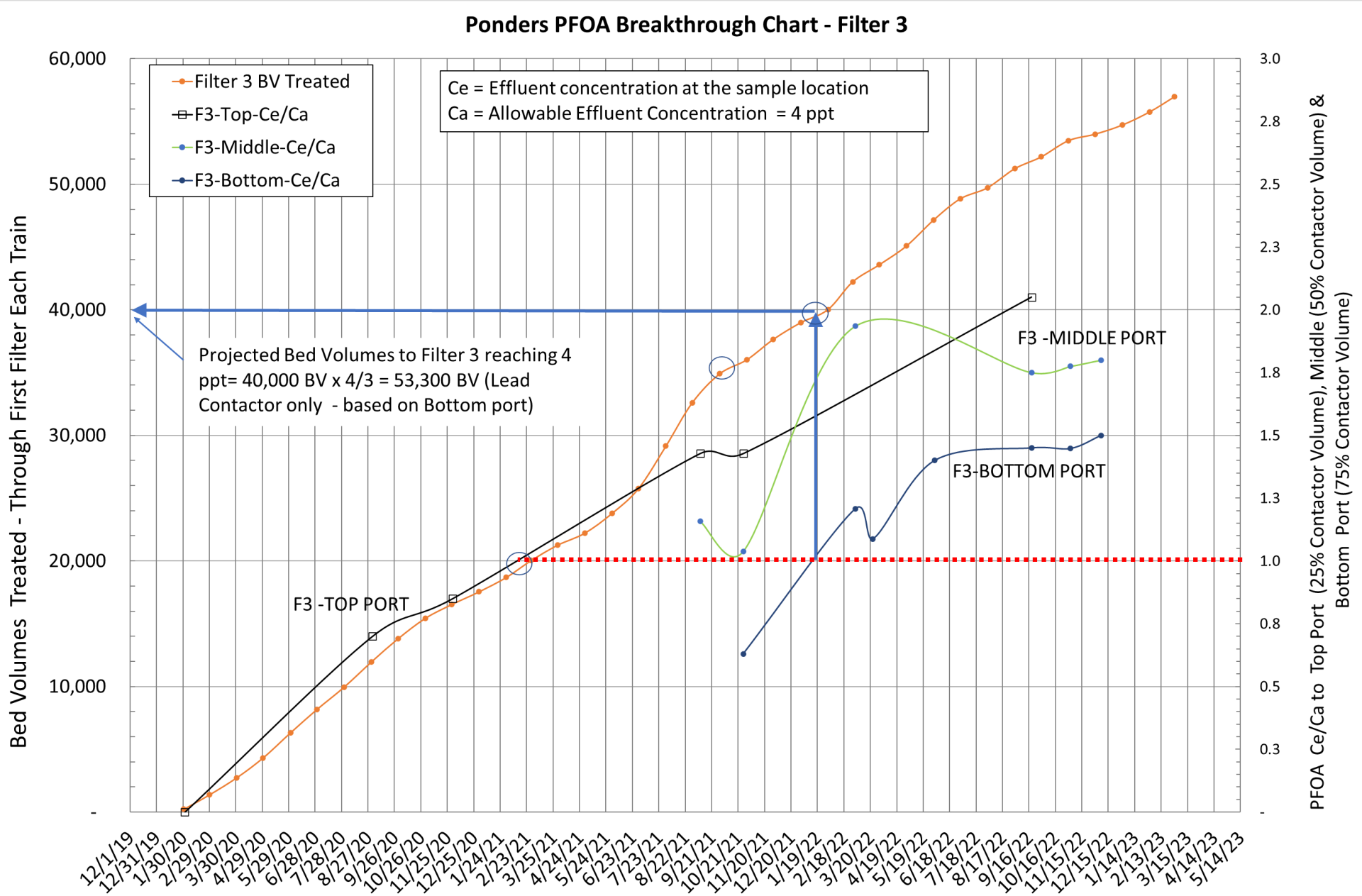
Carbon Utilization


Ponders PFOA Breakthrough Chart - Filter 3
Filter 3 BV Treated
F3-Top-Ce/Ca
F3-Middle-Ce/Ca
F3-Bottom-Ce/Ca
Ce = Effluent concentration at the sample location
Ca = Allowable Effluent Concentration = 4 ppt
Projected Bed Volumes to Filter 3 reaching 4 ppt= 40,000 BV x 4/3 = 53,300 BV (Lead Contactor only - based on Bottom port)
F3 -TOP PORT
F3 -MIDDLE PORT
F3-BOTTOM PORT
Bed Volumes Treated - Through First Filter Each Train
PFOA Ce/Ca to Top Port (25% Contactor Volume), Middle (50% Contactor Volume) & Bottom Port (75% Contactor Volume)
60,000
50,000
40,000
30,000
20,000
10,000
-
3.0
2.8
2.5
2.3
2.0
1.8
1.5
1.3
1.0
0.8
0.5
0.3
-
12/1/19
12/31/19
1/30/20
2/29/20
3/30/20
4/29/20
5/29/20
6/28/20
7/28/20
8/27/20
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3/15/23
4/14/23
5/14/23

Carbon Utilization Rate

$$CUR = \frac{M_{GAC}}{BV_{Ca}\, x\, Vol_{bed}}$$

Where:

CUR = Carbon Utilization Rate – mg Carbon used / L water treated @ Breakthrough

M_{GAC} = GAC Mass to the Ce=Ca breakthrough point (=0.75 x 18,144 = 13,608 Kg @ Bottom Tap)

BV_{ca} = Bed Volumes treated

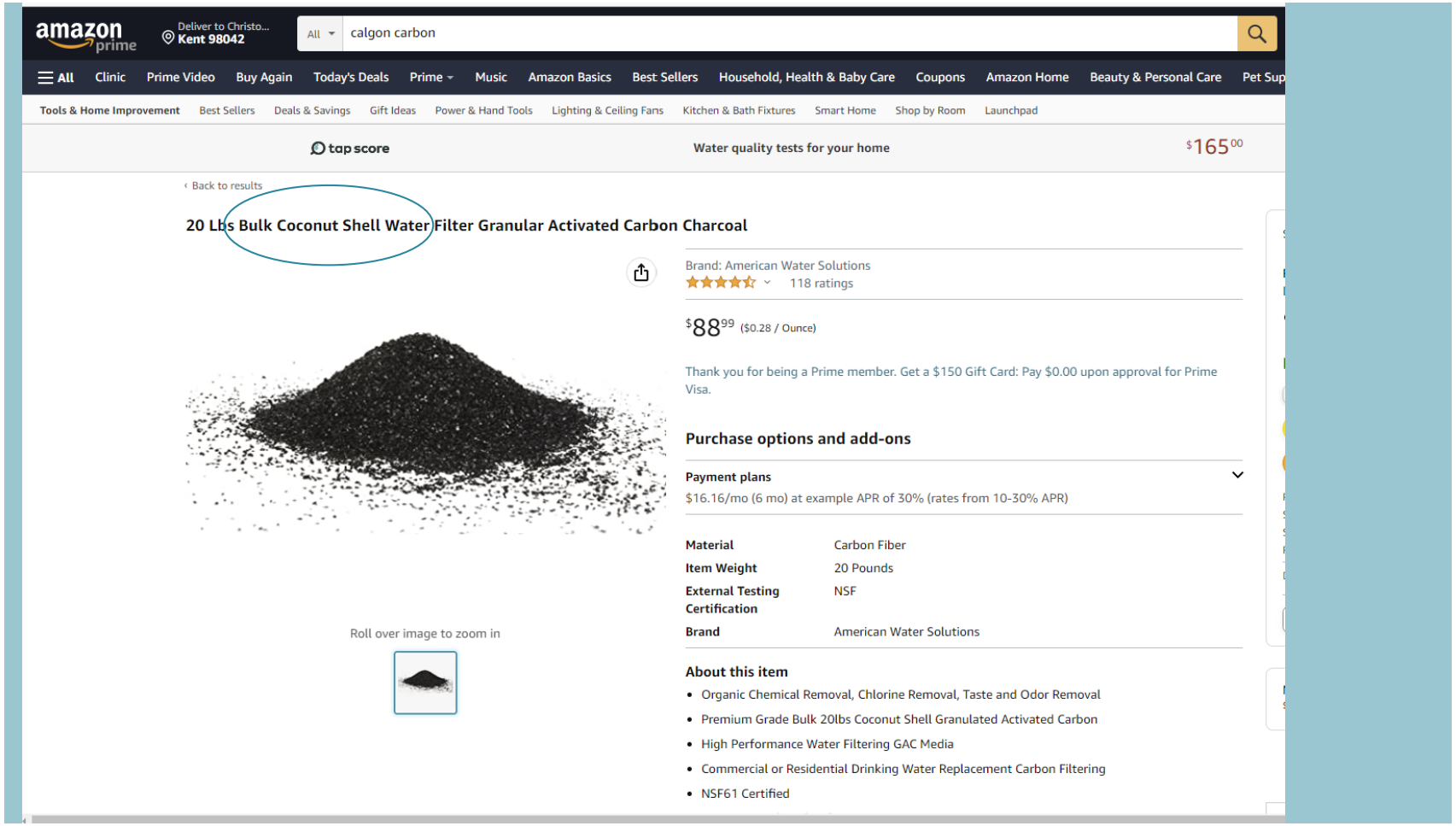
Vol_{bed} = Filter Bed Volume (10,319 gal = 36,058 Liters)

Kempisty, D.M., et al. (2022) Granular activated carbon adsorption of perfluoroalkyl acids from ground and surface water. *AWWA Wat. Sci.* https://doi.org/10.1002/aws2.1269

Carbon Utilization Rate

	Train 1 Filter 1 Bottom Tap		Train 2 Filter 3 Bottom Tap		Carbon Utilization Rate (CUR)[2]		Safety Factor
Contaminant	BVa[1]	Approx. Date	BVa[1]	Approx. Date	F1- CUR (mg Carbon/ Liter Treated)	F3- CUR (mg Carbon/ Liter Treated)	1.25x CUR (mg Carbon/ Liter Treated)
PFOA 4 ppt (Ca/Co≈0.5)	46,000	5/13/22	40,000	2/1/22	7.6	8.7	10.9
PFOS 4 ppt (Ca/Co≈0.1)	N/A[3]	N/A	43,000	3/20/22	N/A	8.1	10.1
PFHxS 9 ppt (Ca/Co≈0.3)	49,000	7/5/22	40,000	2/1/22	7.1	8.7	10.9
PFBS (Ce/Co=0.5)	26,000	7/2/21	23,000	5/15/21	13.4	15.1	18.9

1. BVa: Bed Volumes Treated through the **lead filter** in each train when Ce = Ca at Bottom port.
2. CUR: mass (mg) of GAC required to treat a volume (L) of water to a treatment target Ca for a given PFAS compound (PFOA & PFOS = 4 ppt, PFHxS = 9 ppt). A PFBS target effluent of Ce/Co=0.5 selected for analysis only.
3. Insufficient data to estimate.



Projecting Filter Life

		Lead Filters 1/3				Lag Filters 2/4			
		Top	Middle	Bottom	End	Top	Middle	Bottom	End
Carbon Available (Kg)[1]		4,536	9,072	13,608	18,144	22,680	27,216	31,752	36,287
PFOA **4 ppt (C/Co≈0.5)**	BV_{Ca} Treated[2]	13,333	26,667	40,000	53,333	66,667	80,000	93,333	106,667
	Arrival Date	10/5/20	6/10/21	2/13/22	10/19/22	6/24/23	2/27/24	**11/1/24**	7/7/25
PFOS **4 ppt (C/Co≈0.1)**	BV_{Ca} Treated[2]	14,333	28,667	43,000	57,333	71,667	86,000	100,333	114,667
	Arrival Date	10/24/20	7/17/21	4/10/22	1/1/23	9/25/23	6/18/24	**3/11/25**	12/3/25
PFHxS **9 ppt (C/Co≈0.3)**	BV_{Ca} Treated[2]	13,333	26,667	40,000	53,333	66,667	80,000	93,333	106,667
	Arrival Date	10/5/20	6/10/21	2/13/22	10/19/22	6/24/23	2/27/24	**11/1/24**	7/7/25
PFBS[3]	BV_{Ca} Treated[2]	7,667	15,333	23,000	30,667	38,333	46,000	53,667	61,333
	Arrival Date	6/22/20	11/11/20	4/3/21	8/23/21	1/13/22	6/5/22	10/25/22	3/17/23

1. Carbon available is the cumulative amount through lead and lag filters to the identified location or sample port.
2. Bed Volumes **(BV_{Ca} Treated) is calculated** based on the volume of a single filter (10,319 gallons = 39,508 Liters)
3. PFBS endpoint is Ce/Co = 0.5 used for comparison to actual performance data.

Applying 1.25 Safety Factor

		Lead Filters 1/3				Lag Filters 2/4			
		Top	Middle	Bottom	End	Top	Middle	Bottom	End
Carbon Available (Kg)[1]		4,536	9,072	13,608	18,144	22,680	27,216	31,752	36,287
PFOA 4 ppt (C/Co≈0.5)	BV Treated	10,667	21,333	32,000	42,667	53,333	64,000	74,667	85,333
	Arrival Date	8/16/20	3/3/21	9/17/21	4/4/22	10/19/22	5/5/23	**11/20/23**	6/5/24
PFOS 4 ppt (C/Co≈0.1)	BV Treated	11,467	22,933	34,400	45,867	57,333	68,800	80,267	91,733
	Arrival Date	8/31/20	4/2/21	11/1/21	6/2/22	1/1/23	8/3/23	**3/3/24**	10/2/24
PFHxS 9 ppt (C/Co≈0.3)	BV Treated	10,667	21,333	32,000	42,667	53,333	64,000	74,667	85,333
	Arrival Date	8/16/20	3/3/21	9/17/21	4/4/22	10/19/22	5/5/23	**11/20/23**	6/5/24
PFBS[3]	BV Treated	6,133	12,267	18,400	24,533	30,667	36,800	42,933	49,067
	Arrival Date	5/24/20	9/15/20	1/7/21	5/1/21	8/23/21	12/15/21	4/9/22	8/1/22

Carbon Changeout Date Projection

PFOA: Early: **Nov. 2023** **Late: Nov. 2024**

PFOS: Early: **March 2024** **Late: March 2025**

PFHxS: Early: **Nov. 2023** **Late: Nov. 2024**

If GAC replacement is based on State SALs, these dates can be significantly later.

Tracking breakthrough in the lag vessels will sharpen the estimate.

Forward Looking Monitoring Regime

Period (Months)[1]	Raw Water H-1&H-2	LEAD				LAG			POE
		Top (25%)	Middle (50%)	Bottom (75%)	Between Lead-Lag	Top (25%)	Middle (50%)	Bottom (75%)	
1-12	M	M							Q[2]
13-18	M	B[3]	M						Q[2]
19-24	M	Q[2]	B[3]	M					Q[2]
25-30	M		Q[2]	B[3]	M				Q[2]
31-36	M			Q[2]	B[3]	M			Q[2]
37-42	M				Q[2]	B[3]	M		Q[2]
43-48	M					Q[2]	B[3]	M	Q[2]

Notes

1. Estimated Timeline: Shift monthly monitoring to next port after Ce = 4 ppt (PFOS or PFOA), or PFHxS = 9 ppt

2. Quarterly

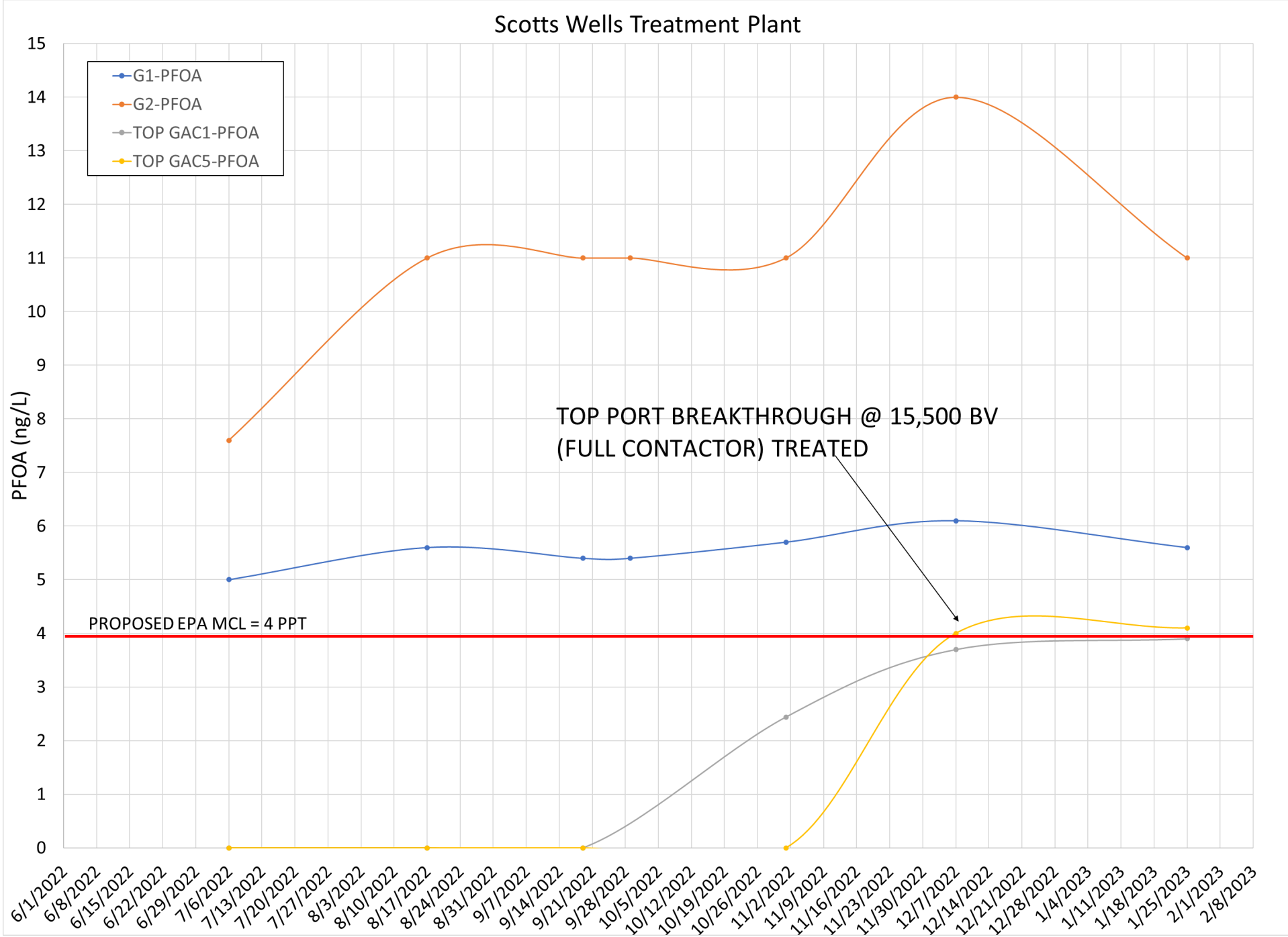
3. Bimonthly

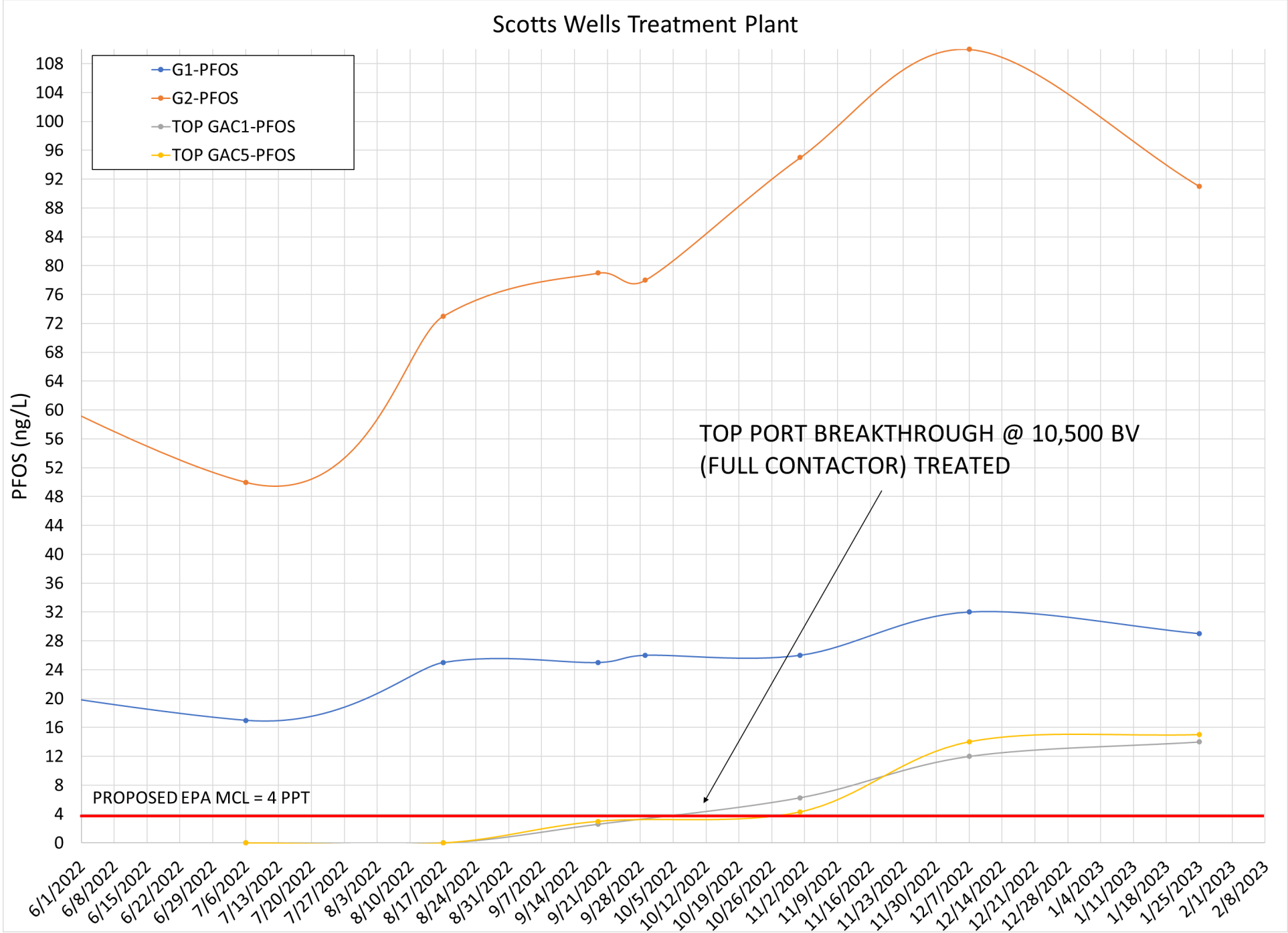
Three Trains
Plant Flow ~ 2,200 GPM
EBCT ~ 14 minutes (Lead Vessel)

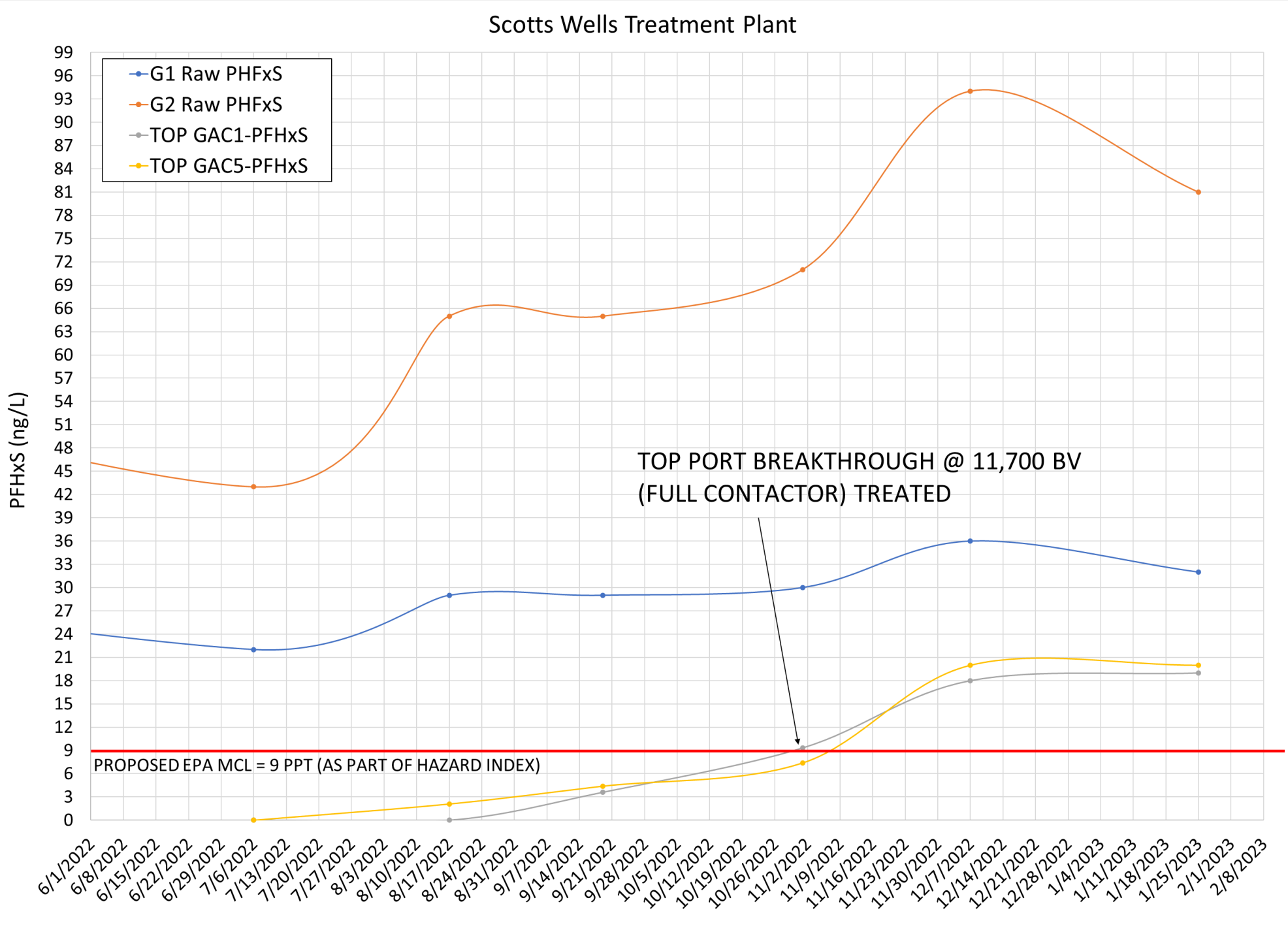
Wells G-1 & G-2
Same Site
Same Well log
Same Screened Interval

G-2 [PFOA]≈ 1.8 x G-1[PFOA]
G-2 [PFOS] ≈ 3.0 x G-1[PFOS]
G-2 [PFHxS] ≈ 2.0 x G-1[PFHxS]

First Look at Scotts Data


Scotts Wells Treatment Plant
G1-PFOA
G2-PFOA
TOP GAC1-PFOA
TOP GAC5-PFOA
PFOA (ng/L)
TOP PORT BREAKTHROUGH @ 15,500 BV
(FULL CONTACTOR) TREATED
PROPOSED EPA MCL = 4 PPT
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
6/1/2022
6/8/2022
6/15/2022
6/22/2022
6/29/2022
7/6/2022
7/13/2022
7/20/2022
7/27/2022
8/3/2022
8/10/2022
8/17/2022
8/24/2022
8/31/2022
9/7/2022
9/14/2022
9/21/2022
9/28/2022
10/5/2022
10/12/2022
10/19/2022
10/26/2022
11/2/2022
11/9/2022
11/16/2022
11/23/2022
11/30/2022
12/7/2022
12/14/2022
12/21/2022
12/28/2022
1/4/2023
1/11/2023
1/18/2023
1/25/2023
2/1/2023
2/8/2023


Scotts Wells Treatment Plant
G1-PFOS
G2-PFOS
TOP GAC1-PFOS
TOP GAC5-PFOS
PFOS (ng/L)
TOP PORT BREAKTHROUGH @ 10,500 BV
(FULL CONTACTOR) TREATED
PROPOSED EPA MCL = 4 PPT


Scotts Wells Treatment Plant
G1 Raw PHFxS
G2 Raw PHFxS
TOP GAC1-PFHxS
TOP GAC5-PFHxS
PFHxS (ng/L)
TOP PORT BREAKTHROUGH @ 11,700 BV
(FULL CONTACTOR) TREATED
PROPOSED EPA MCL = 9 PPT (AS PART OF HAZARD INDEX)
99
96
93
90
87
84
81
78
75
72
69
66
63
60
57
54
51
48
45
42
39
36
33
30
27
24
21
18
15
12
9
6
3
0
6/1/2022
6/8/2022
6/15/2022
6/22/2022
6/29/2022
7/6/2022
7/13/2022
7/20/2022
7/27/2022
8/3/2022
8/10/2022
8/17/2022
8/24/2022
8/31/2022
9/7/2022
9/14/2022
9/21/2022
9/28/2022
10/5/2022
10/12/2022
10/19/2022
10/26/2022
11/2/2022
11/9/2022
11/16/2022
11/23/2022
11/30/2022
12/7/2022
12/14/2022
12/21/2022
12/28/2022
1/4/2023
1/11/2023
1/18/2023
1/25/2023
2/1/2023
2/8/2023

Conclusions

- GAC Adsorption with Calgon FILTRASORB® 400 media is effectively removing target PFAS
- Variable adsorption across multiple treatment trains (Ponders: YES, Scotts: NO*)
  - Different media placement and preparation
  - Flow split across filter trains
  - Sample water details
  - Differing backwash characteristics
  - GAC batch variability
- The controlling contaminant will be site specific
- Optimize monitoring programs to balance data resolution with cost

**But it is early*

Closing observation

"In closing, I reflect upon the prospect given by Baylis (3) after rediscovering the technology in his classic work on taste and odor control in the 1930's. Let him be the prophesier—"carbon (adsorption) is staging a comeback which seems destined to be permanent."

Dr. Walter Weber (1934-2018), Evolution of a Technology *J. Env. Engineering*, ASCE, 1984

Removal of PFAS in Groundwater

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Thank You!

American Water Works Association
Pacific Northwest Section

2023 Section Conference May 3-5, 2023
Kennewick, WA

LAKEWOOD WATER DISTRICT

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