



NPDES Compliance with Passive Treatment for Acid, Iron, Manganese, and Aluminum-bearing AMD

Presenter: Tim Danehy, QEP

Contributors:

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Cody “Buck” Neely, PE, Donovan M. Clayton, EIT

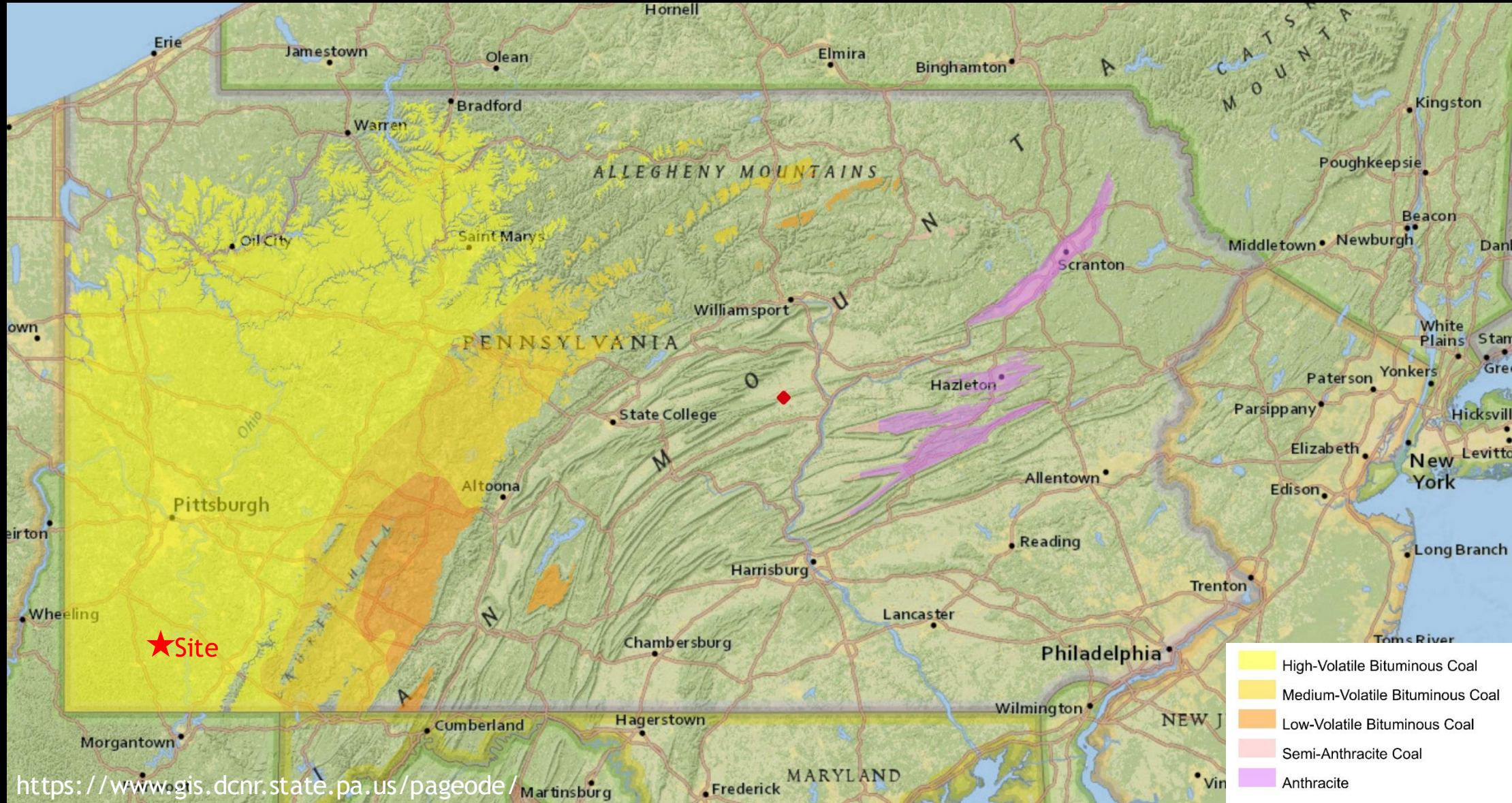
BioMost, Inc. www.biomost.com

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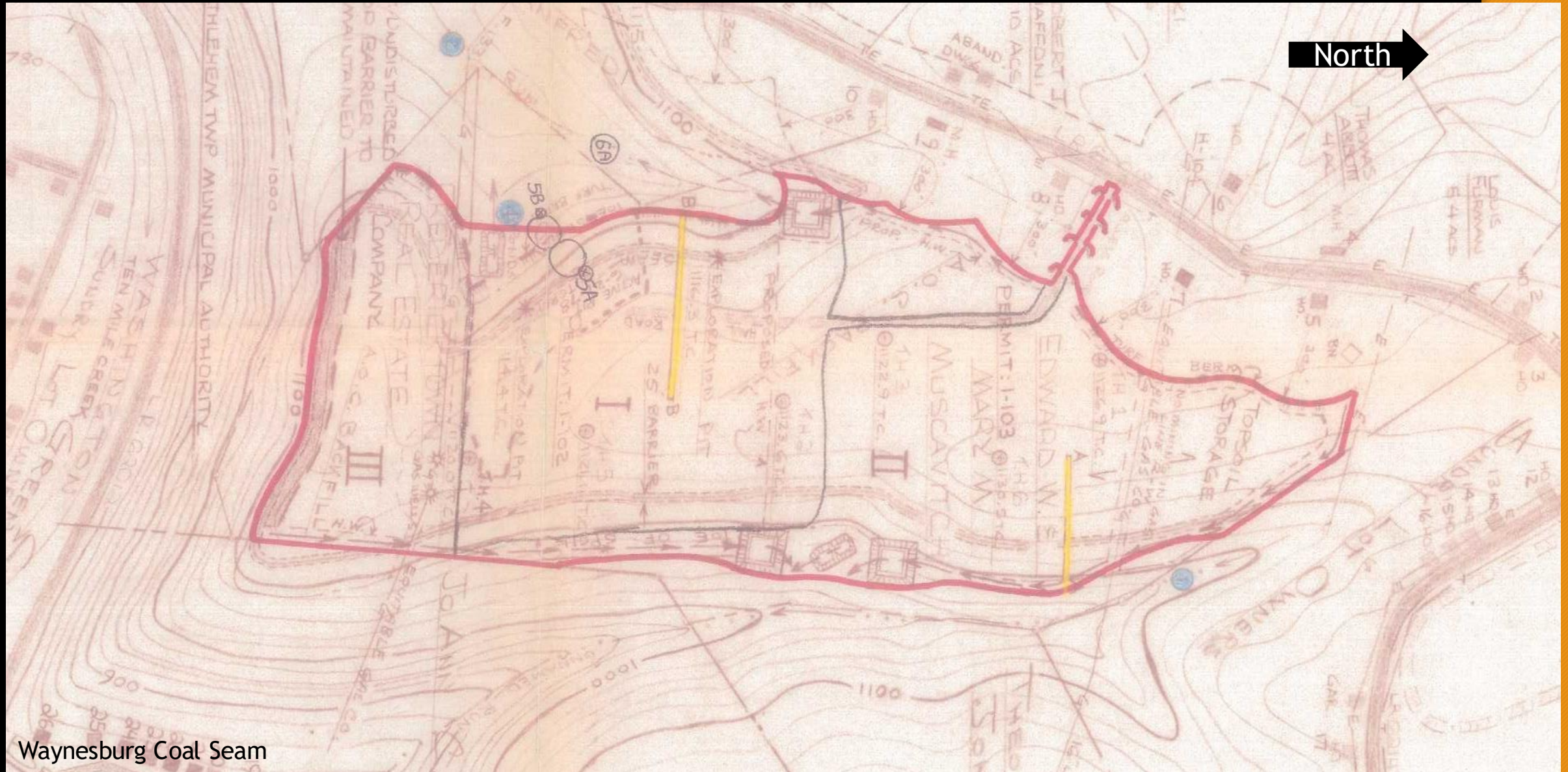
2024 Conference “Reclamation in Diverse Settings

June 2-5, 2024, Knoxville, TN

Postmining Surface Coal Mine Discharge



Muscavitch Mine (Completed c. 1984)



Muscavitch Mine (Reclaimed c. 1984)



Postmining Discharge



Previous Pump & Treat Operation

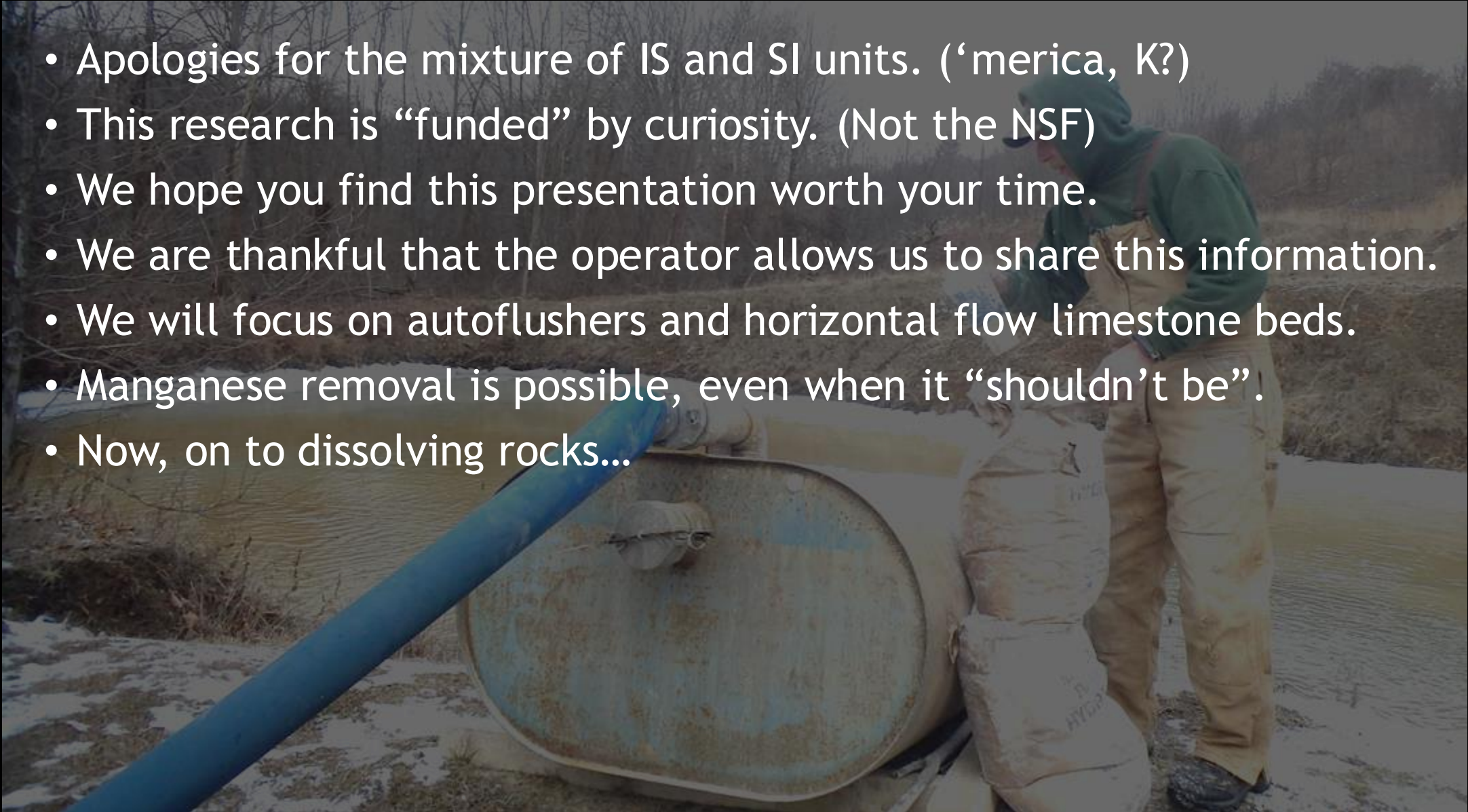


Previous Pump & Treat Operation



Before we begin...

- Apologies for the mixture of IS and SI units. ('merica, K?)
- This research is “funded” by curiosity. (Not the NSF)
- We hope you find this presentation worth your time.
- We are thankful that the operator allows us to share this information.
- We will focus on autoflushers and horizontal flow limestone beds.
- Manganese removal is possible, even when it “shouldn’t be”!
- Now, on to dissolving rocks...

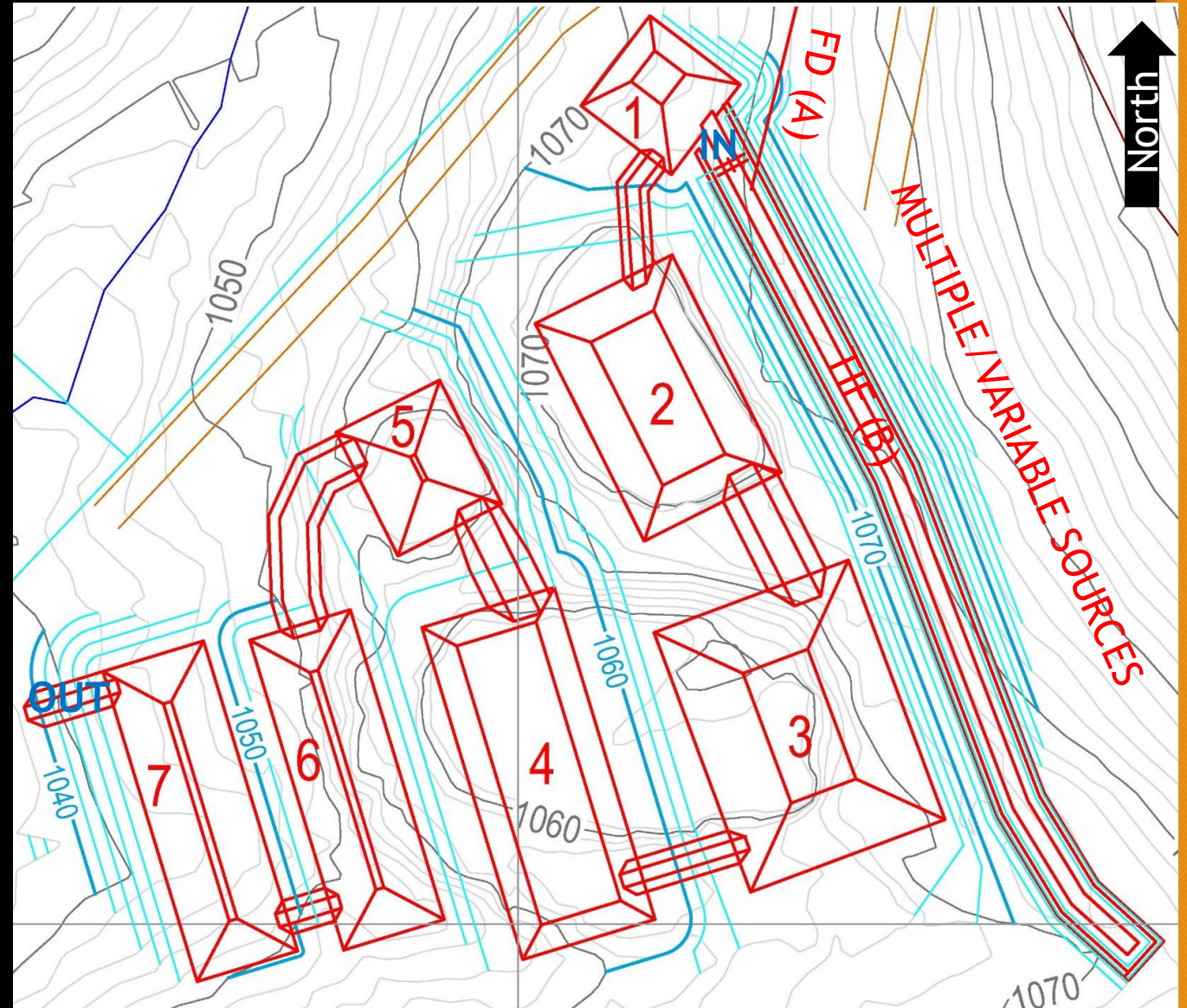


Design Characteristics & NPDES Permit Limits

	Flow Gpm Avg/Max	pH s.u.	(Hot) Acid. mg/LCaCO ₃	Fe mg/L	Mn mg/L	Al mg/L	SO ₄ mg/L	(Hot) Acid. lb/day	Fe lb/day	Mn lb/d	Al lb/d
“Design”	8 / 12	3.0	300	27	58	33	3,000	28.1	2.6	5.6	3.2
Limits (Mo. Avg)		6.0 - 9.0	<Alk.	3.0	2.0	2.0					

Treatment System

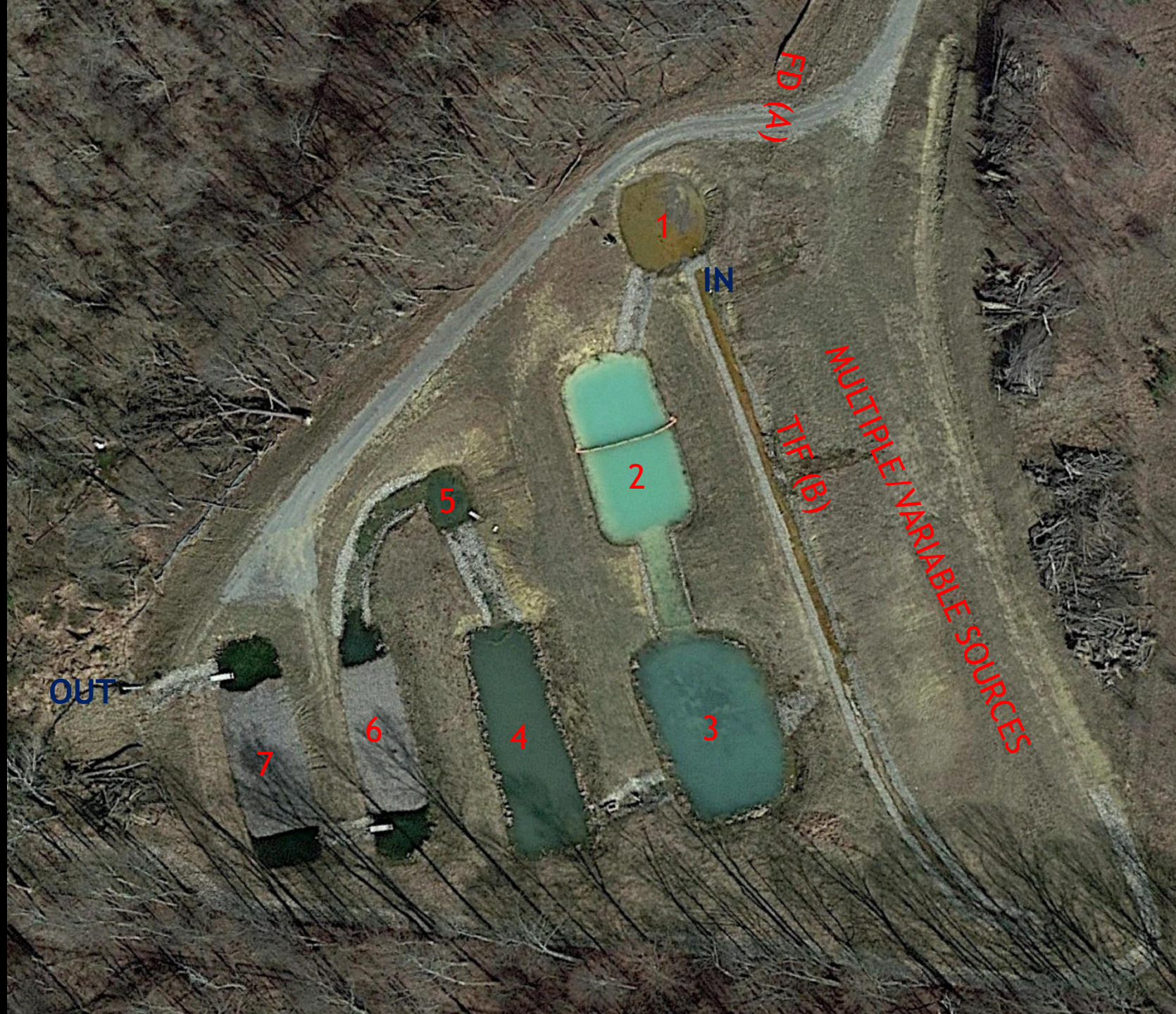
- A. 700 ft French Drain (FD)
- B. 2,000 SF TIF
- 1. 250 Ton LS-Only AFVFP
- 2. 5,000 SF Settling Pond 1
- 3. 340T/260 CY JVFP
- 4. 7,000 SF Wetland
- 5. 2,000 SF Settling Pond 2
- 6. 450 Ton HFLB 1
- 7. 450 Ton HFLB 2 (001 Outfall)



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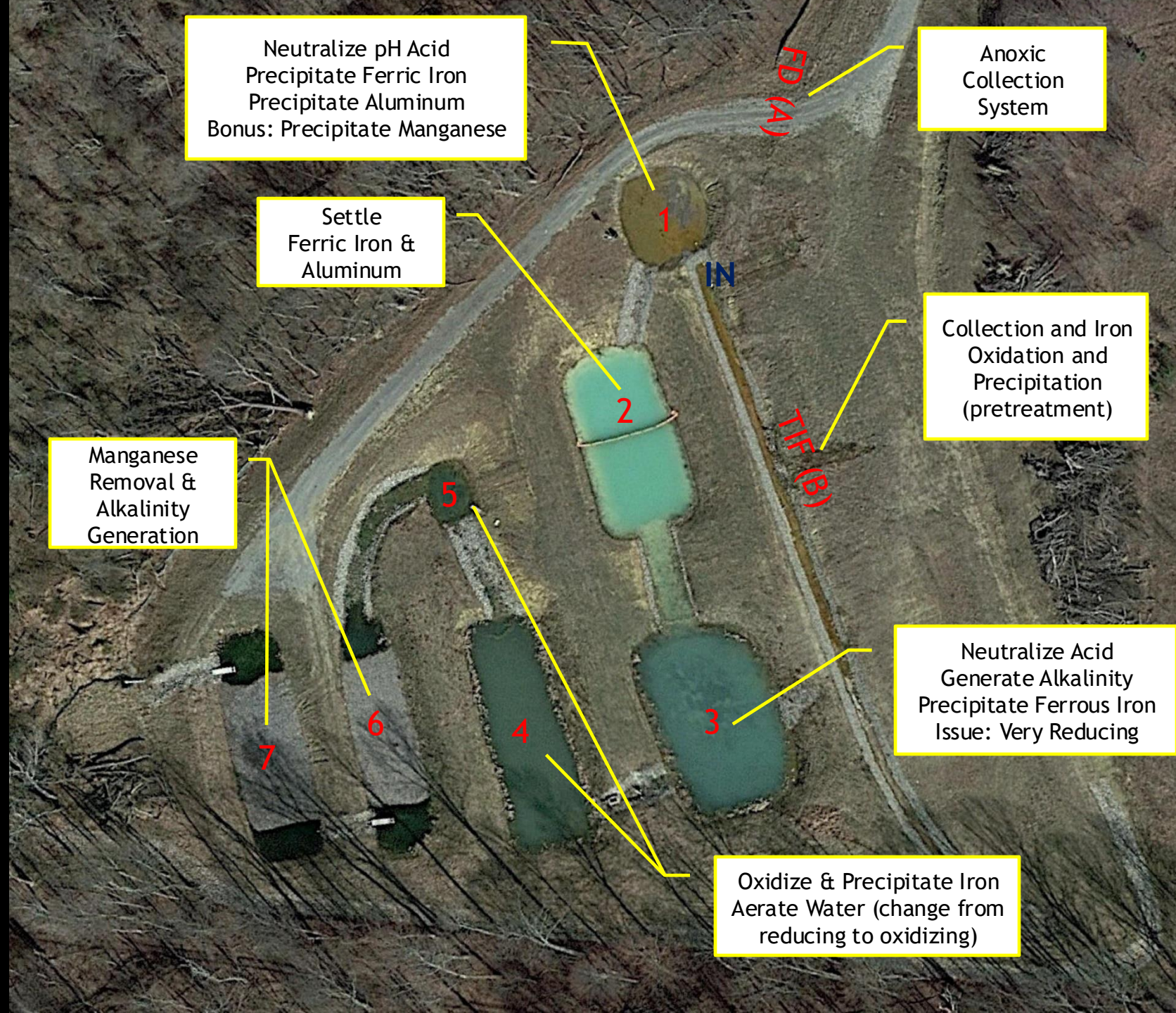
System Online November 2019



Treatment System

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- 7. 450 Ton HFLB 2

System Online November 2019



Raw (5A) Water Characteristics (Post-Construction)

Date	Flow gpm	Field pH	Lab pH	Temp °C	Alk. mg/LCaCO ₃	(Hot) Acid. mg/LCaCO ₃	Fe mg/L	Mn mg/L	Al mg/L	SO ₄ mg/L	Sus. Solids mg/L	Cond. umho/cm	Osm. Pres. mOsm/kg
01/14/20	20	3.6	3.3	10.0	0	215	11.7	33.3	15.6	1081	0	2105	20
02/05/20	16	3.7	3.7	10.1	0	200	10.6	28.2	15.3	1001	0	1861	
03/04/20	47	3.7	3.6	10.9	0	238	14.0	37.3	15.3	1145	16	2147	
05/31/20	25	3.7	3.4	16.3	0	284	16.5	36.1	24.3	1260	22	2112	23
07/21/20	11	3.6	3.2	24.4	0	350	20.6	42.3	19.9	1646	0	2768	
03/03/21	32	4.1	4.0	12.7	0	153	16.6	29.8	13.1	954	8	1709	15
01/19/22	8	4.0	3.7	8.6	0	250	35.1	41.4	17.6	1214	0	2288	21
03/04/22	25	3.9	3.5	11.2	0	210	11.5	24.8	14.8	1184	0	1915	
06/06/23	7	3.2	3.0	20.3	0	348	24.1	56.4	27.9	1249	0	2875	
03/05/24	13	3.8	3.37	17.6	0	190	22.0	40.0	20.5	1320	0	2180	22
Minimum	7	3.2	3.0	8.6	0	153	10.6	24.8	13.1	954	0	1709	15
Maximum	47	4.1	4.0	24.4	0	350	35.1	56.4	27.9	1646	22	2875	23
Average	21	3.7	3.5	14.7	0	244	18.3	37.0	18.4	1205	5	2196	20

Design vs. Actual Raw Characteristics

	Flow gpm Avg/Max	Lab pH	(Hot) Acid. mg/LCaCO ₃	Fe mg/L	Mn mg/L	Al mg/L	SO ₄ mg/L	(Hot) Acid. lb/day	Fe lb/day	Mn lb/d	Al lb/d
“Design”	8 / 12	3.0	300	27	58	33	3,000	28.1	2.6	5.6	3.2
Raw Avg.	13	3.5	244	18	37	18	1,205	57.9	4.0	8.8	4.3
Raw “Worst”	65	3.0	350	35	56	28	1,646	134.2	7.9	21.0	8.6

- Limited Raw Water Monitoring (only required 1X/year)
 - Samples weighted to typical high-flow period
 - Average raw load shown is likely higher than actual
- Flow measured 2X/month with Outfall sample

Sample Points

Raw (5A / TIF Outlet)

SP1 (after AFVFP)

Jchan (overflow)

Jpipe (through media)

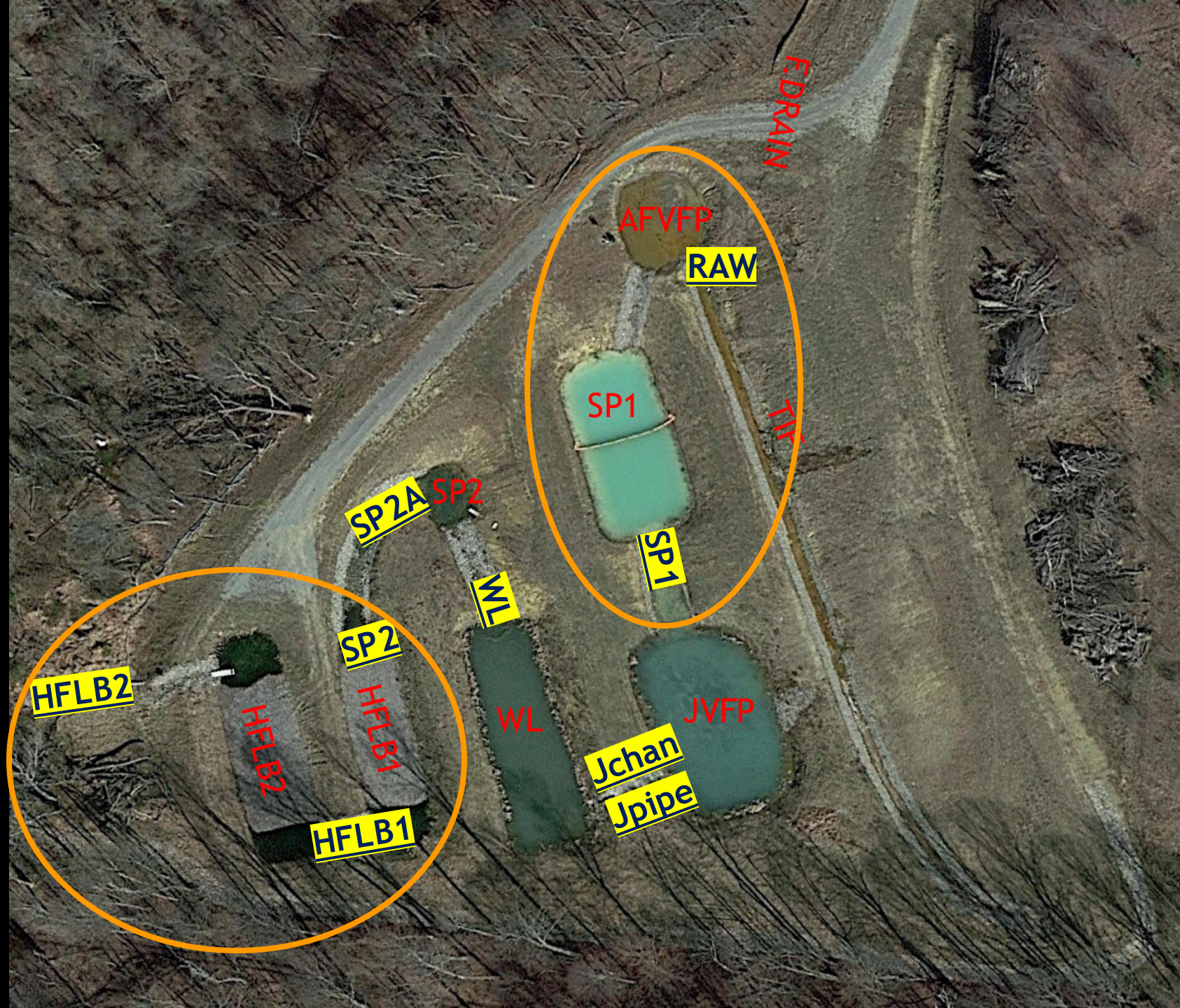
WL

SP2A (top of channel)

SP2 (end of channel)

HFLB1

HFLB2 (Outfall 001)



Jpipe & Jchan

Two-Cell Underdrain

Two Riser Primary Outlet

One Outlet Riser Shut

One Outlet Riser Valved

- "Jpipe"

- 1" Globe Valve

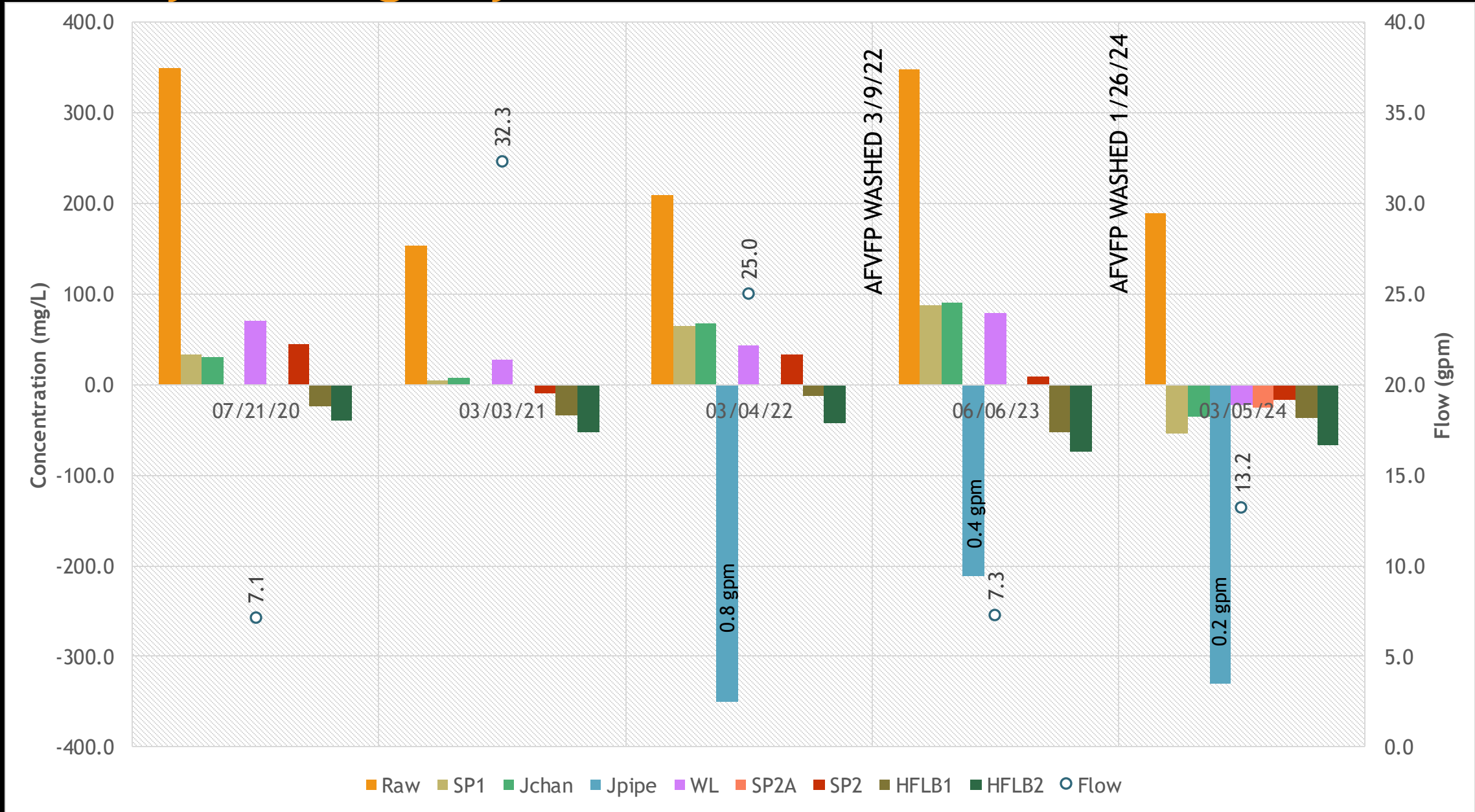
(max flow ~8 gpm)

Channel Secondary Outlet

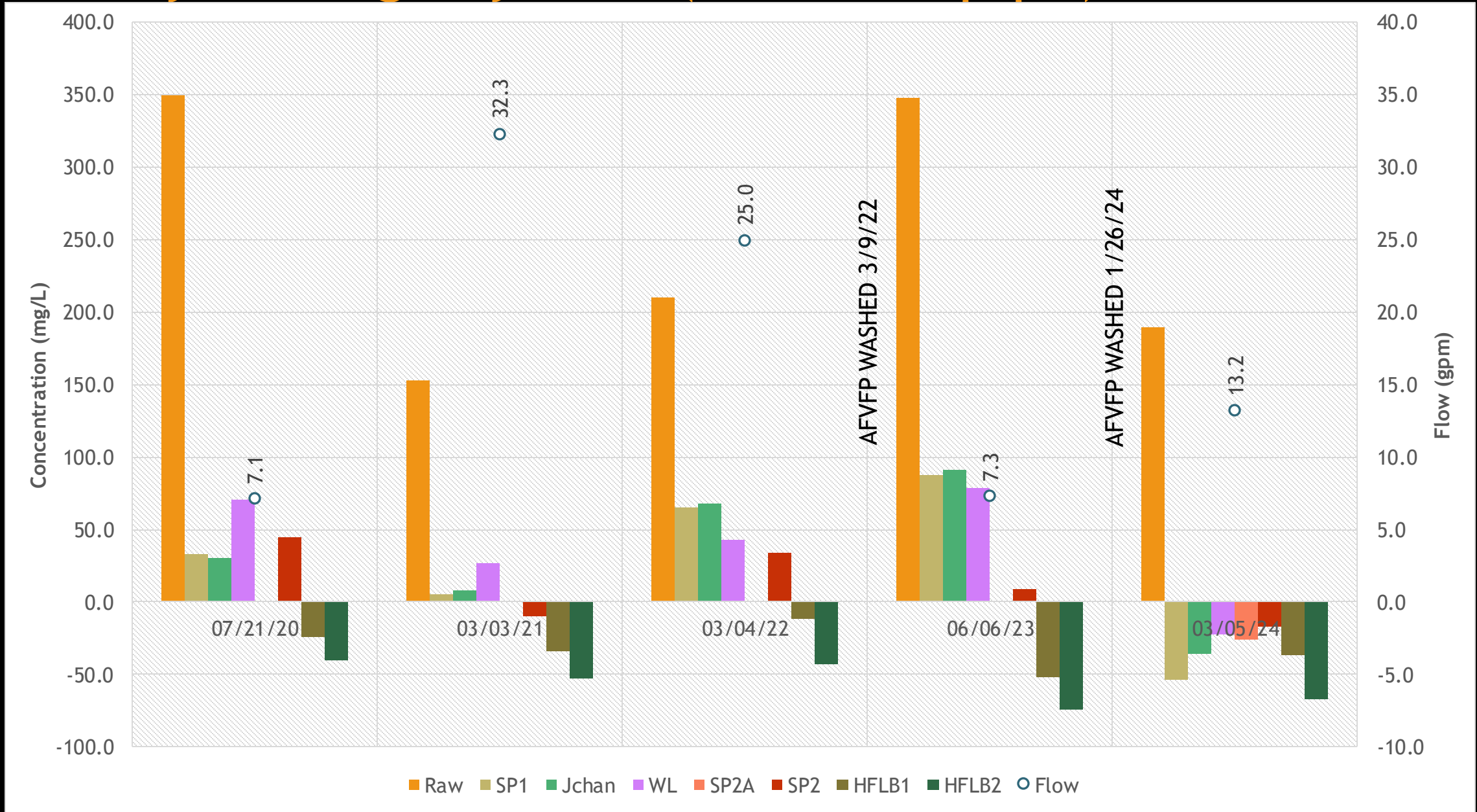
- "Jchan"



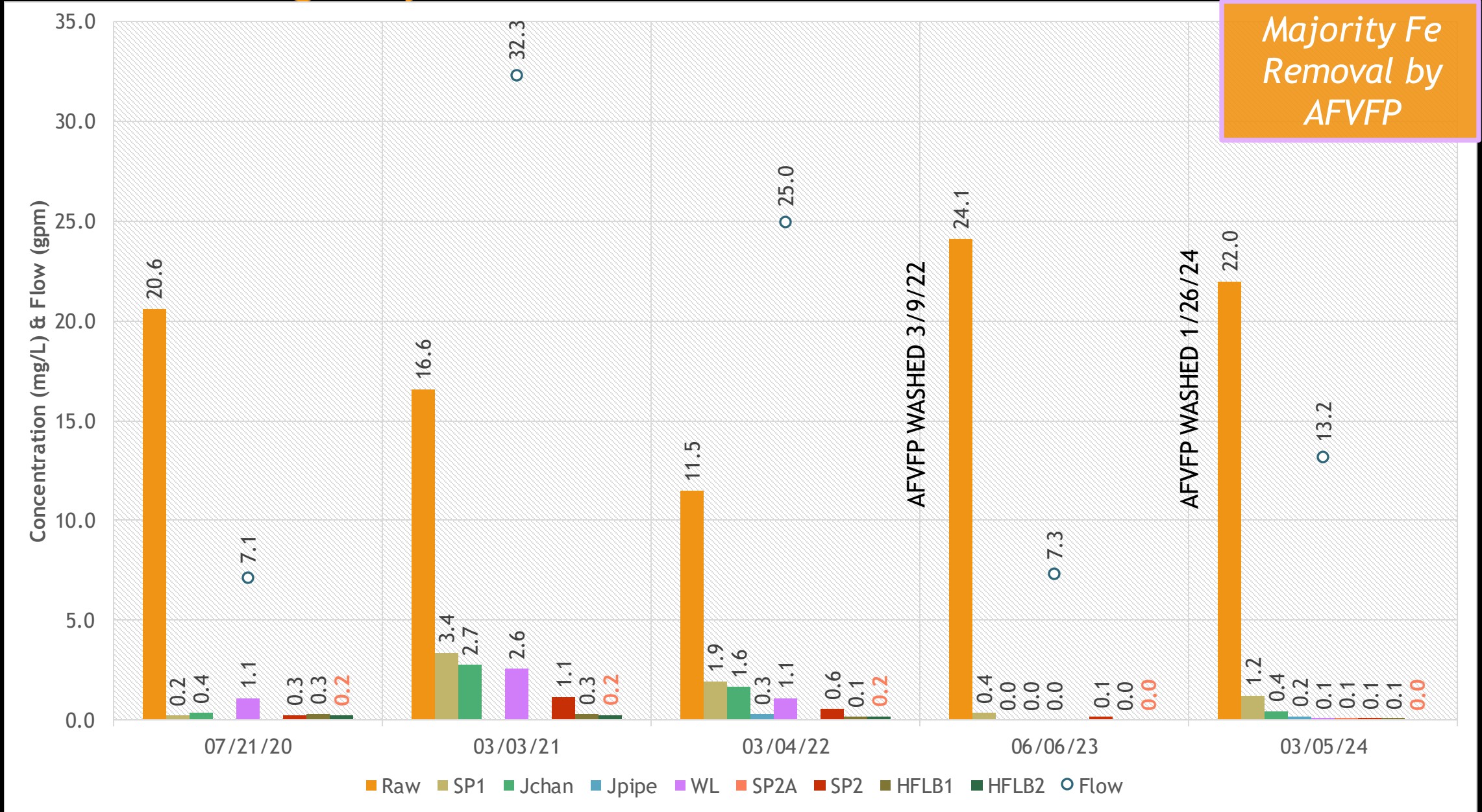
Acidity Through System



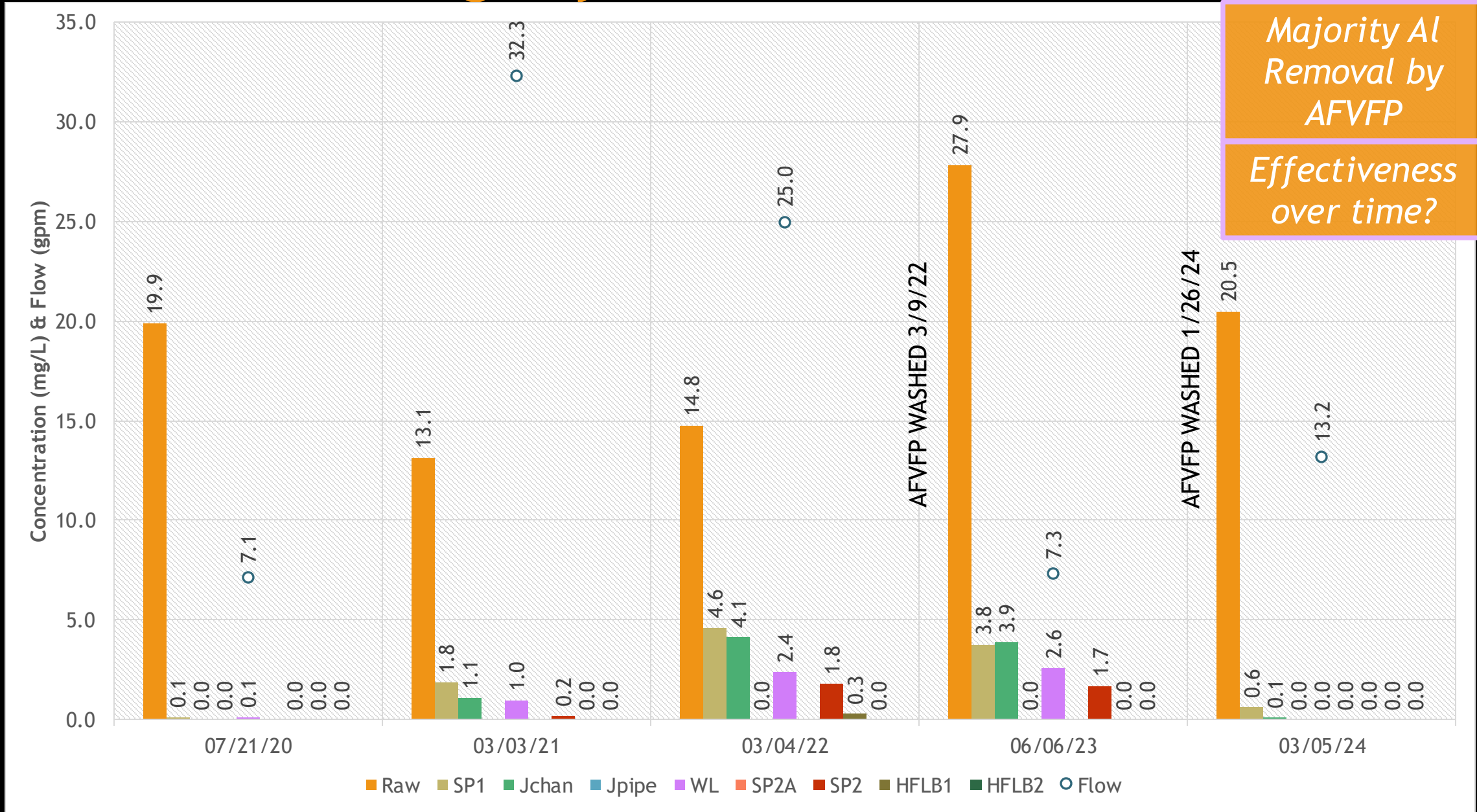
Acidity Through System (without Jpipe)



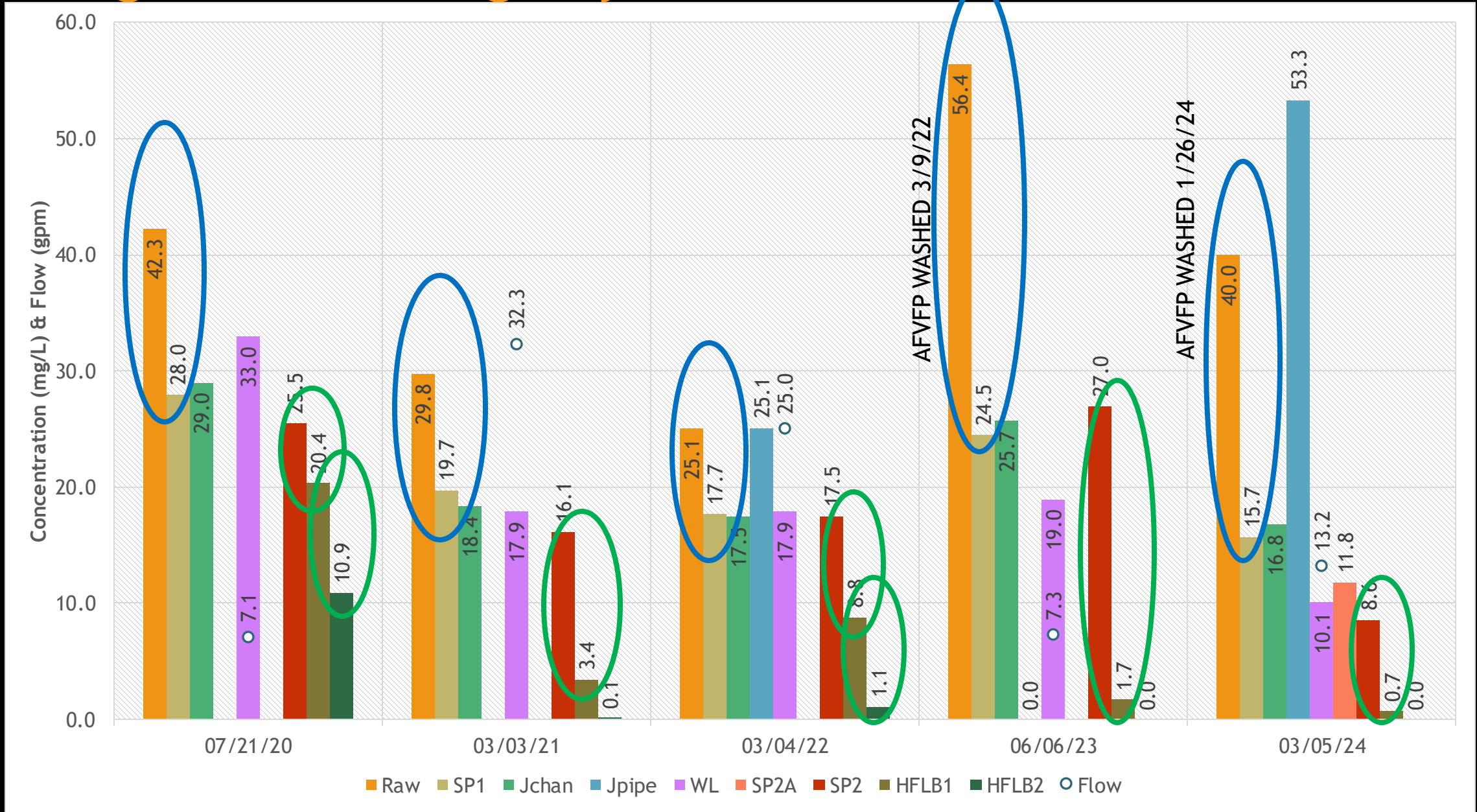
Iron Through System



Aluminum Through System



Manganese Through System



Sample Points

Raw (5A / TIF Outlet)

SP1 (after AFVFP)

Jchan (overflow)

Jpipe (through media)

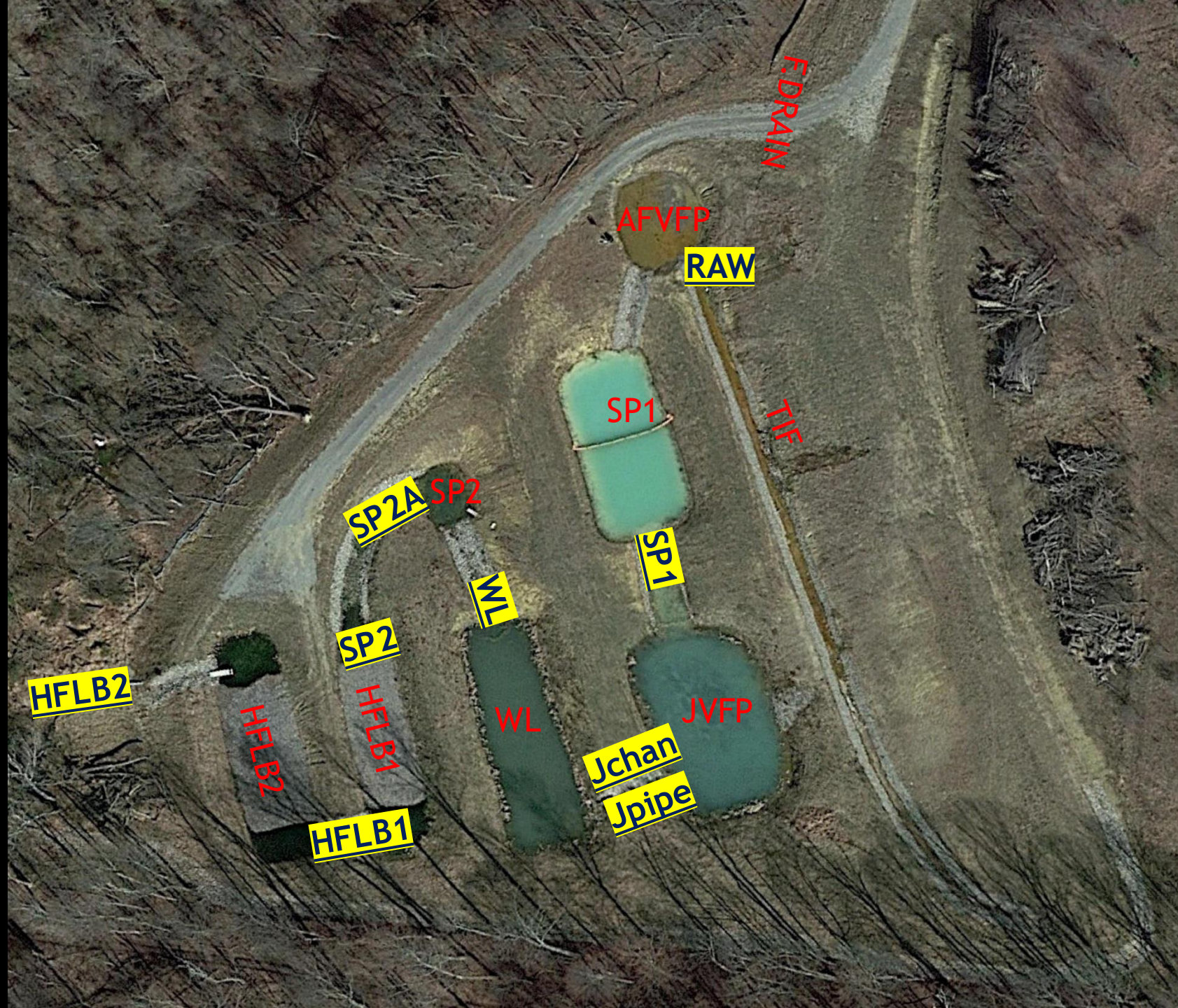
WL

SP2A (top of channel)

SP2 (end of channel)

HFLB1

HFLB2 (Outfall 001)



French Drain

Collect Subsurface
Drainage

6" SDR35 PVC (Perf.)
Sandstone Aggregate
Geotextile on Top
Cleanout at Midpoint



Terraced Iron Formation (TIF)

Collect Drainage and Remove Iron (Multiple Sources Along Channel)



Raw Water (5A) Inlet to AFVFP

TIF and French Drain Outlet to AFVFP



AFVFP Design

250 T AASHTO #1 92% CaCO_3 LS
Agri Drain Smart Drain
Flush 1X/Day

Design Basis:

Target: 5+ pH Effluent

(Acid Targets: H^+ , Fe^{3+} , Al)

Estimated Minimum 12 Hour Avg.
Hold (24 hr gradual fill, flush)

1.35 Tons/CY LS Bulk Density

49% Void Space (Watzlaf 2004)



AFVFP Design Projections

Acid Load Targeted:

3.0 pH to 5.0: 45 mg/L Acid

½ Fe as Fe³⁺ (14 mg/L): 40 mg/L Acid

½ Al (17 mg/L): 95 mg/L Acid

Total Acid: 180 mg/L

Average Flow (8 gpm): 17.3 lb/day Acid (*0.07 lb acid/day/ton*)

Max Flow (12 gpm): 26.0 lb/day Acid (*0.10 lb acid/day/ton*)

Average: Dissolve 3.4 tons of 92% CaCO₃ LS/Year (51 tons/15 Years)



AFVFP Void Space

Flow Through:

49% Void (Watzlaf 2004 DOE)

Flow Through >12.7 gpm

18,300 gallons void

30% Void (Tasker 2024 IMWA)

Flow Through >7.8 gpm

11,232 gallons void

25% Void (Guy 2024 ASRS)

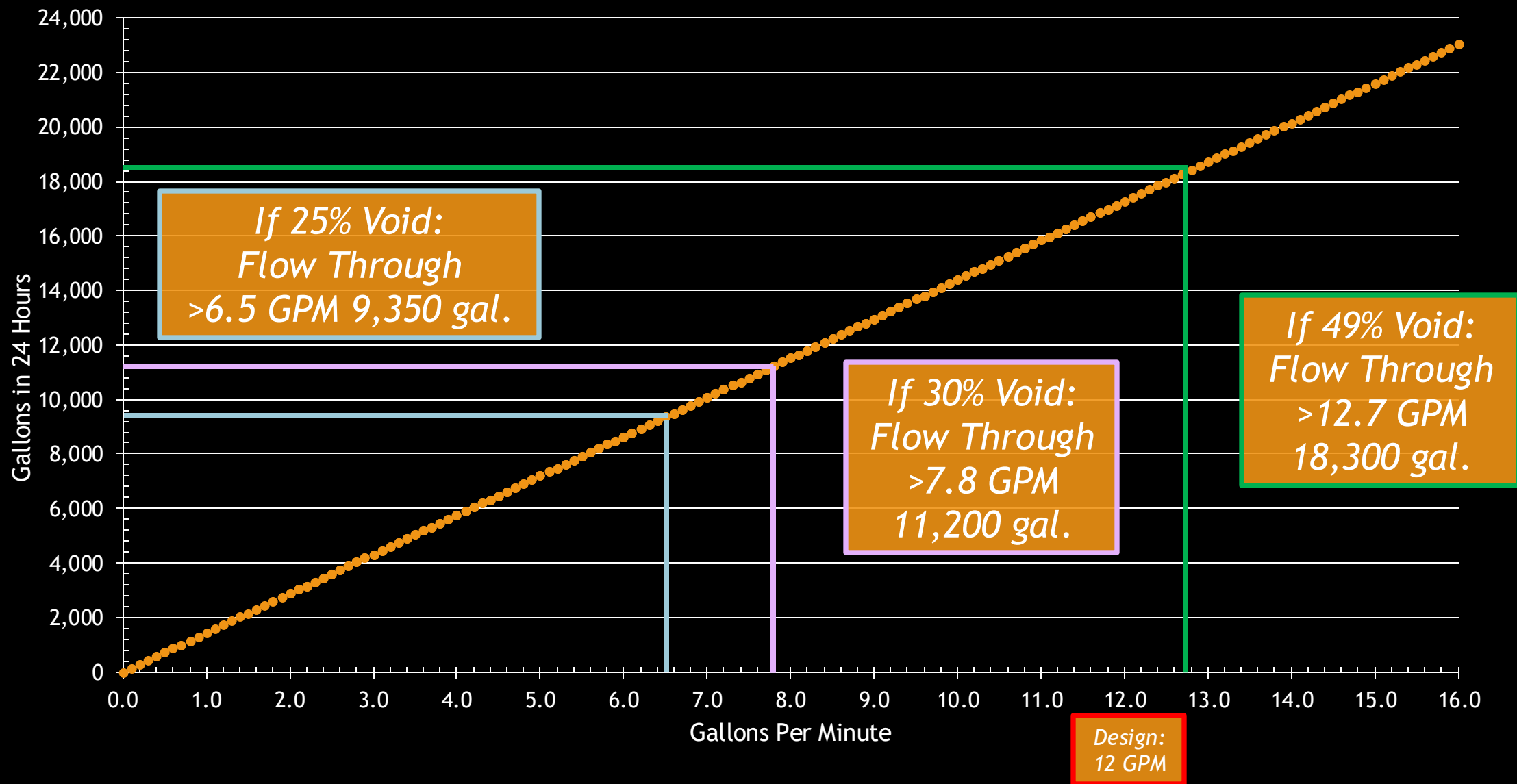
Flow Through >6.5 gpm

9,350 gallons void

Photo 2/23/23



250 Tons LS: 24-Hr Flow Through/Flow Rate/Void %



AFVFP

Designed to be Cleaned
6" DR17 HDPE Pipe (Perf.)
Fernco Connections
Dry Fit Caps

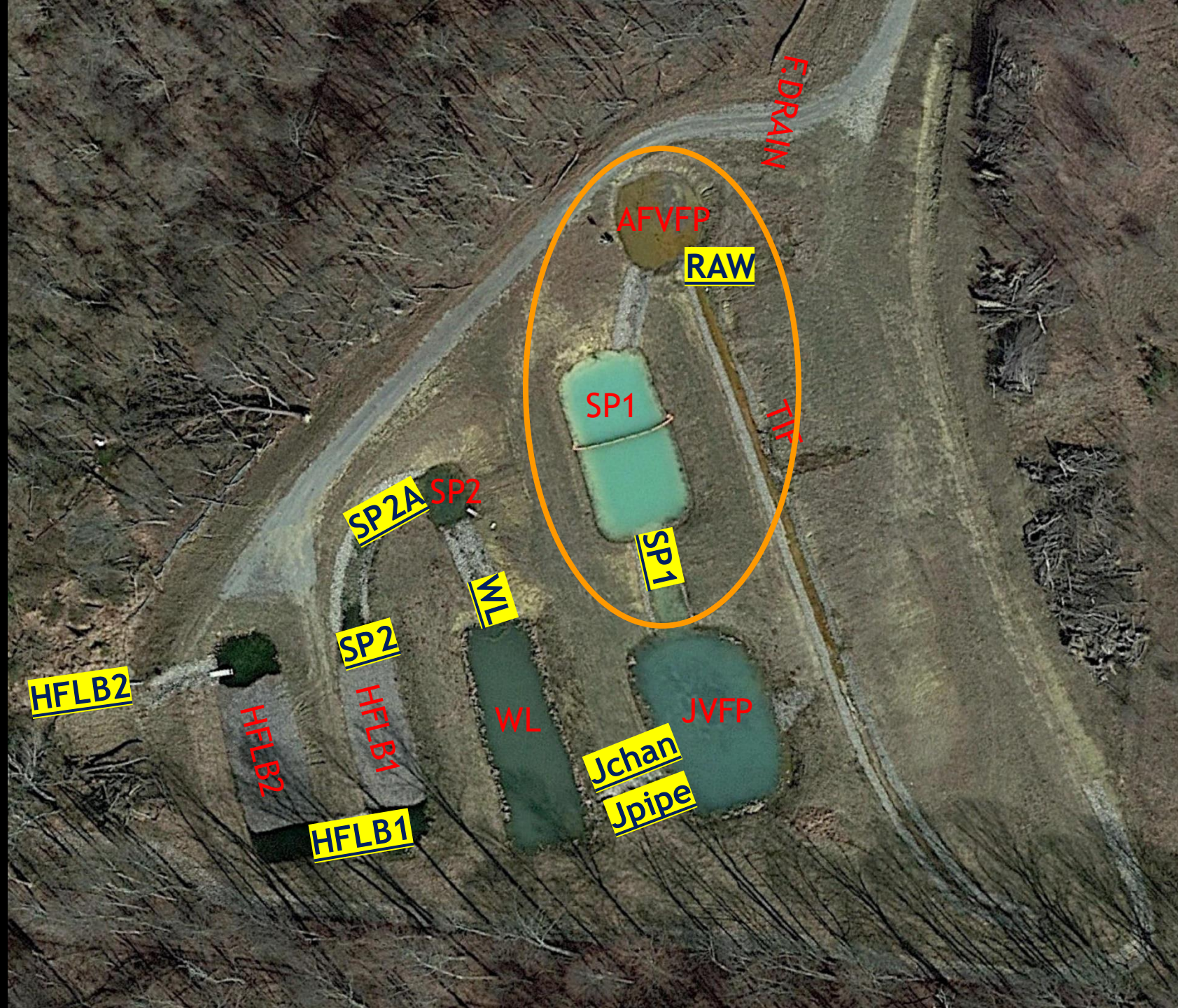
Photo 1/26/24



AFVFP Evaluation

Raw (5A / TIF Outlet)

SP1 (after AFVFP)



AFVFP Performance Evaluation

Flow Measured at Raw (5A/TIF Outlet)

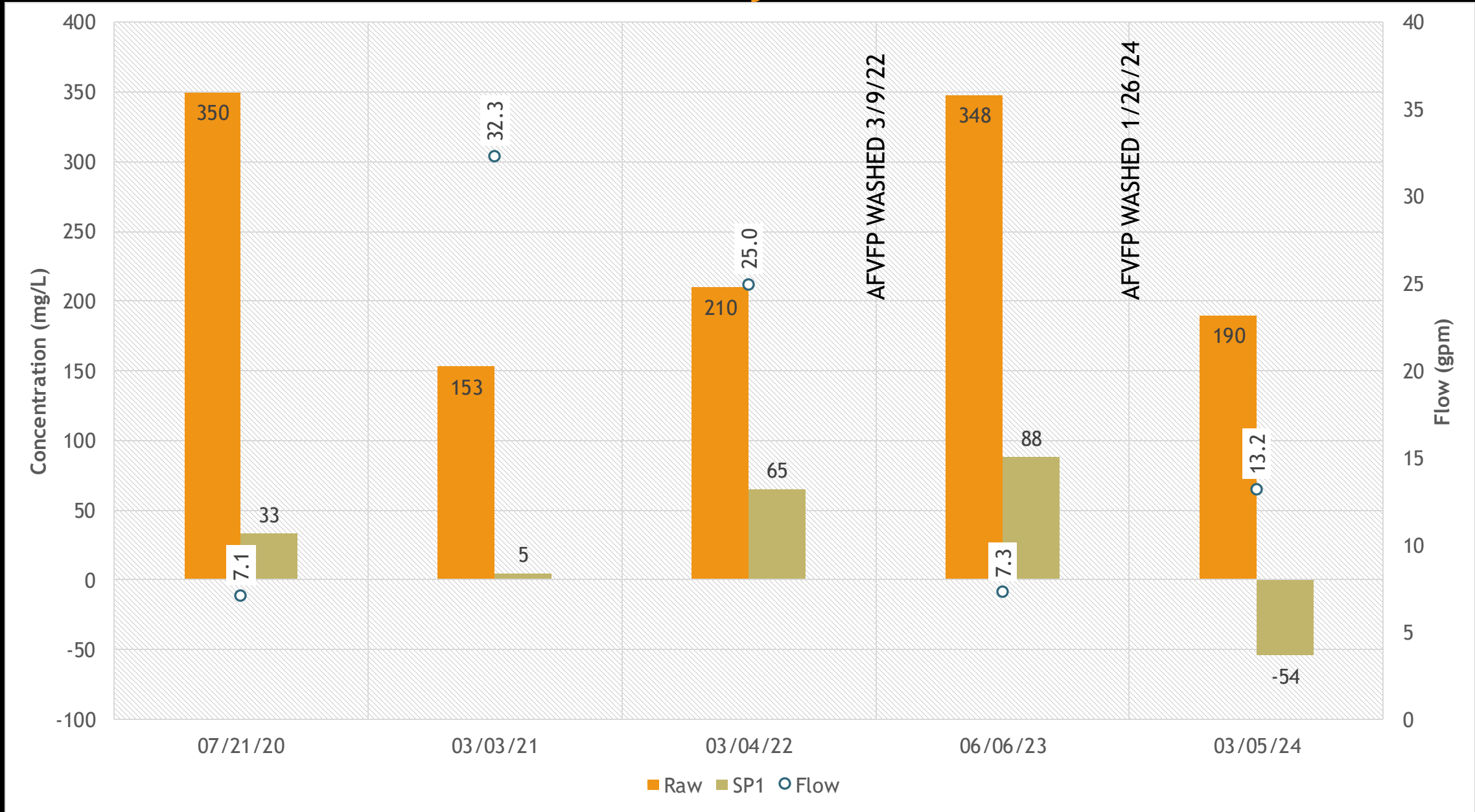
Inflow Sampled at 5A (5A/TIF Outlet)

Outflow Sampled at SP1

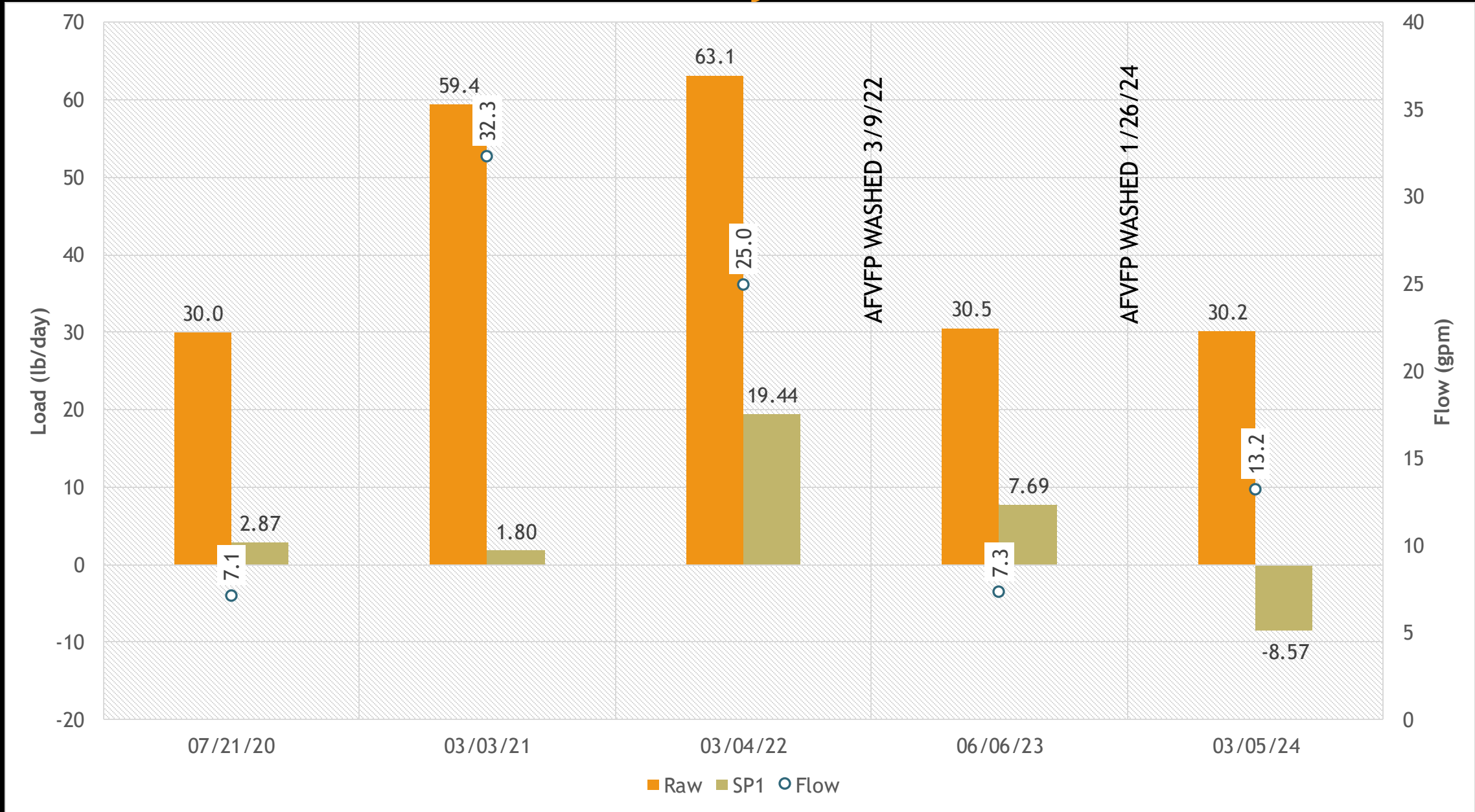
Photo 5/26/24



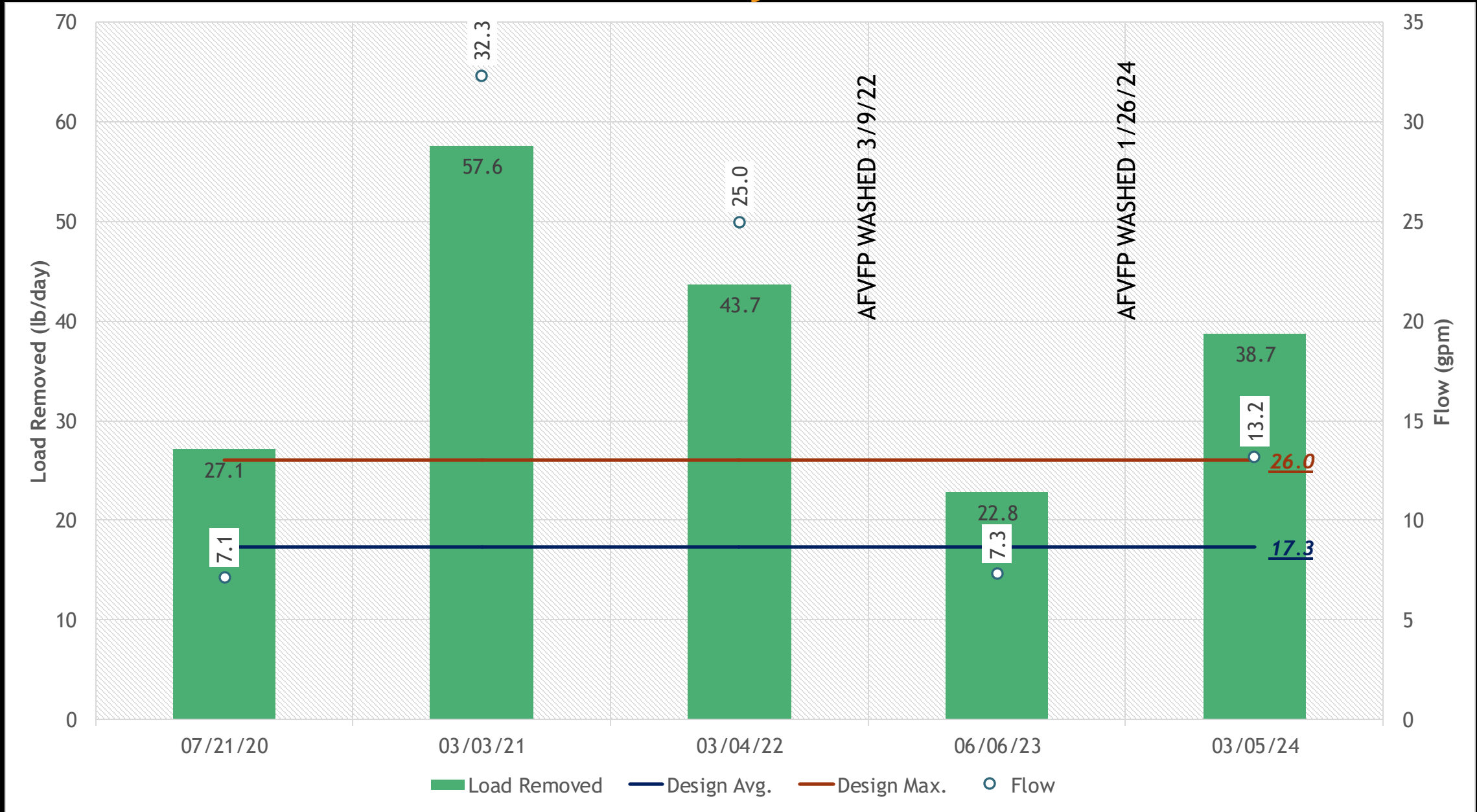
AFVFP Performance: Acidity Concentration



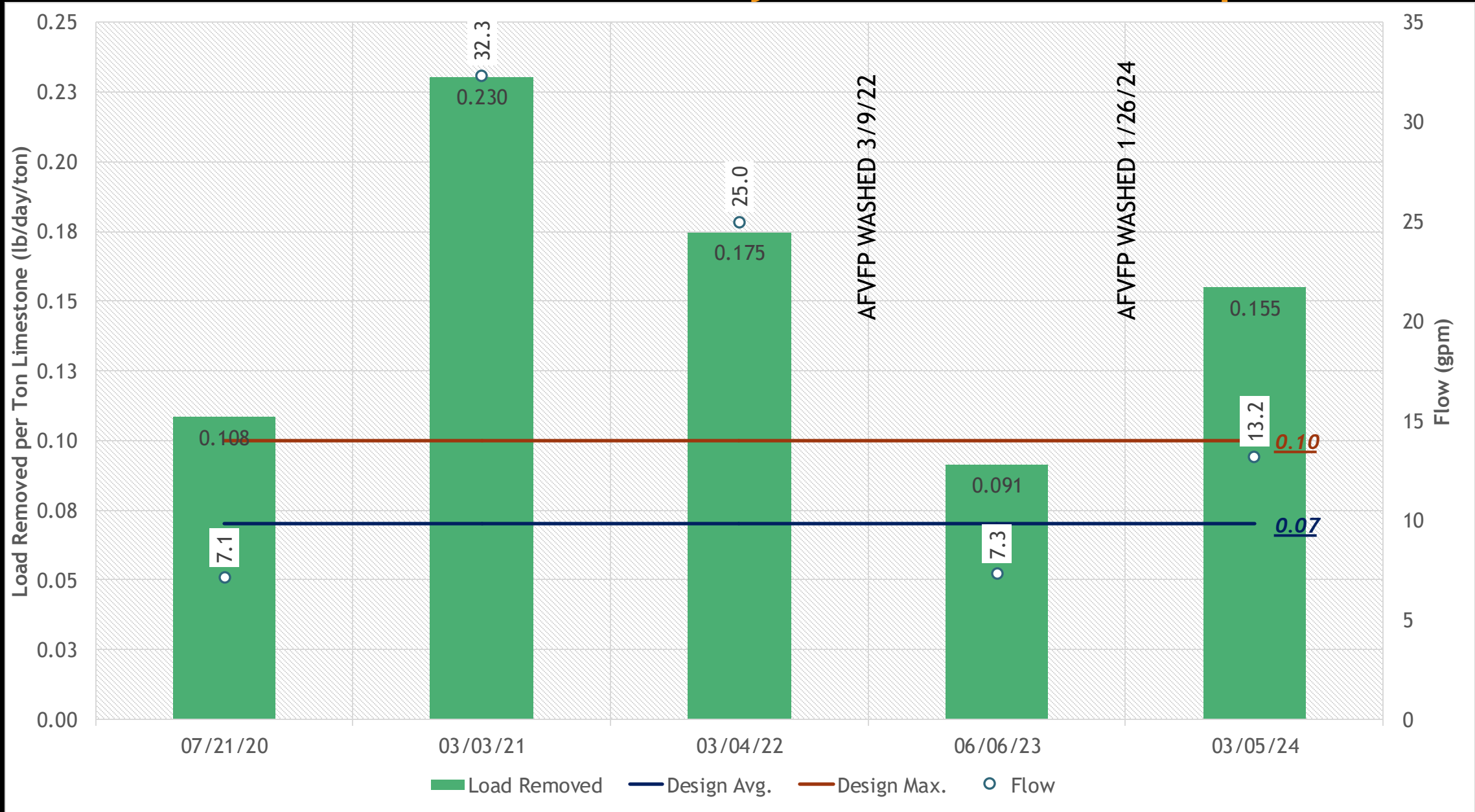
AFVFP Performance: Acidity Load



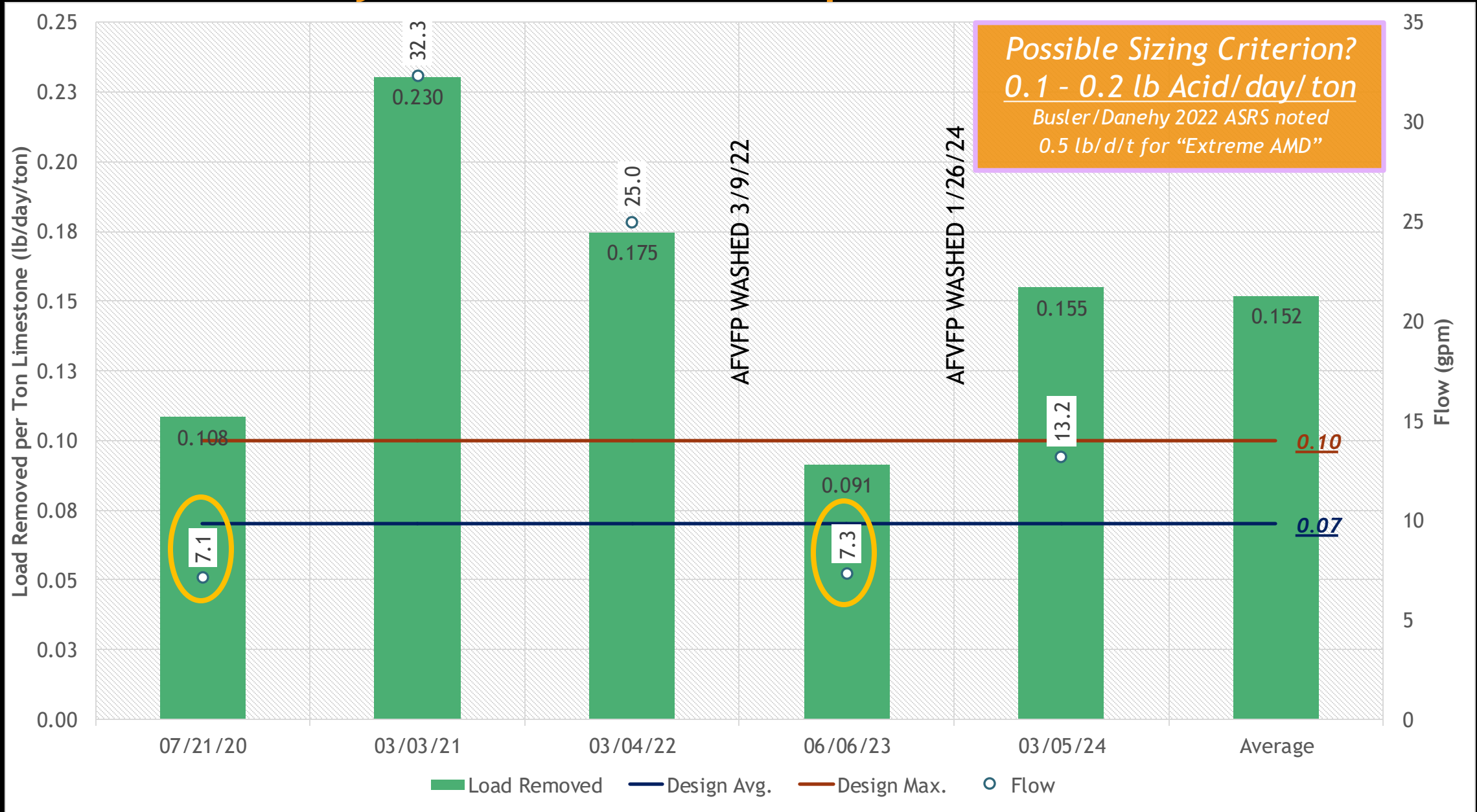
AFVFP Performance: Acidity Load Removed



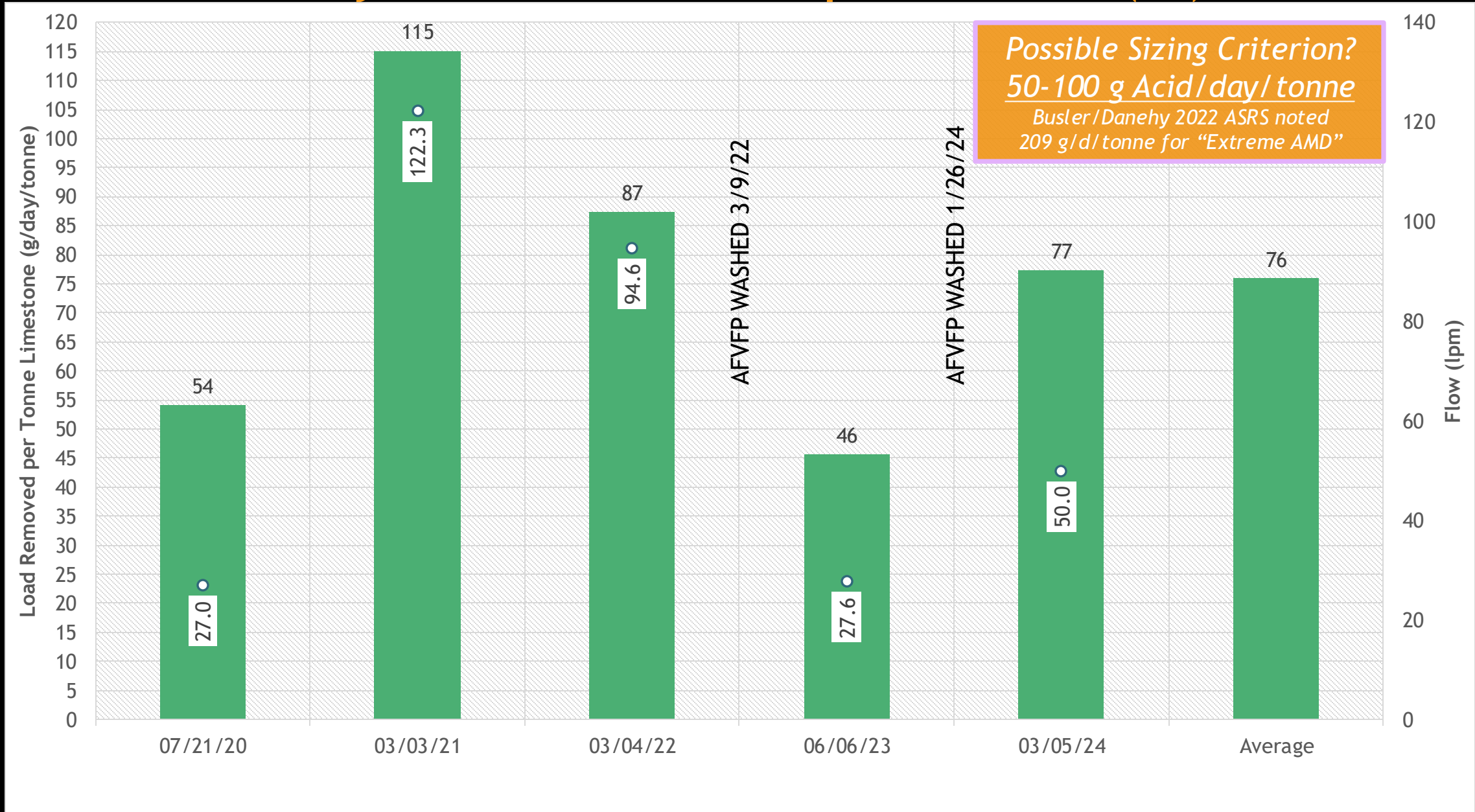
AFVFP Performance: Acidity Load Removed per Ton



AFVFP Acidity Load Removed per Ton



AFVFP Acidity Load Removed per Tonne (SI)



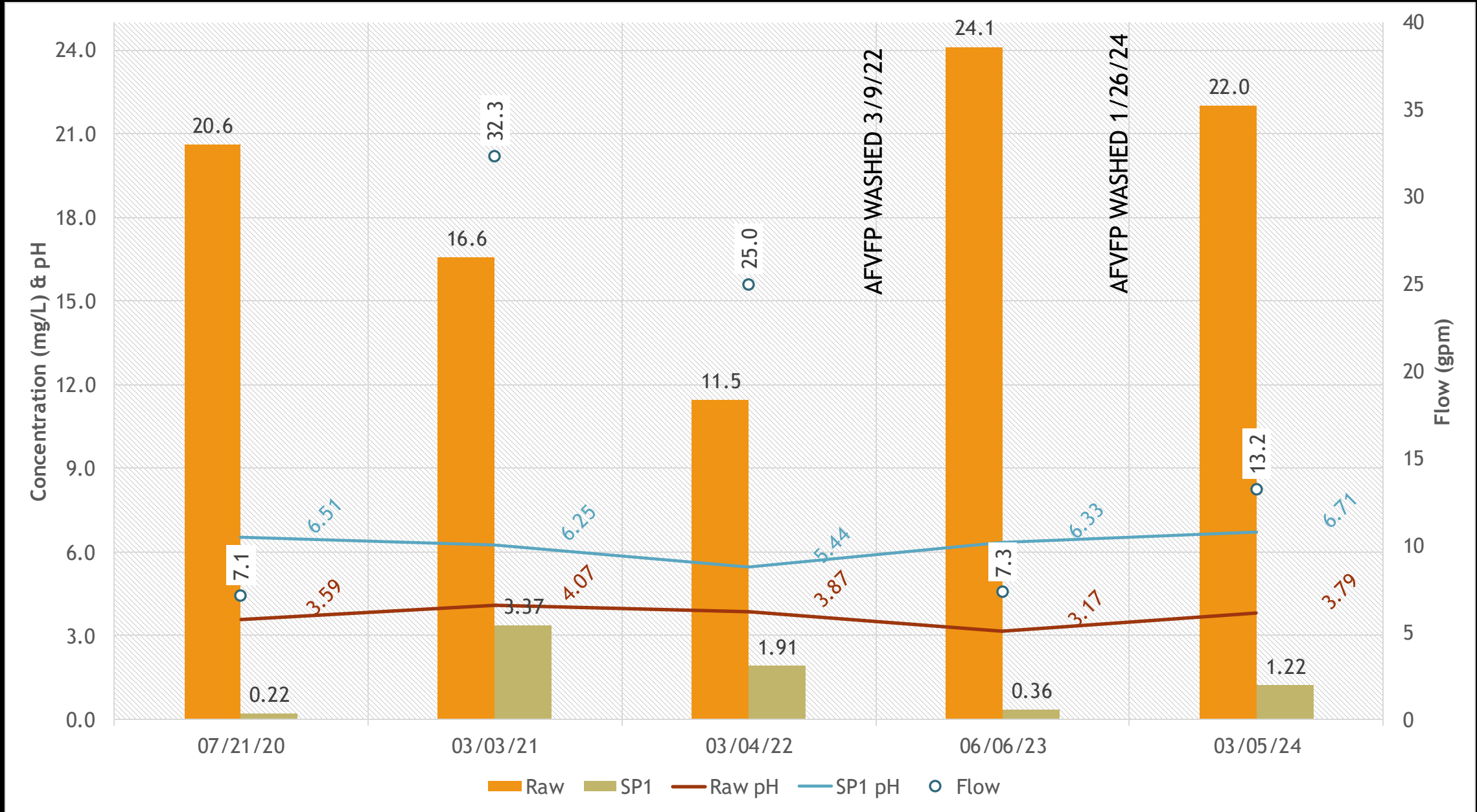
AFVFP Limestone Consumption

Limited Raw to SP1 data available.
Use average Raw to SP1 Acid Change.
Raw Acid - SP1 Acid (includes neg. acid).
Use avg. 2X/month flow measurement.

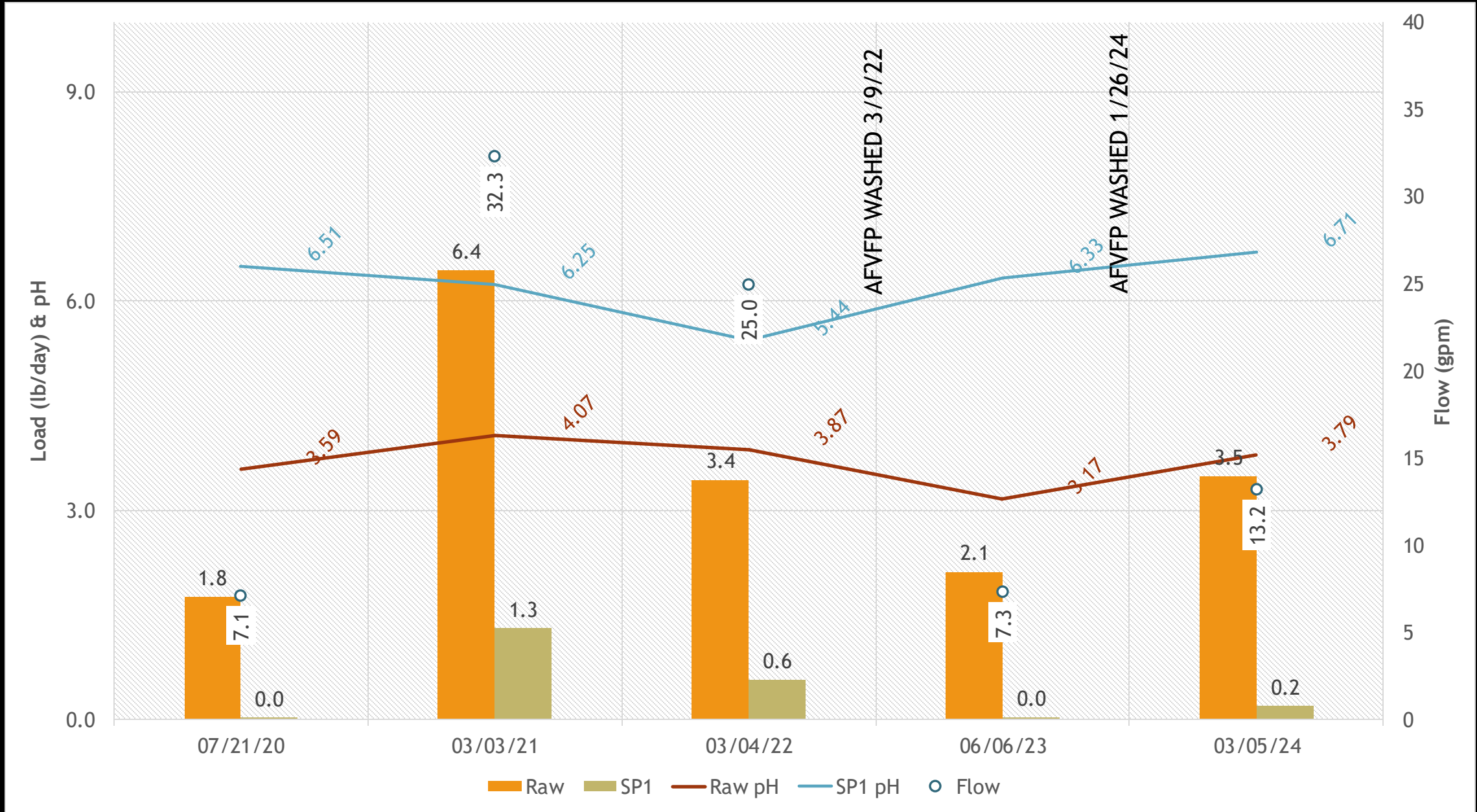


$223 \text{ mg/L Acid } \Delta \times 12.9 \text{ gpm} \times 0.01202 = 34.6 \text{ lb/day CaCO}_3$
 $34.6 \text{ lb/day} \times 365 \text{ day/yr} \div 2000 \text{ lb/ton} = 6.3 \text{ ton/yr}$
 $6.3 \text{ ton/yr} \div 92\% \text{ CaCO}_3 = 6.8 \text{ ton/yr (twice the projected rate)}$
Nov. '19 to Jun. '24 = 56 months (4.7 years) = 32 tons (13%)

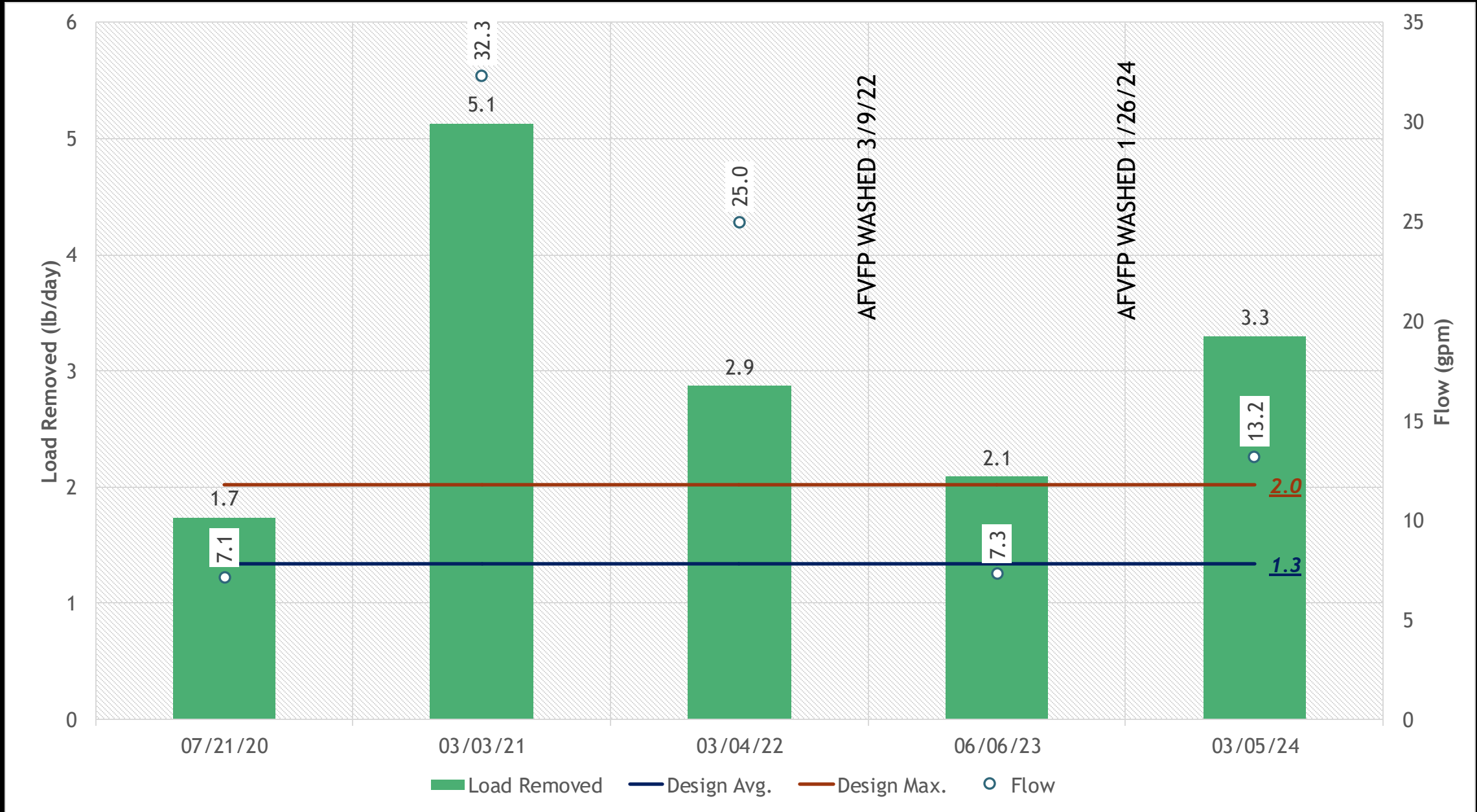
AFVFP Performance: Iron Concentration



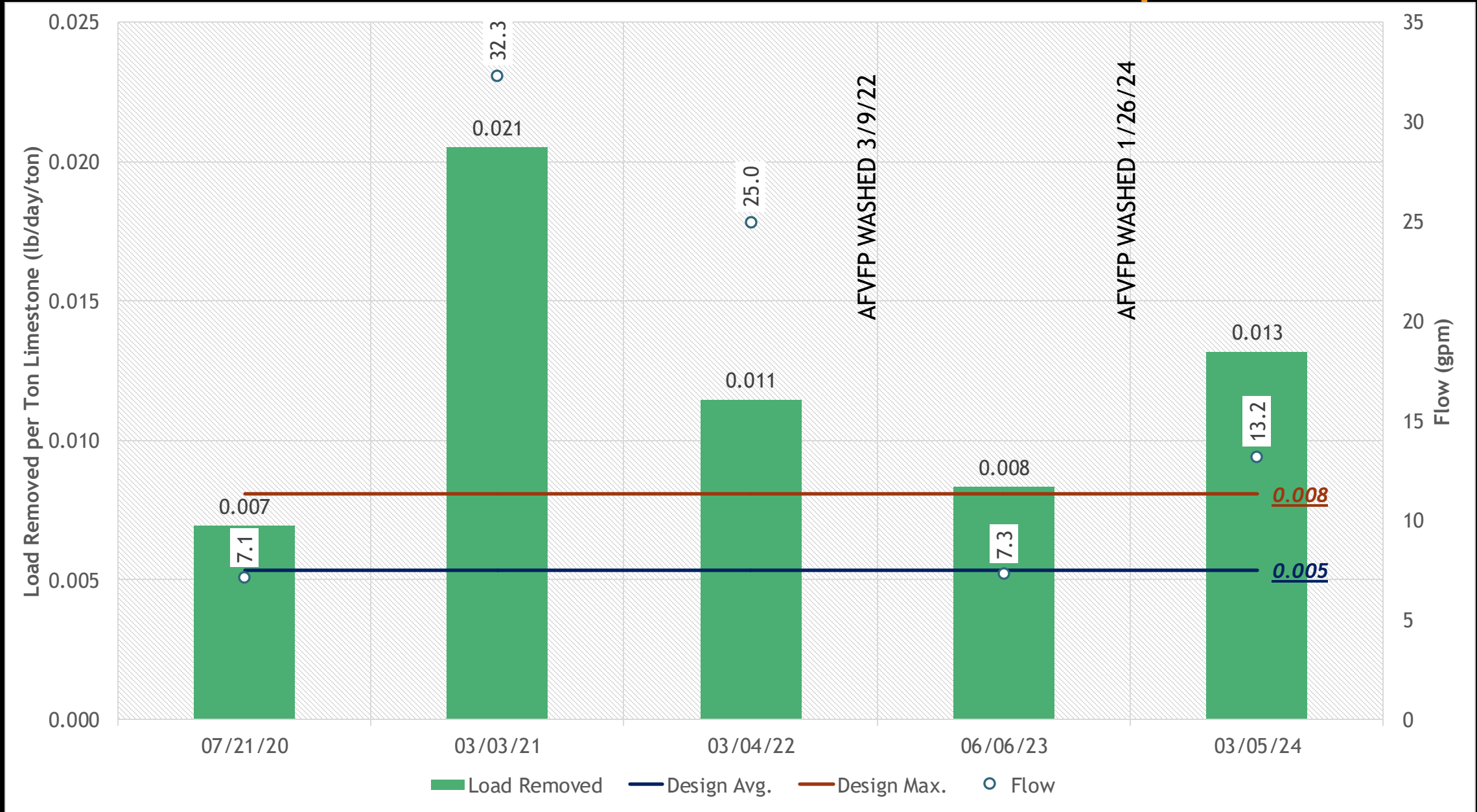
AFVFP Performance: Iron Load



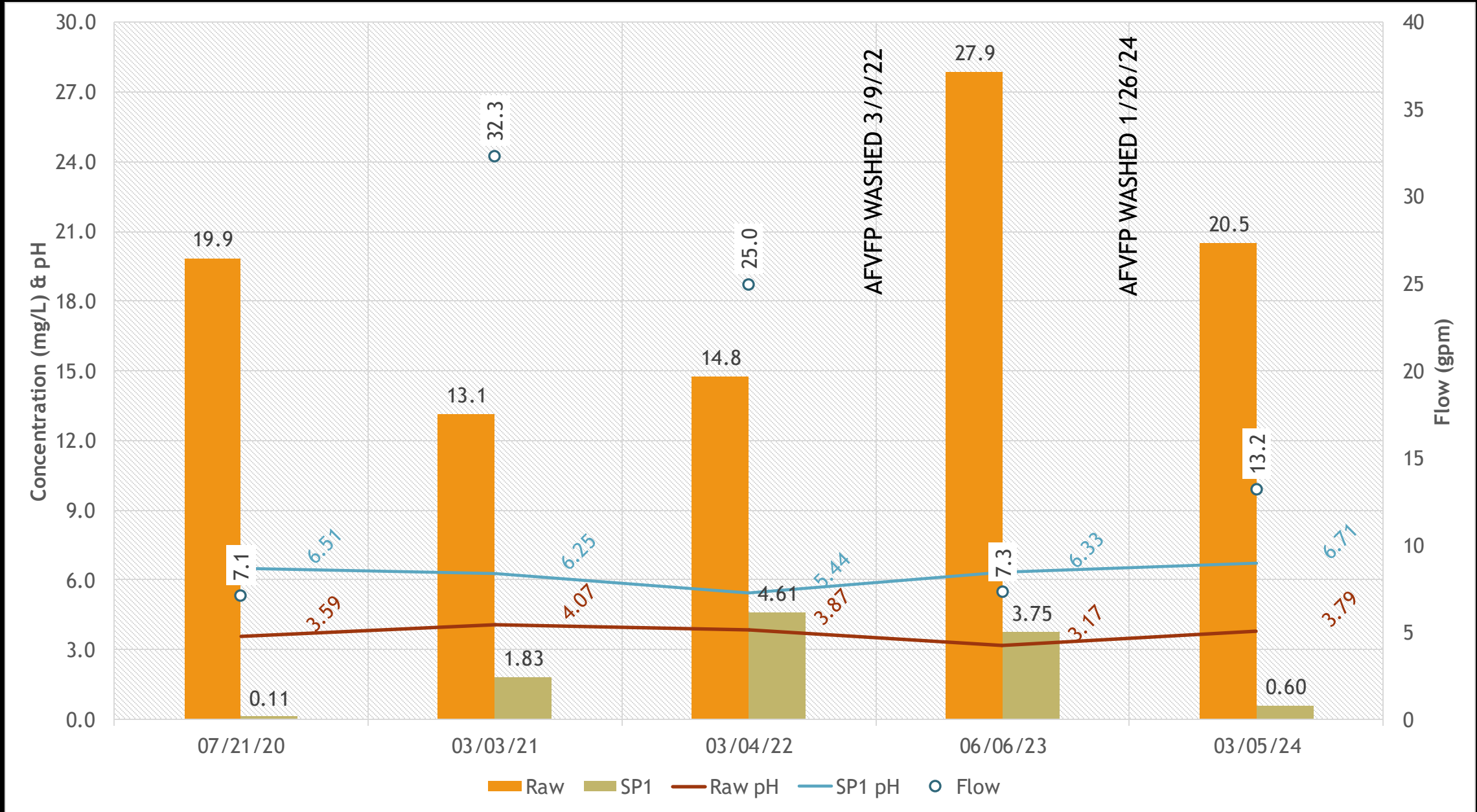
AFVFP Performance: Iron Load Removed



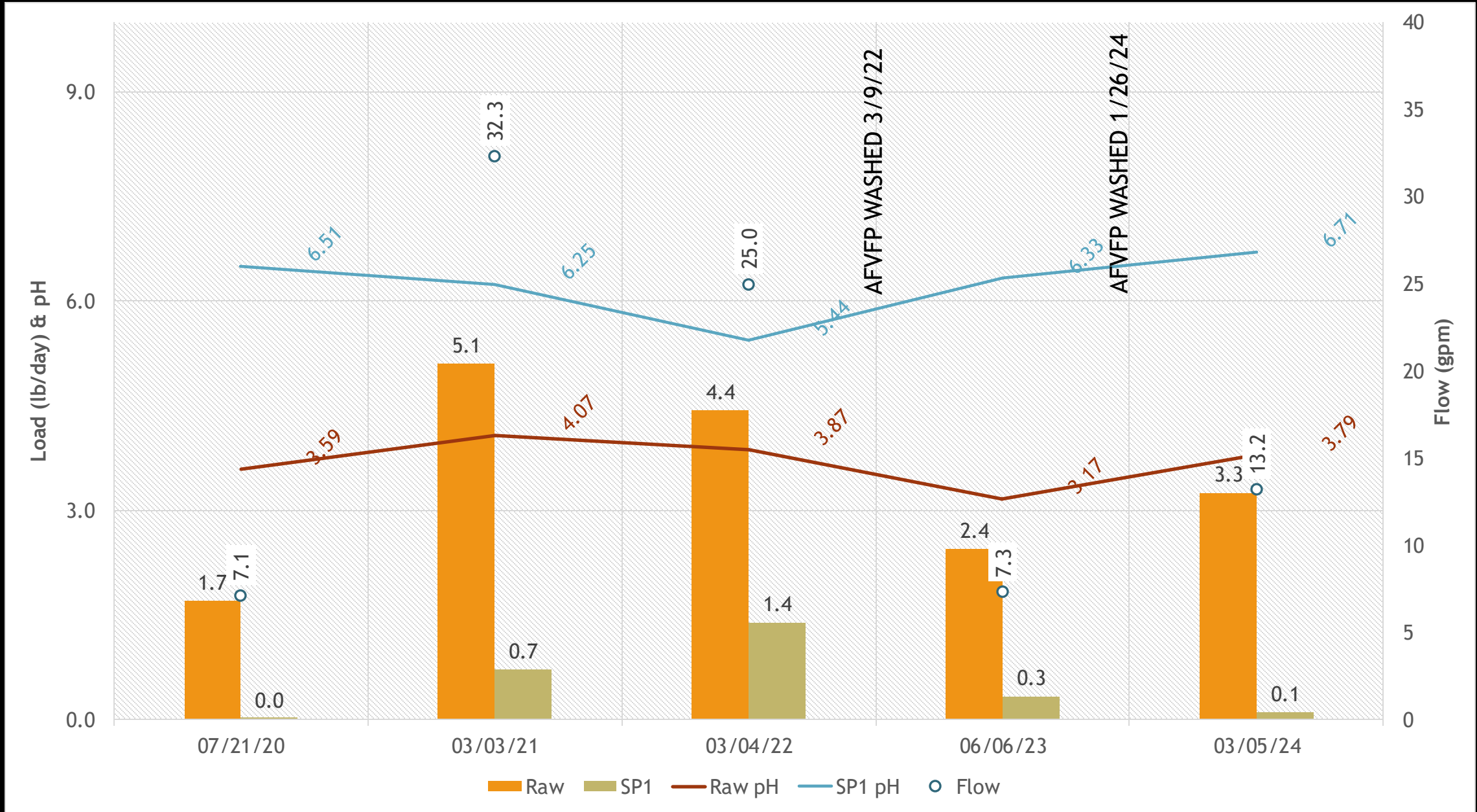
AFVFP Performance: Iron Load Removed per Ton



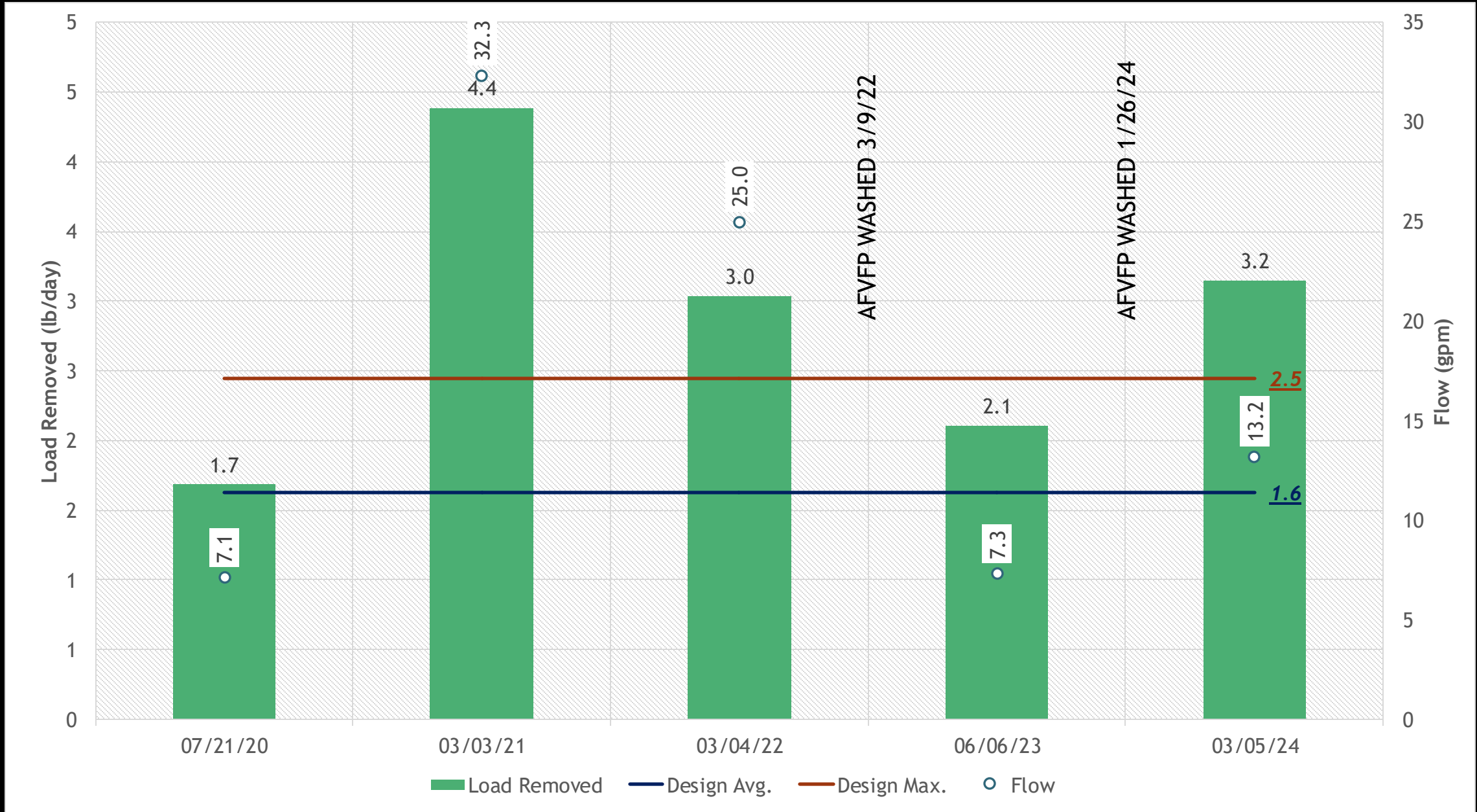
AFVFP Performance: Aluminum Concentration



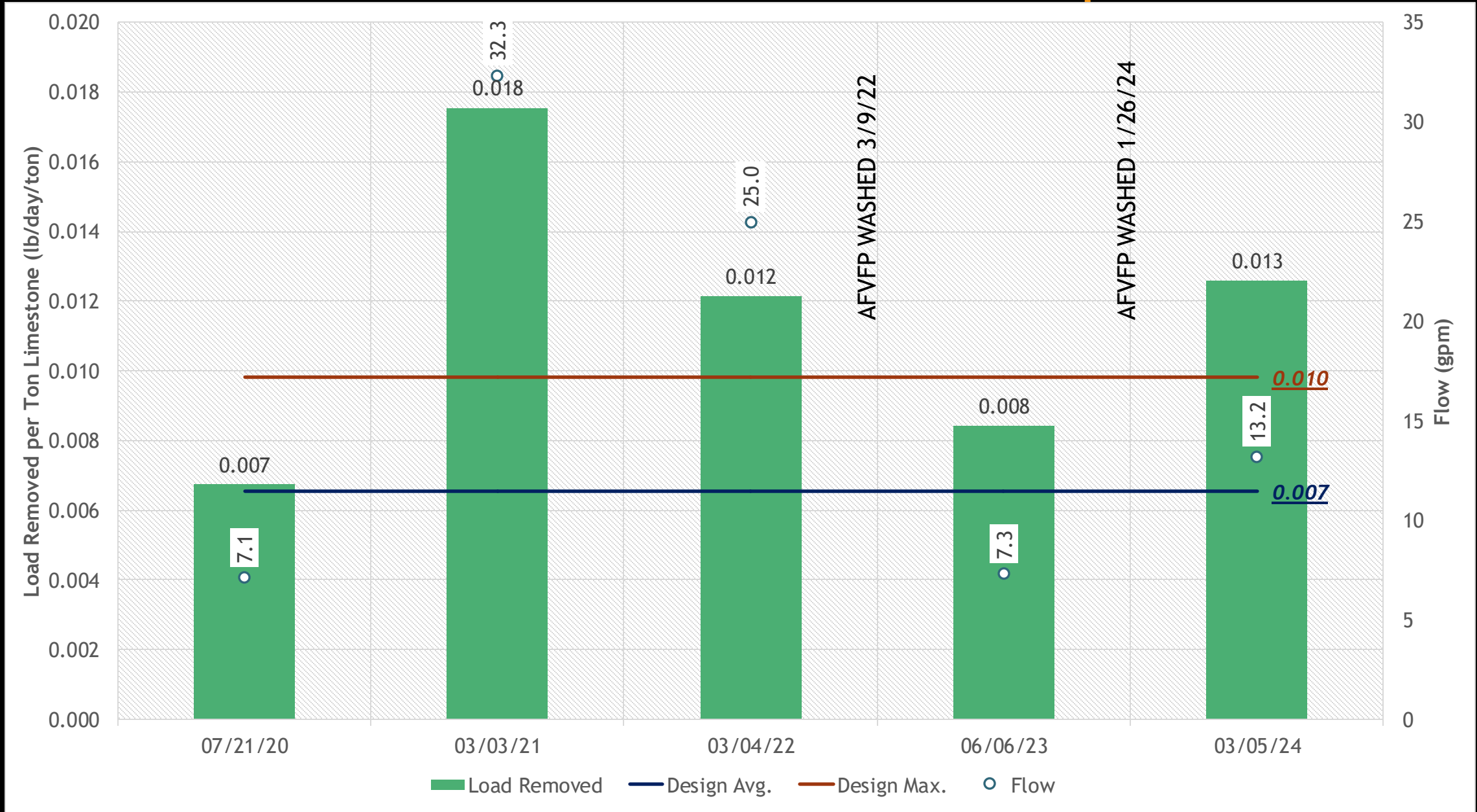
AFVFP Performance: Aluminum Load



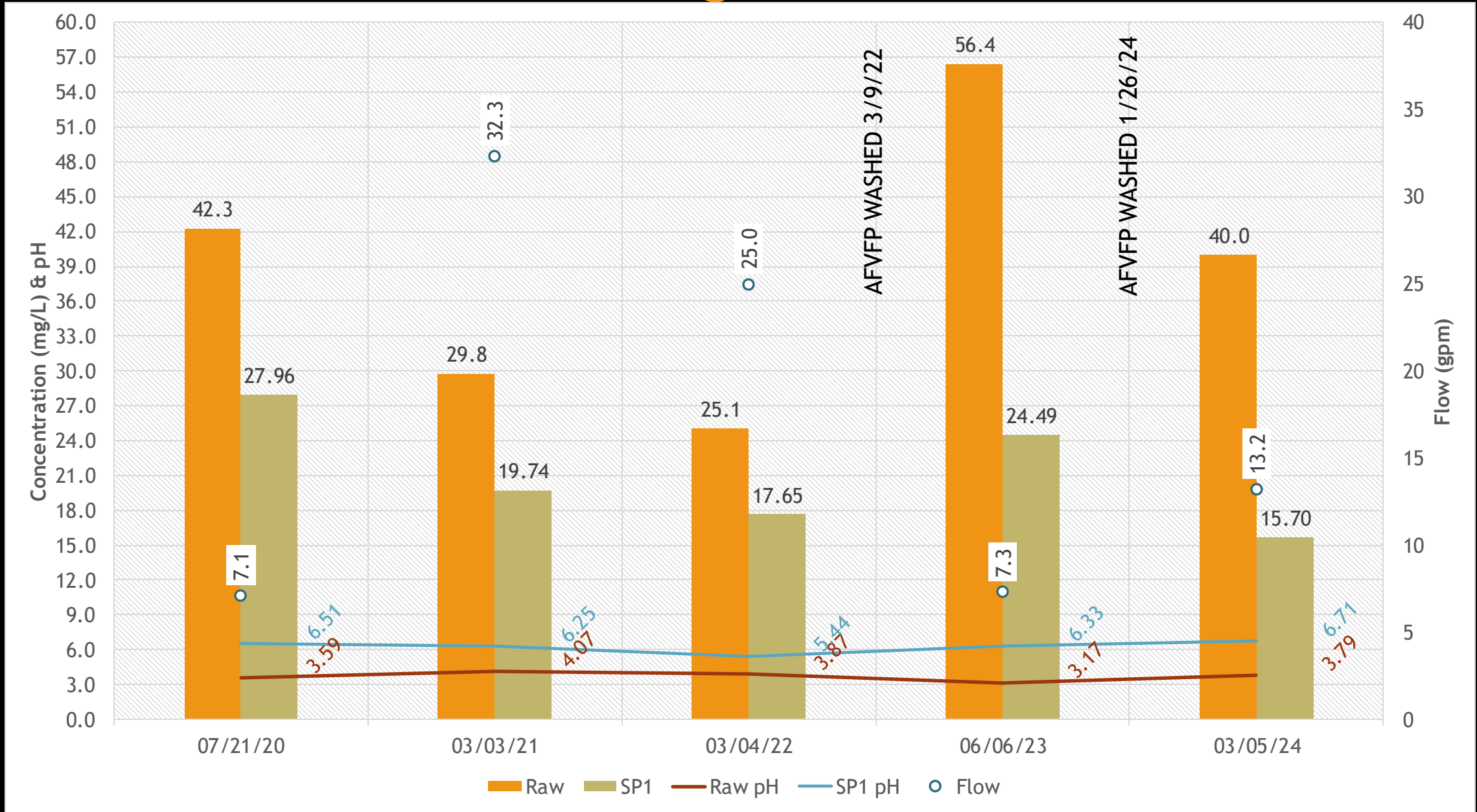
AFVFP Performance: Aluminum Load Removed



AFVFP Performance: Al Load Removed per Ton



AFVFP Performance: Manganese Concentration



Historical Geochemistry...

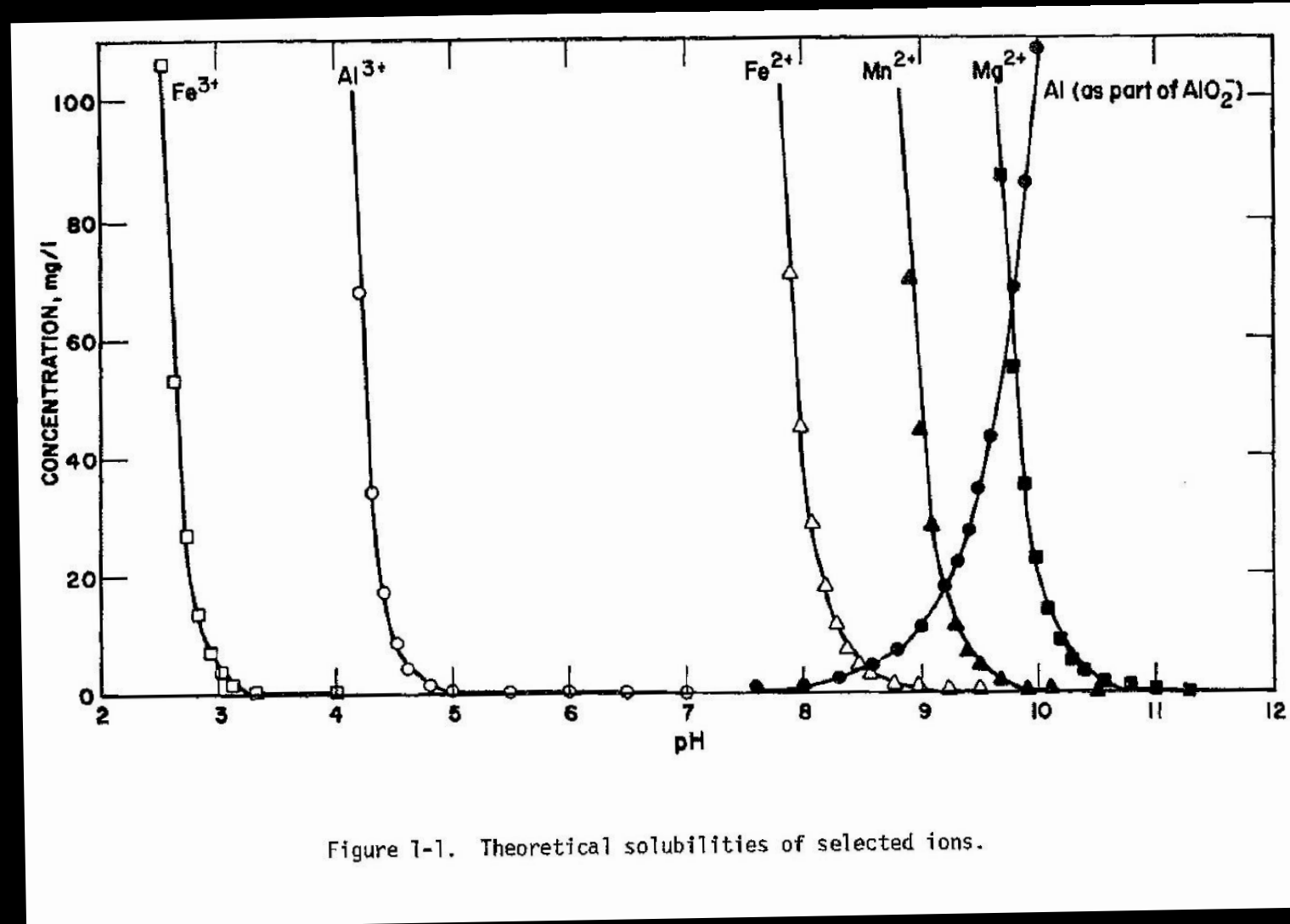
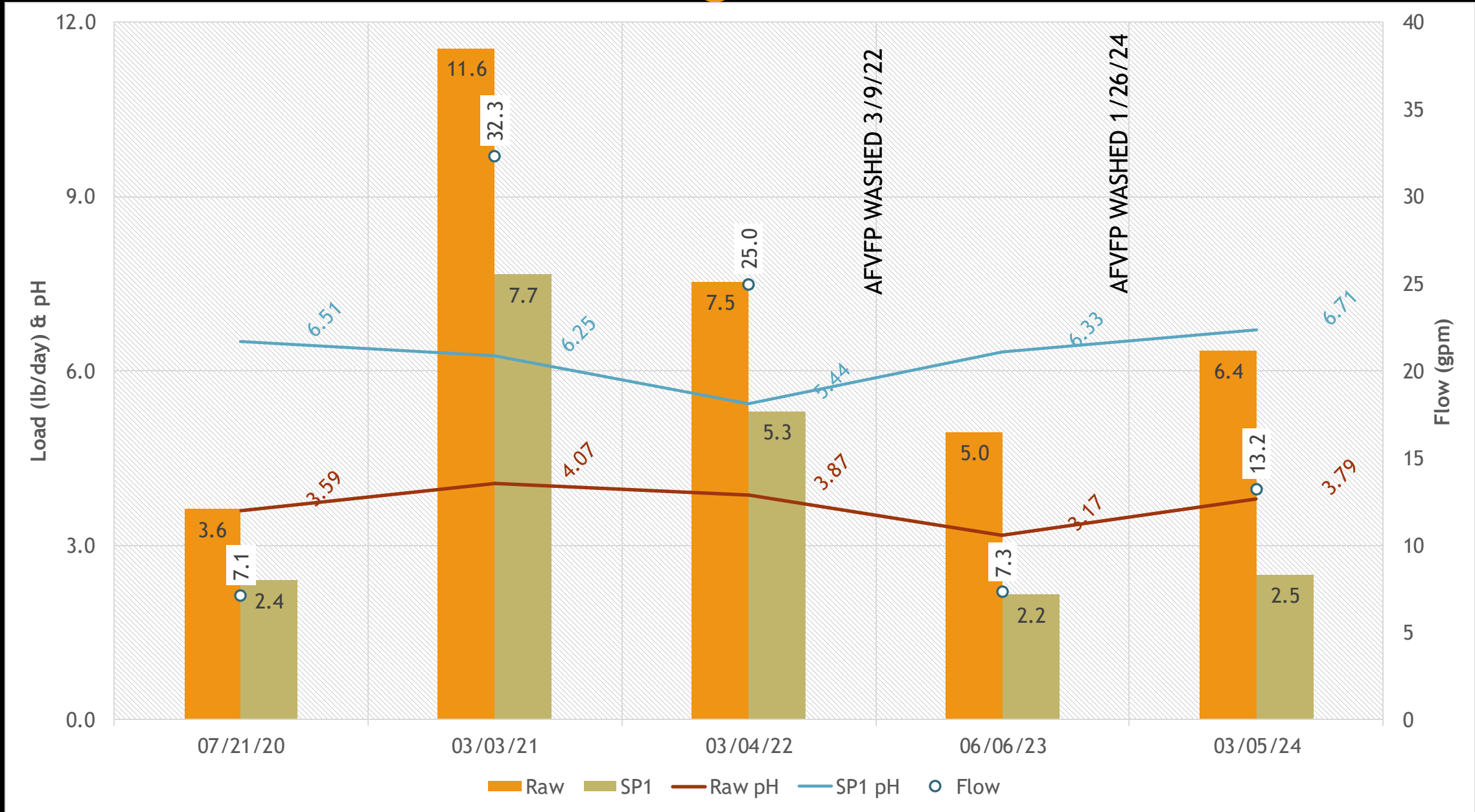
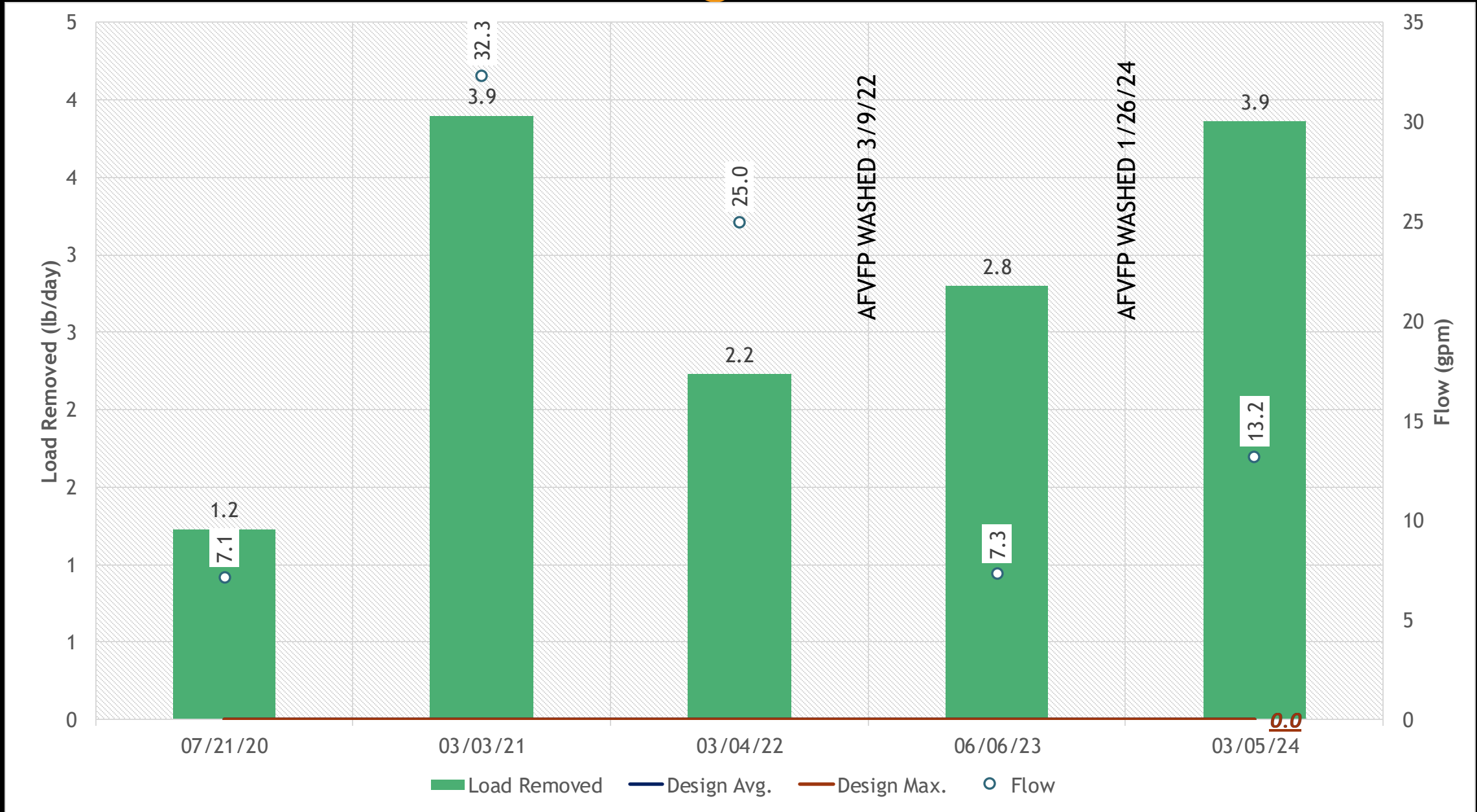


Figure 1-1. Theoretical solubilities of selected ions.

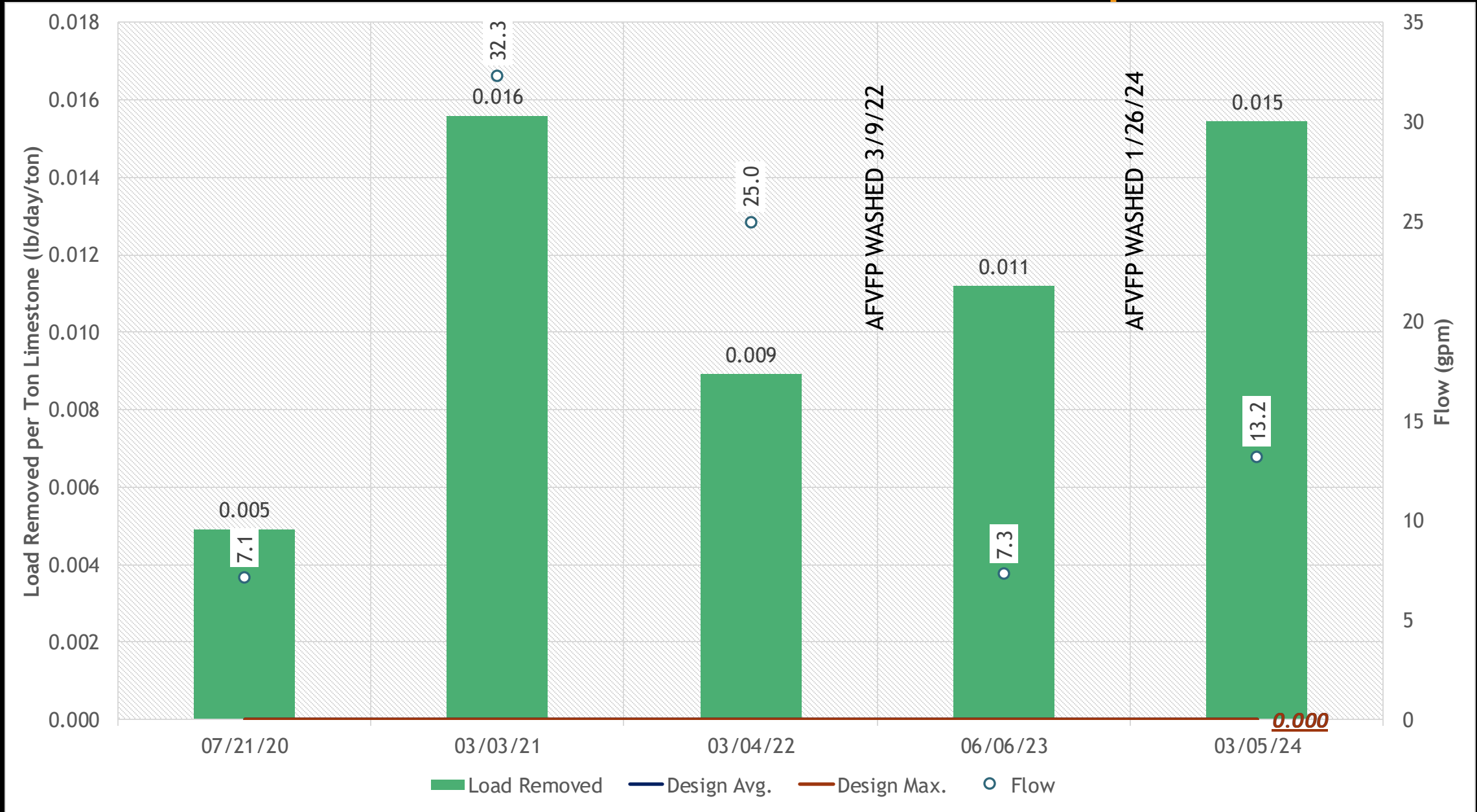
AFVFP Performance: Manganese Load



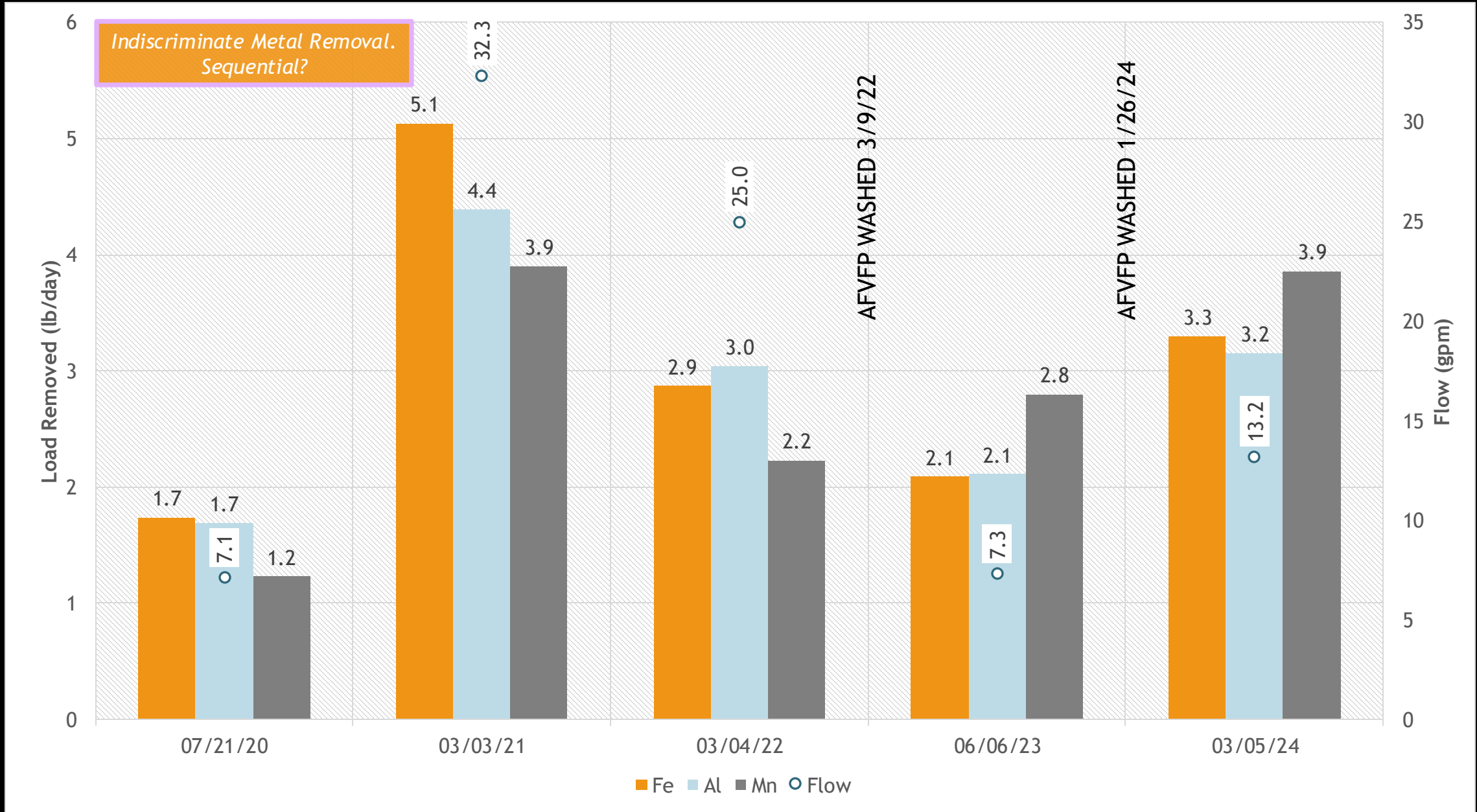
AFVFP Performance: Manganese Load Removed



AFVFP Performance: Mn Load Removed per Ton



AFVFP Performance: Metal Load Removal



Sorp This.....

“Most authors use the terms sorption, adsorption (surface sorption), absorption (matrix sorption), coprecipitation (coprecipitation), or surface complexation to describe reactions between different components in water, without specifically committing themselves to a mechanism...As expected, utter confusion thus reigns in the literature...”

- *Christian Wolkersdorfer*

Mine Water Treatment - Active and Passive Methods. Springer 2023, Page 26.

(<https://doi.org/10.1007/978-3-662-65770-6>) (used with permission)

HFLB Mn Removal

SP2 (end of channel)

HFLB1

HFLB2 (Outfall 001)

450 T (each) AASHTO #1

92% CaCO₃ Limestone

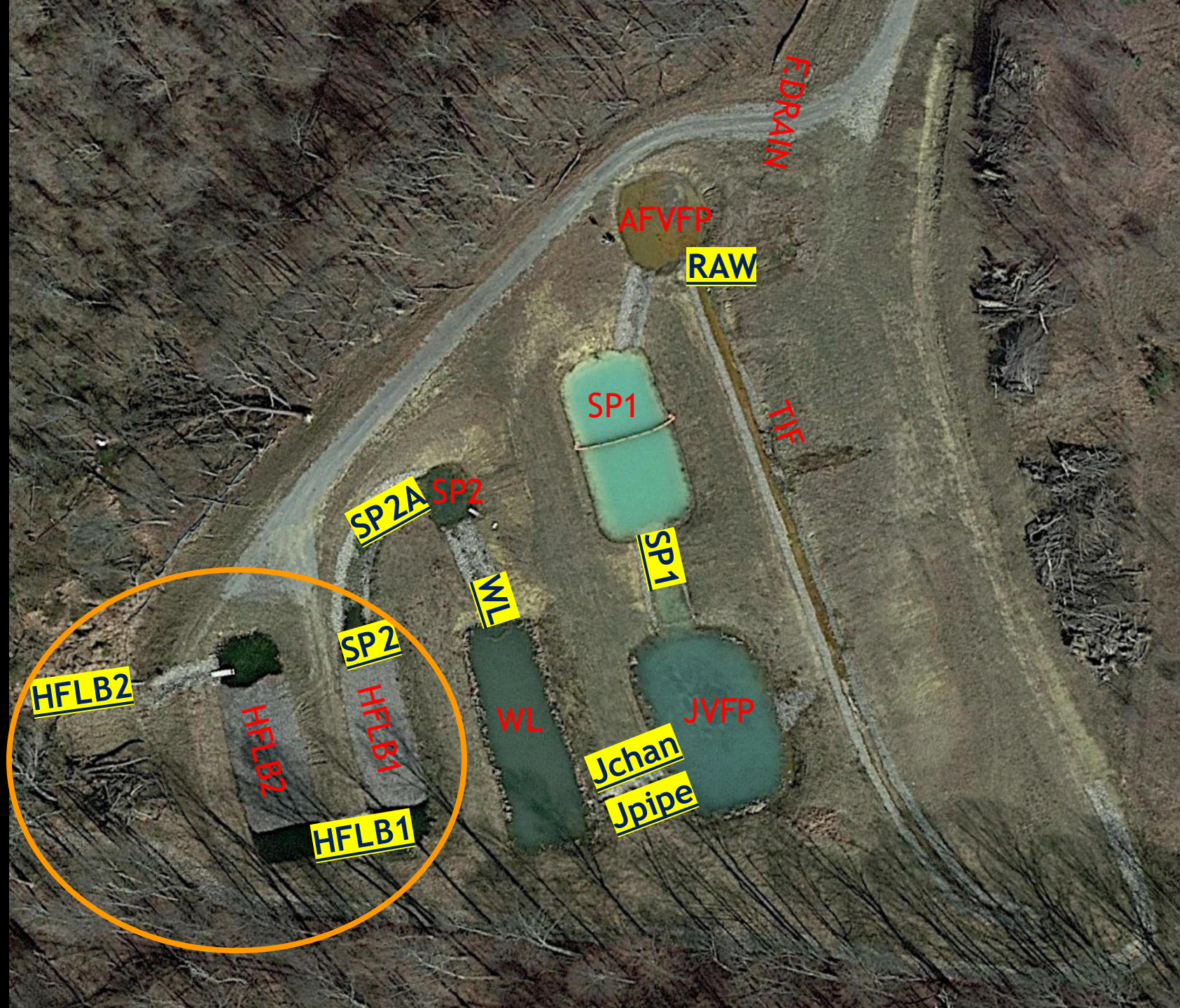
0.010 lb Mn/day/ton

(Denholm ASRS 2008)

7.0 lb Mn/day

$7.0 \div 0.01 = 700$ Tons

+25% Safety Factor



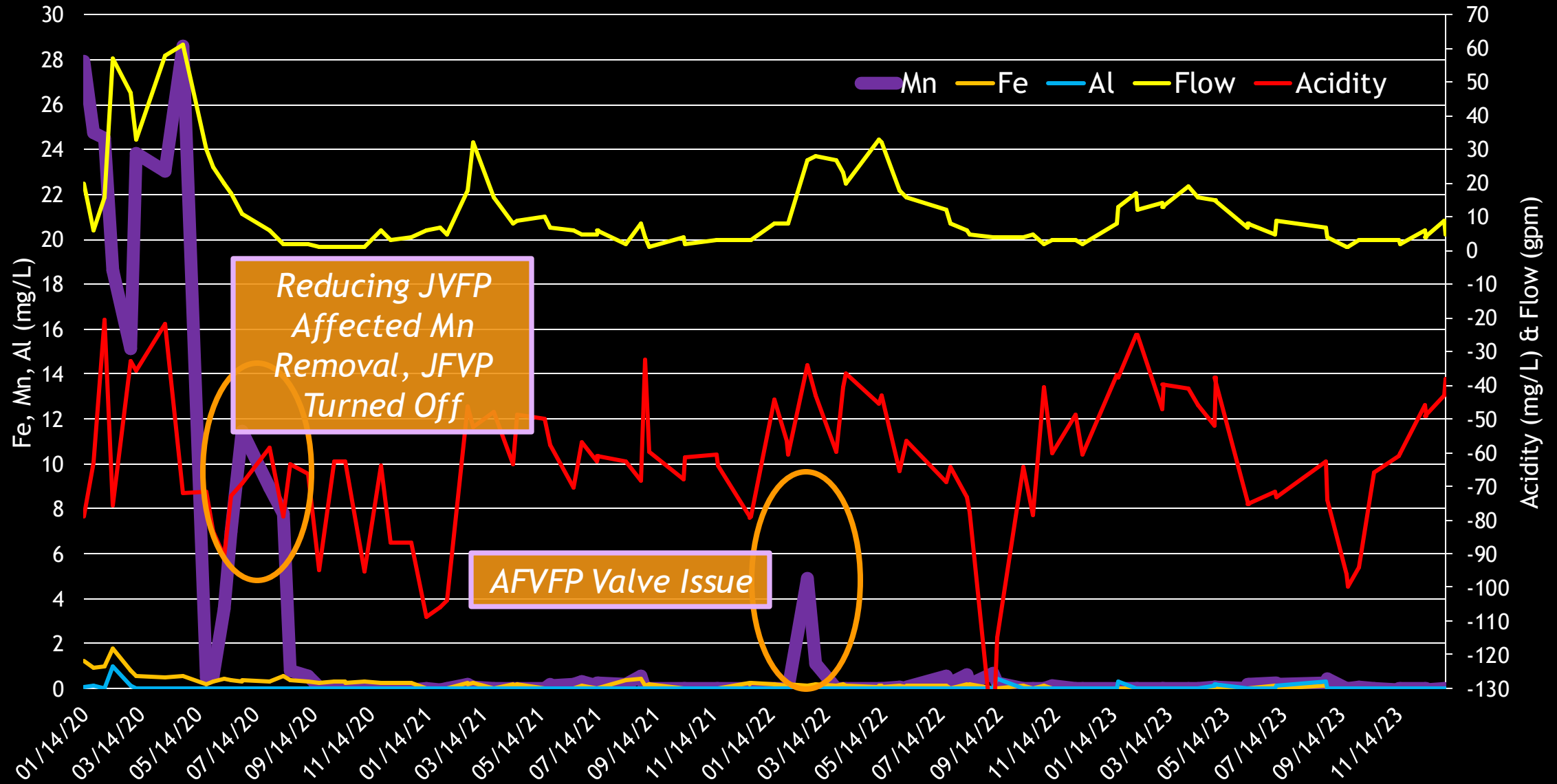
HFLB Mn Removal



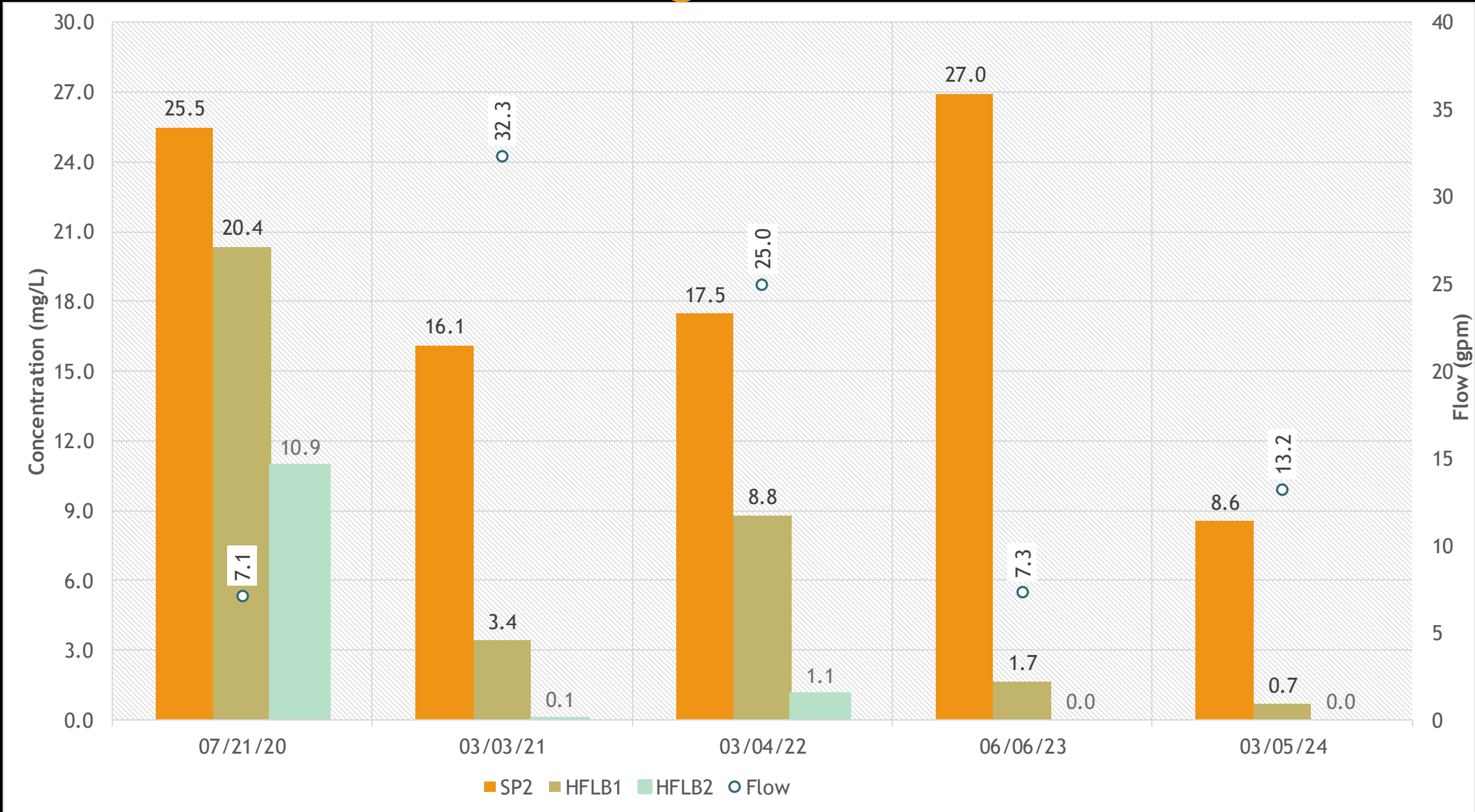
HFLB2 Inlet Pool (foreground) and Outlet Pool (top)

Photo 1/26/24

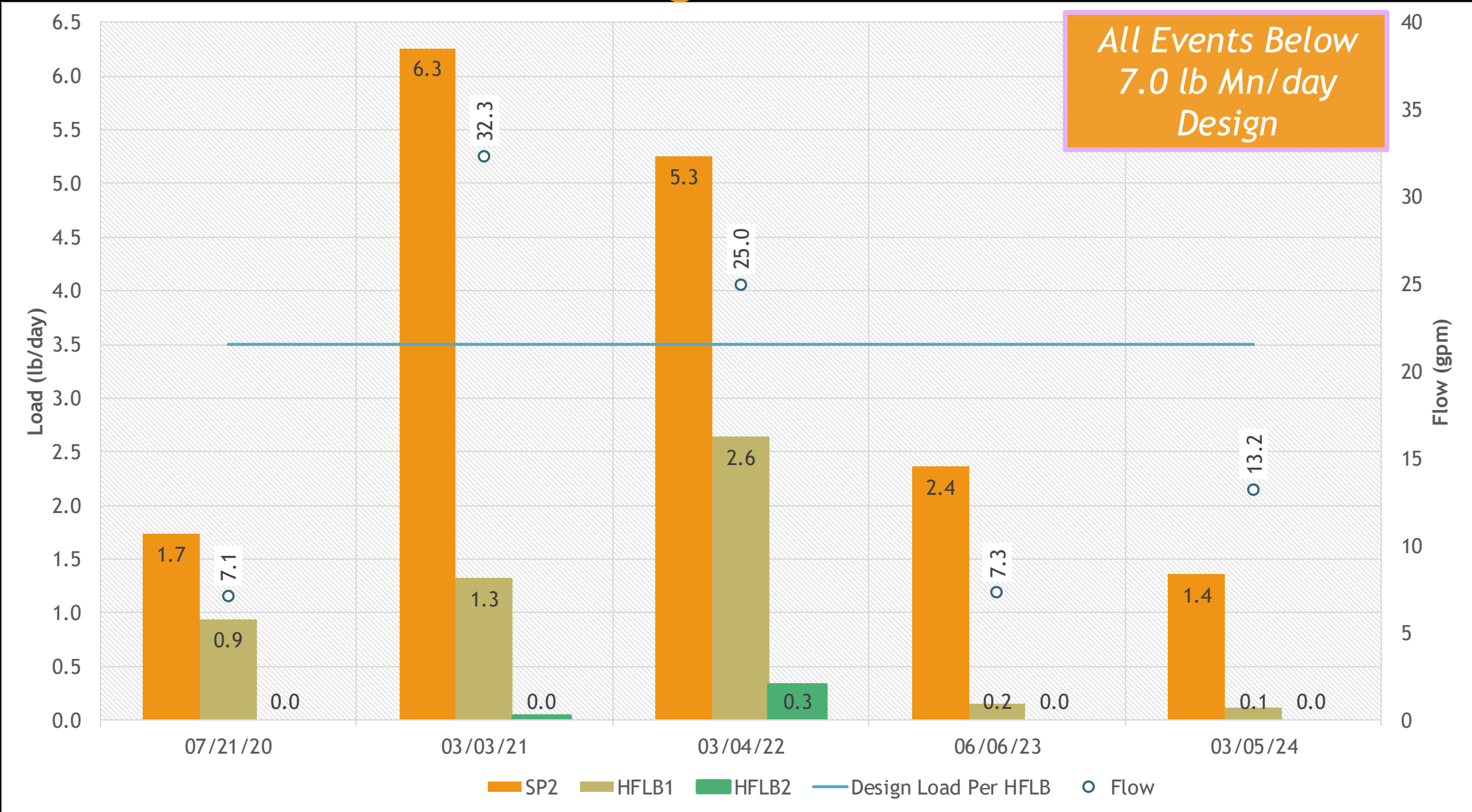
Effluent Characteristics (HFLB2/001 Outfall)



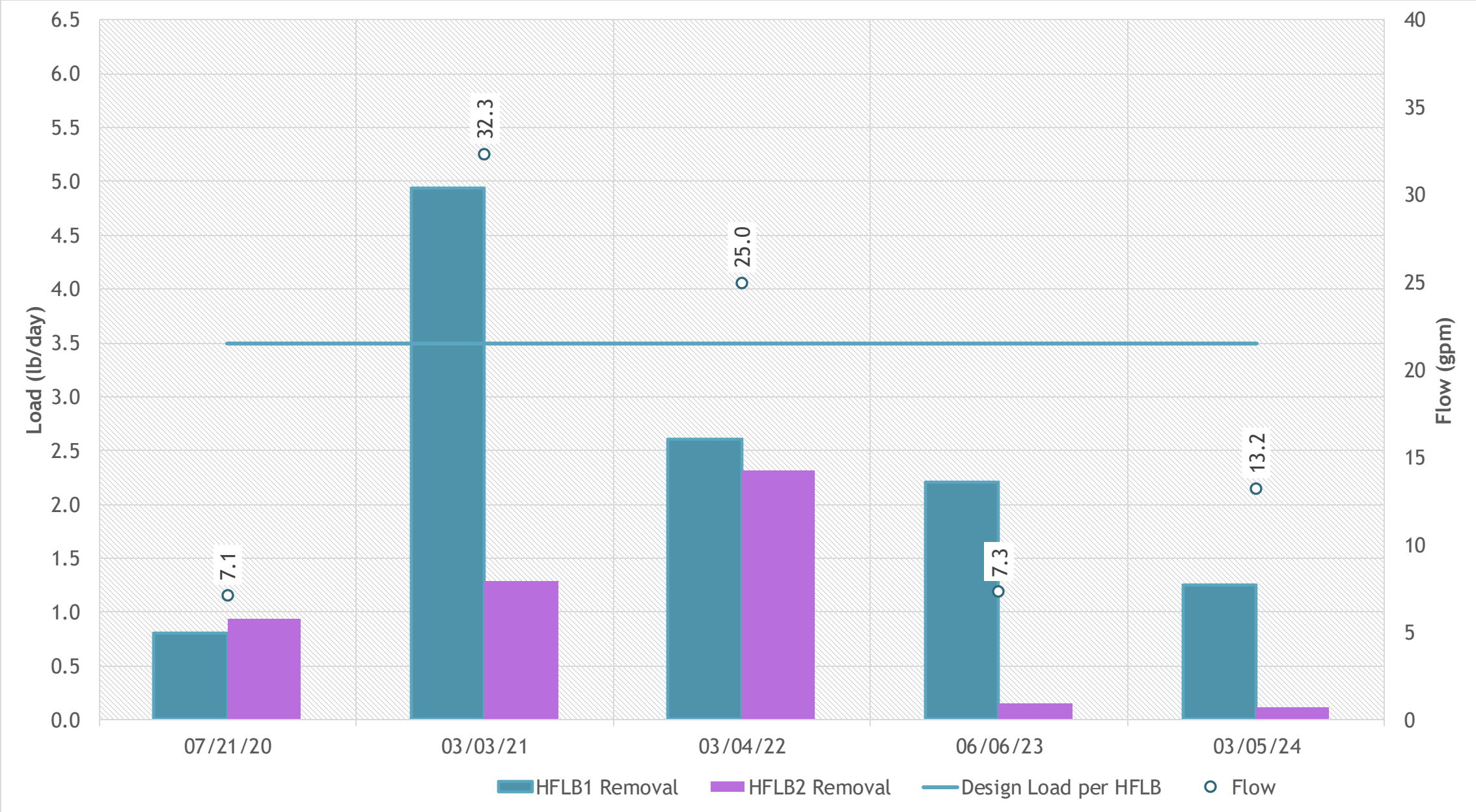
HFLB Performance: Manganese Concentration



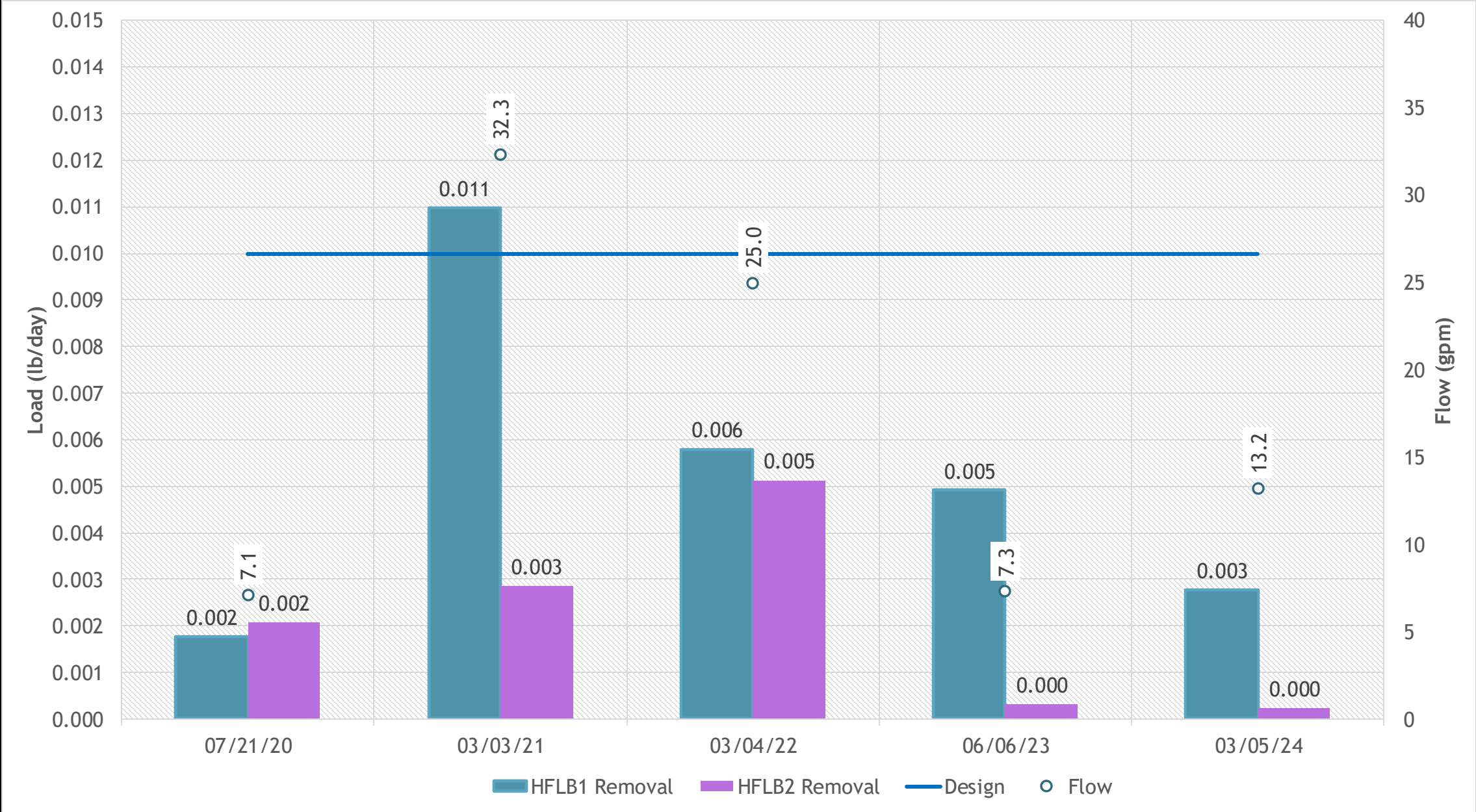
HFLB Performance: Manganese Load



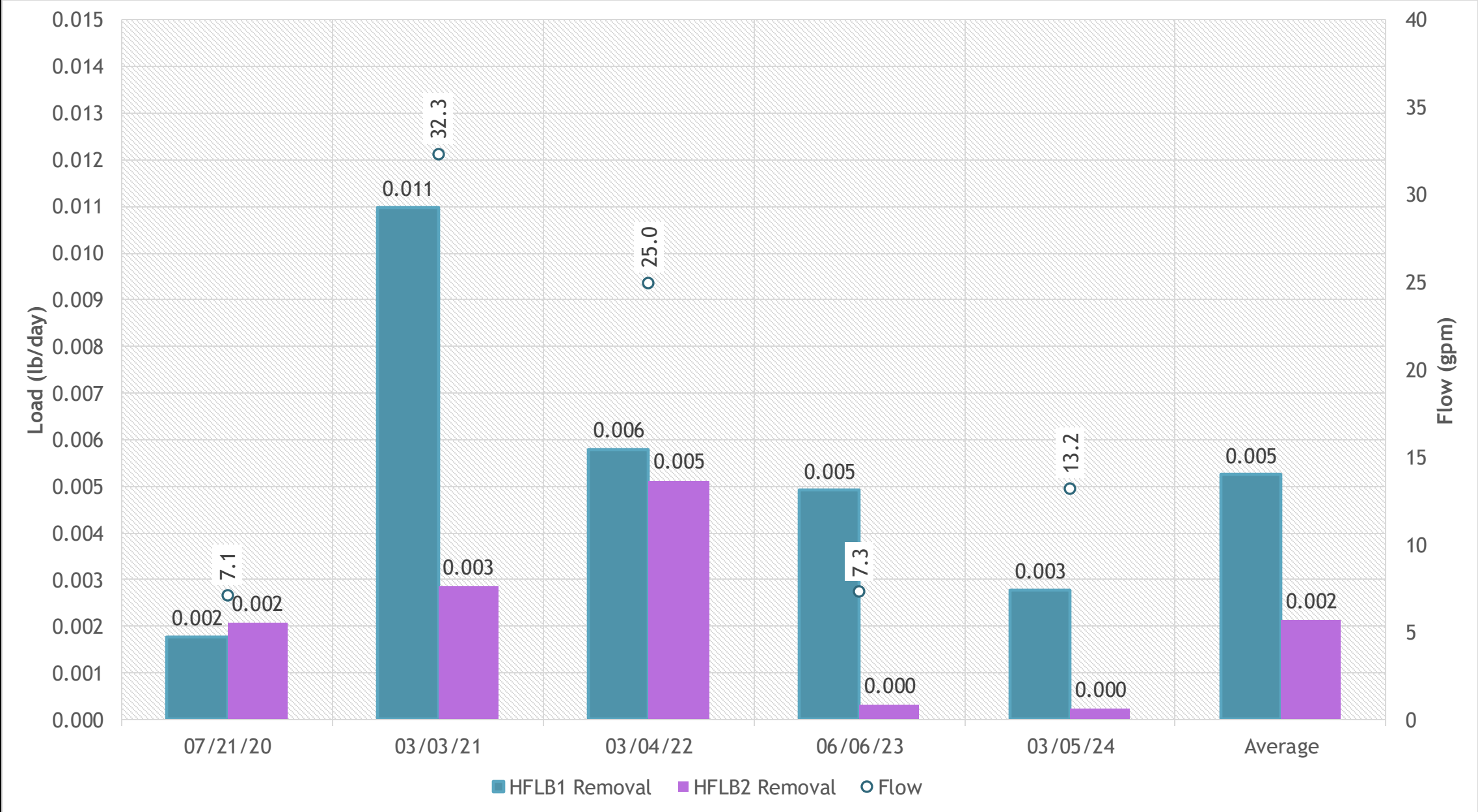
HFLB Performance: Manganese Load Removal



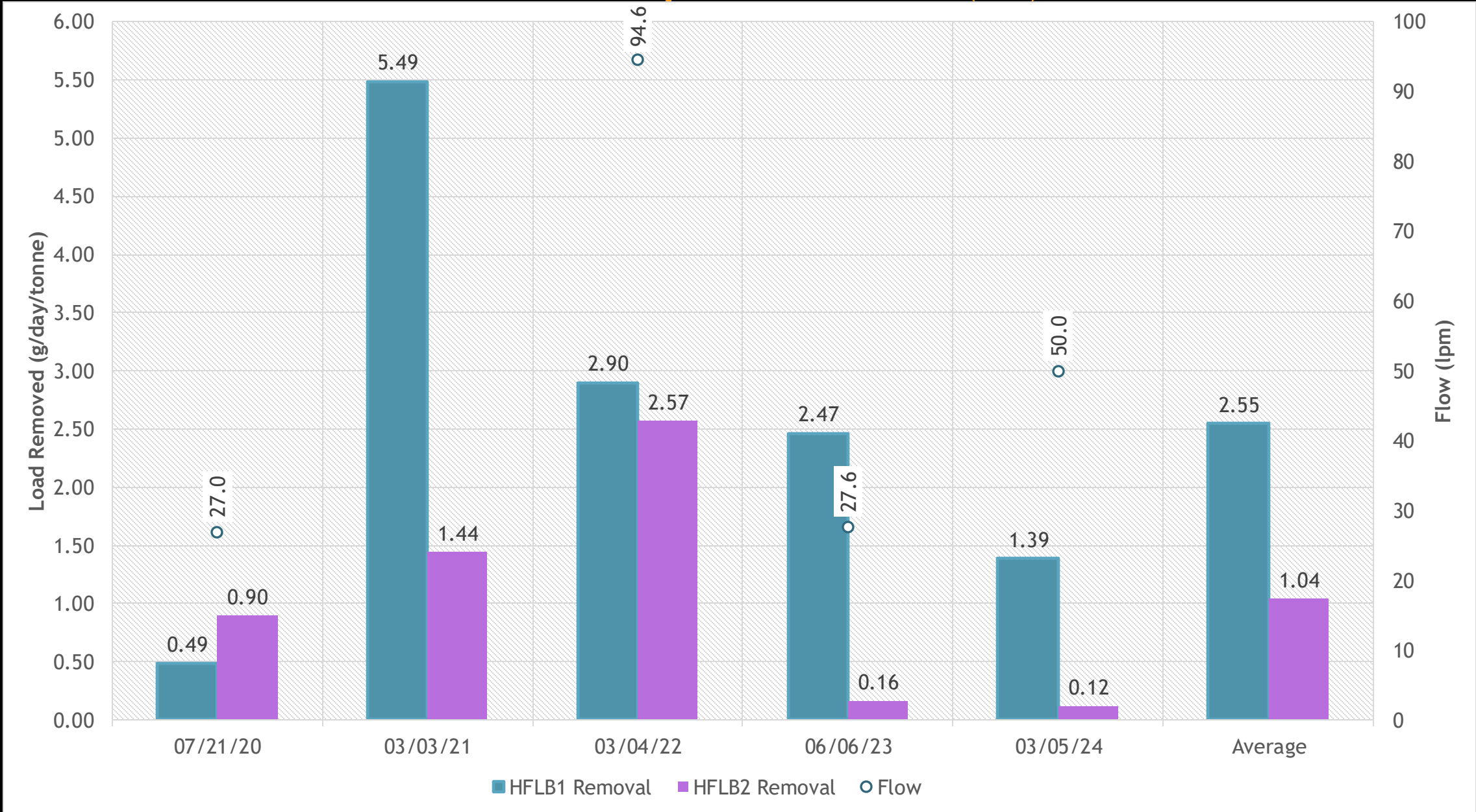
HFLB Performance: Mn Load Removal per Ton



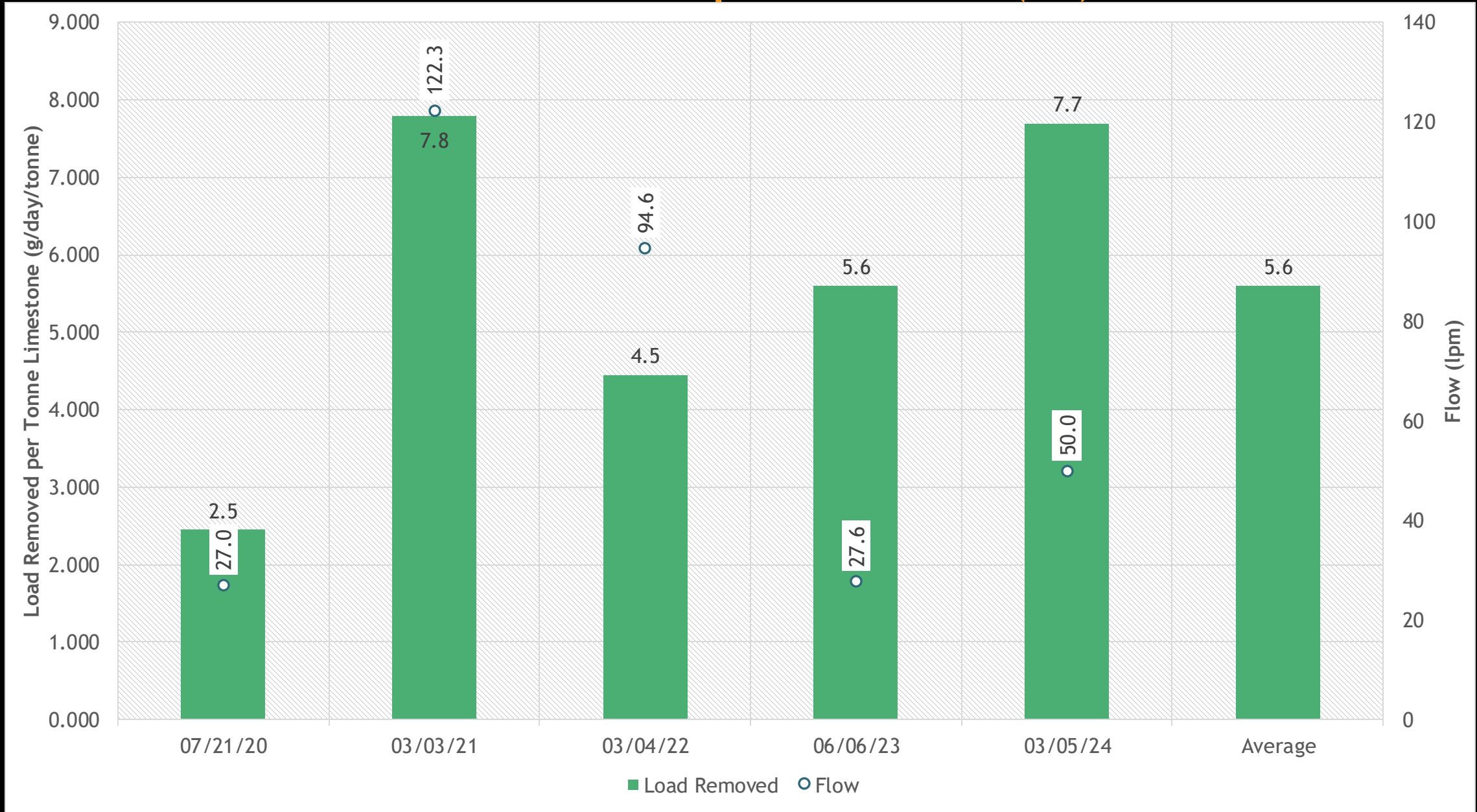
HFLB Mn Load Removal per Ton with Average



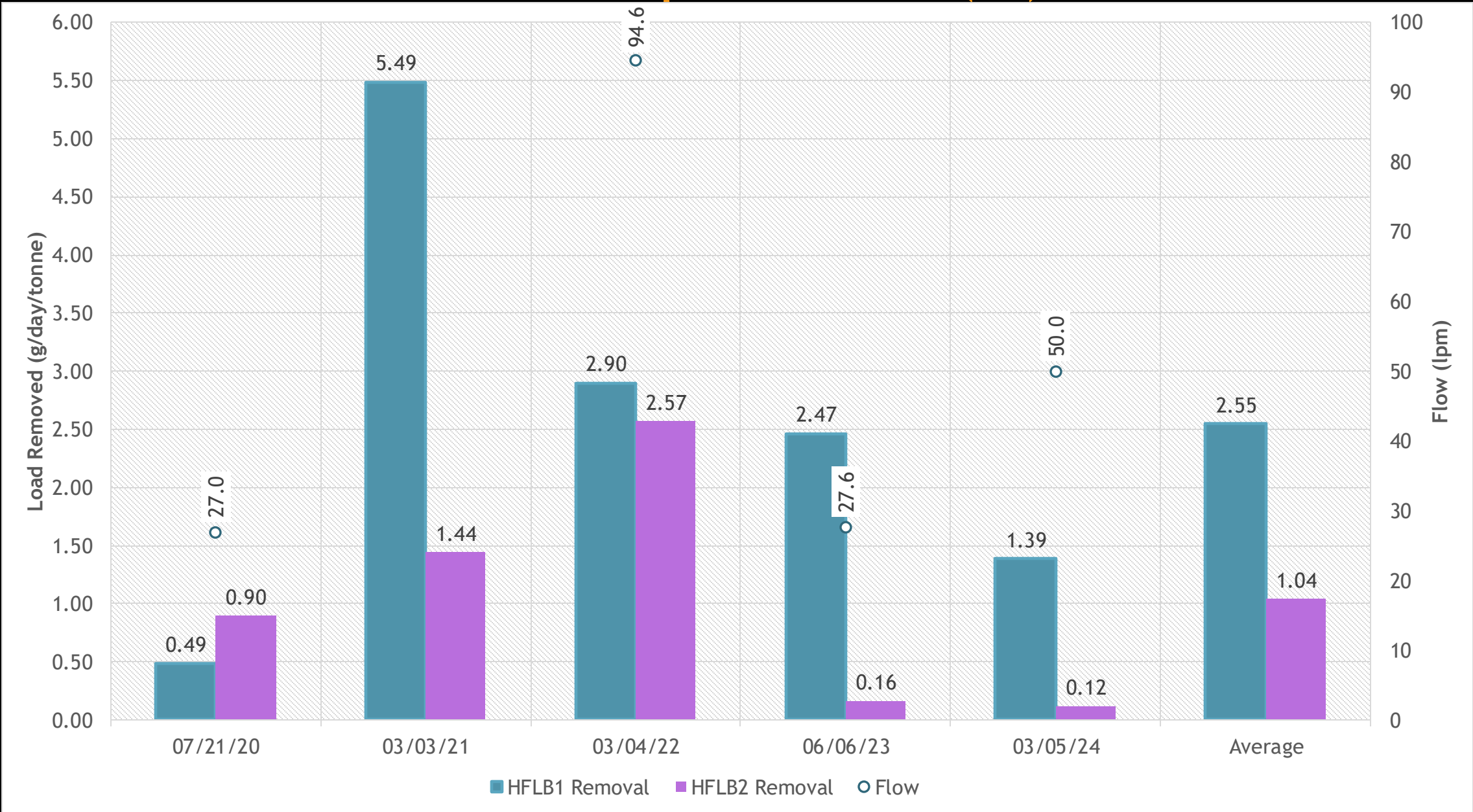
HFLB Mn Load Removal per Tonne (SI)



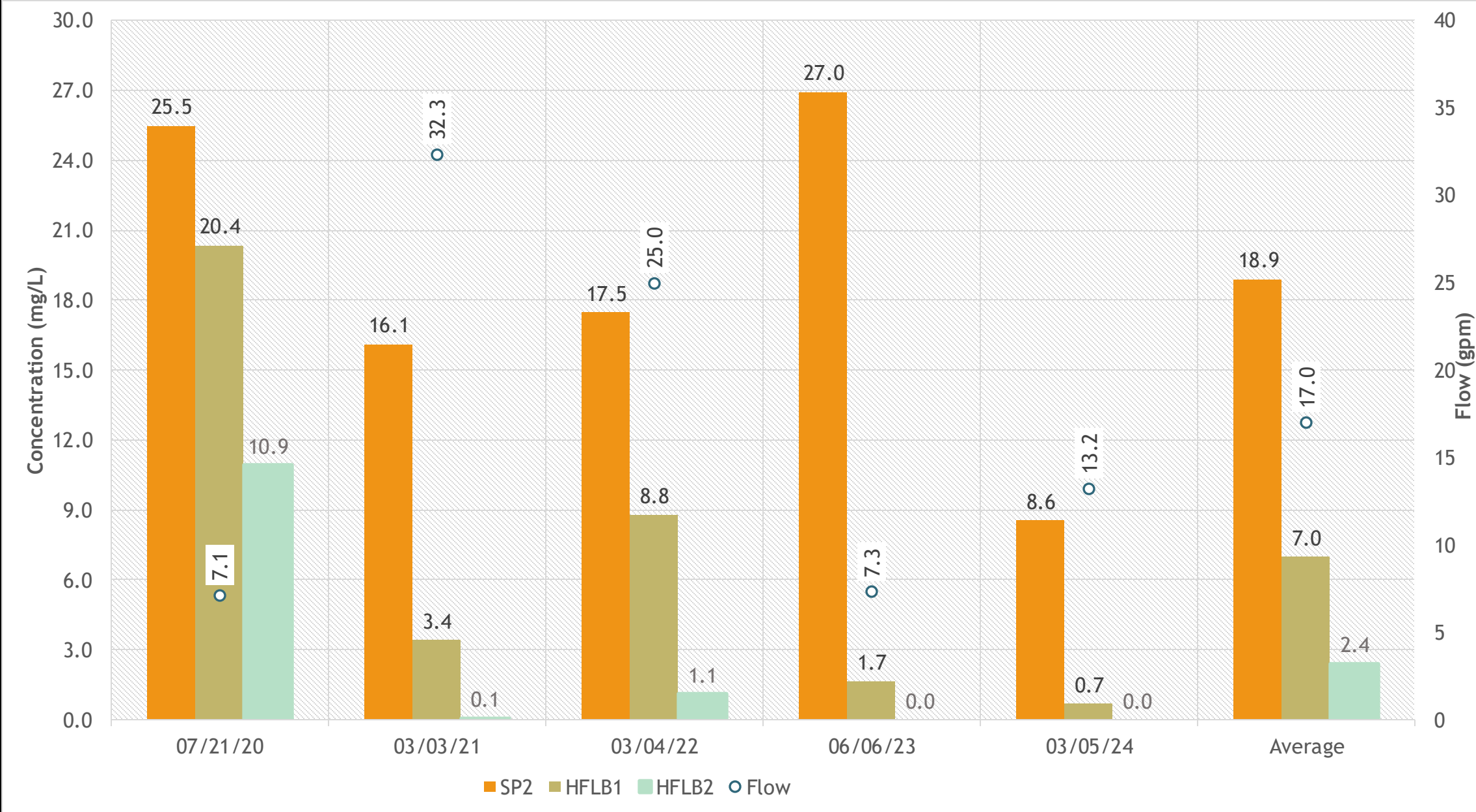
AFVFP Mn Load Removed per Tonne (SI)



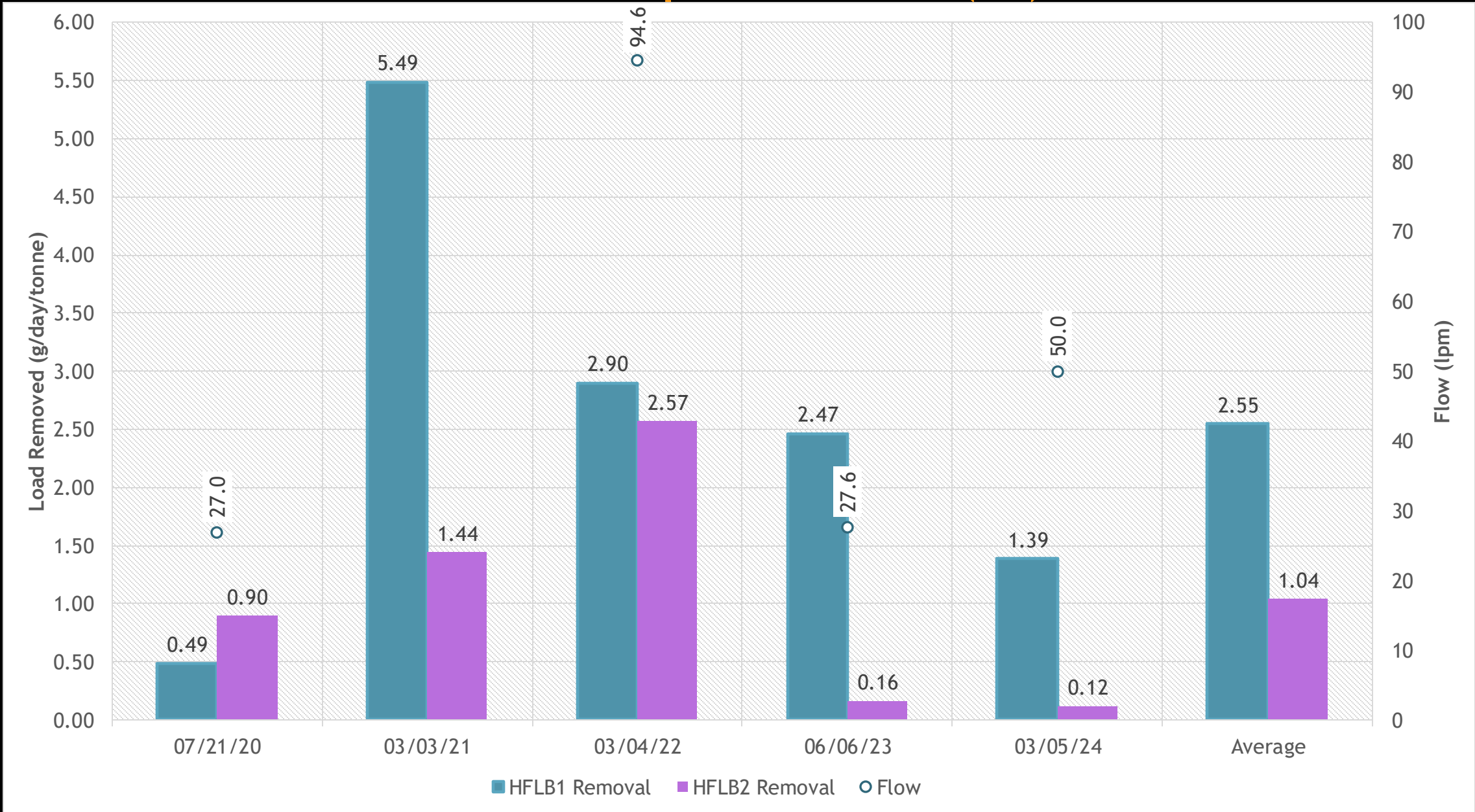
HFLB Mn Load Removal per Tonne (SI)



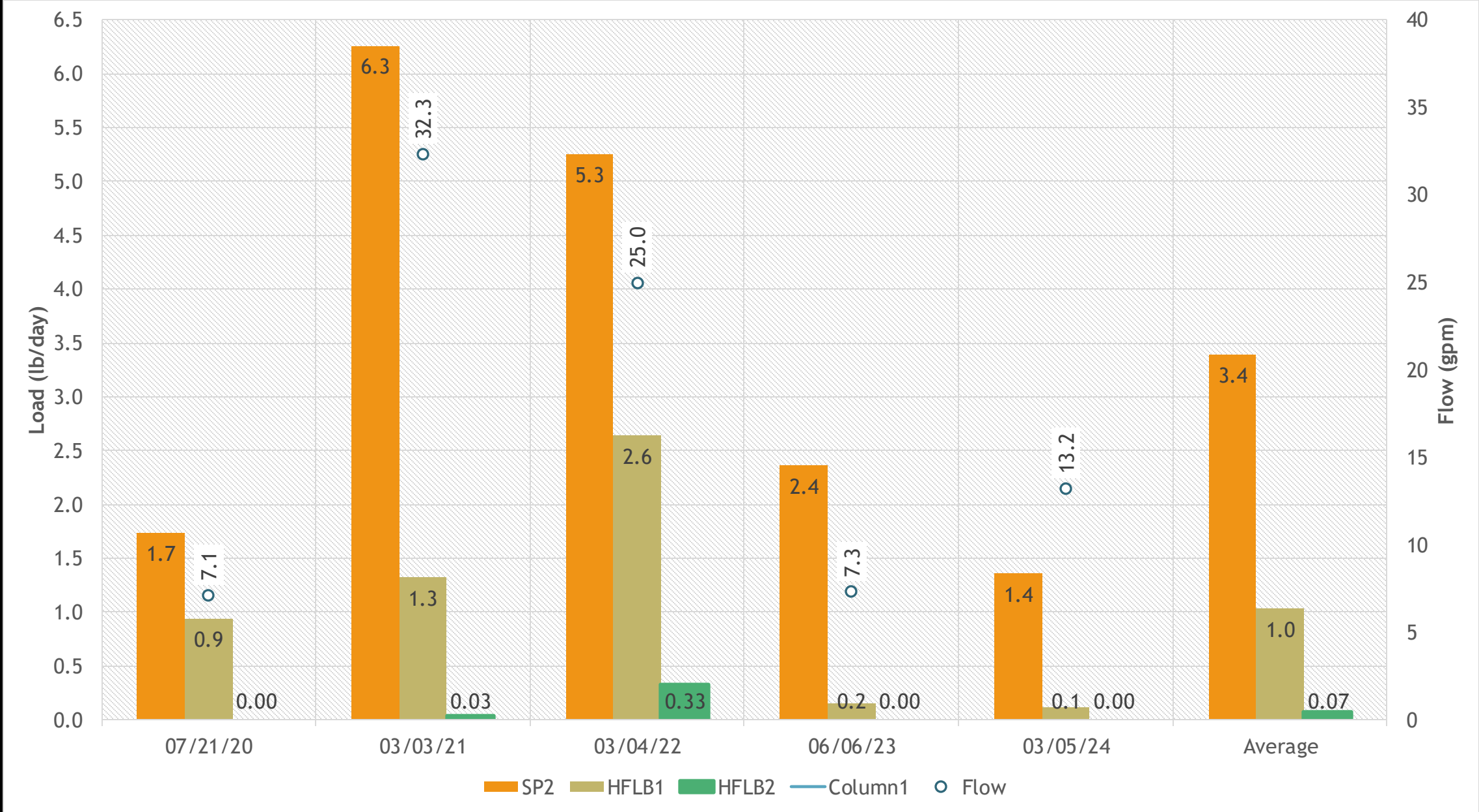
HFLB Mn Concentration with Average



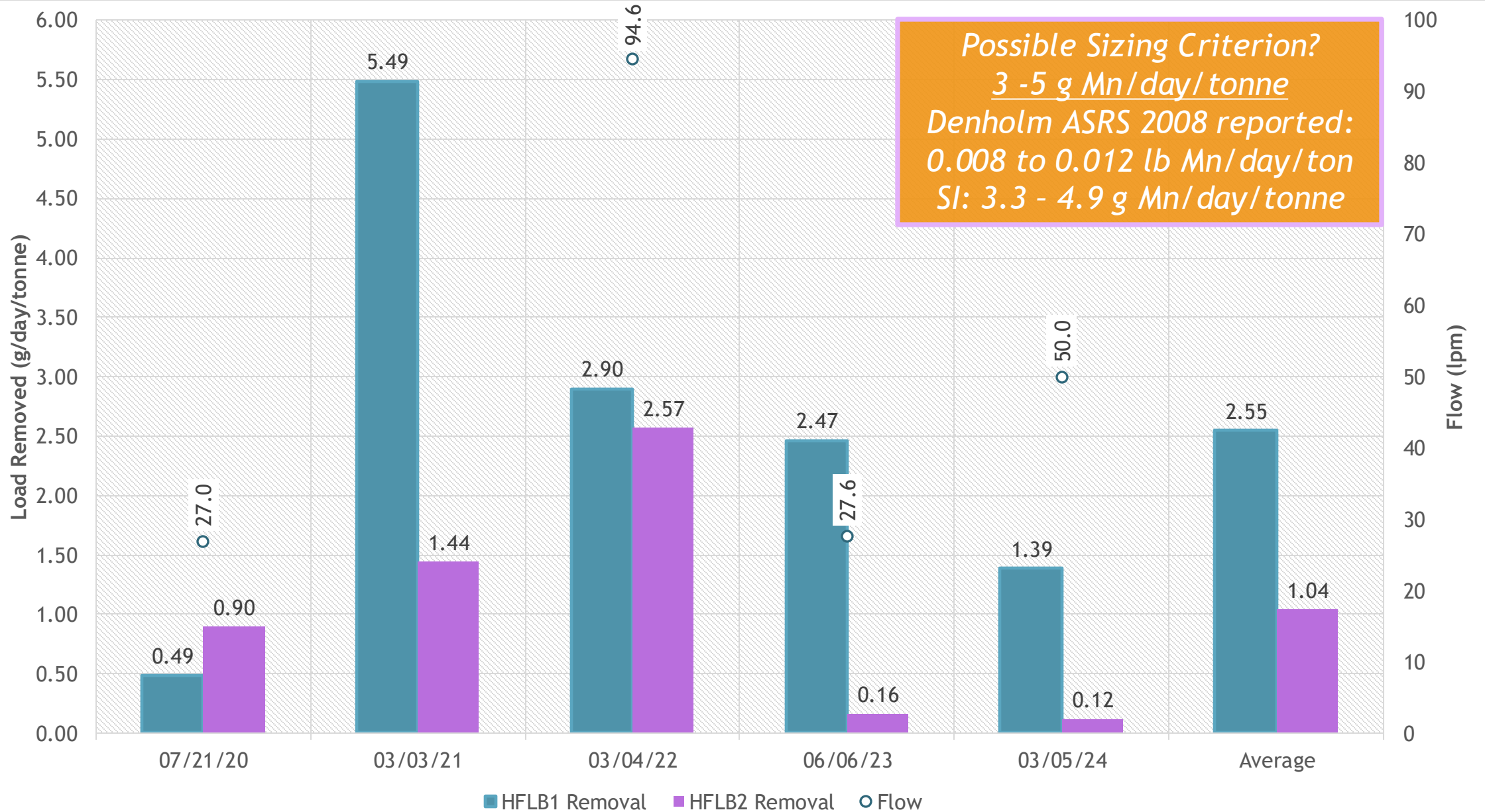
HFLB Mn Load Removal per Tonne (SI)



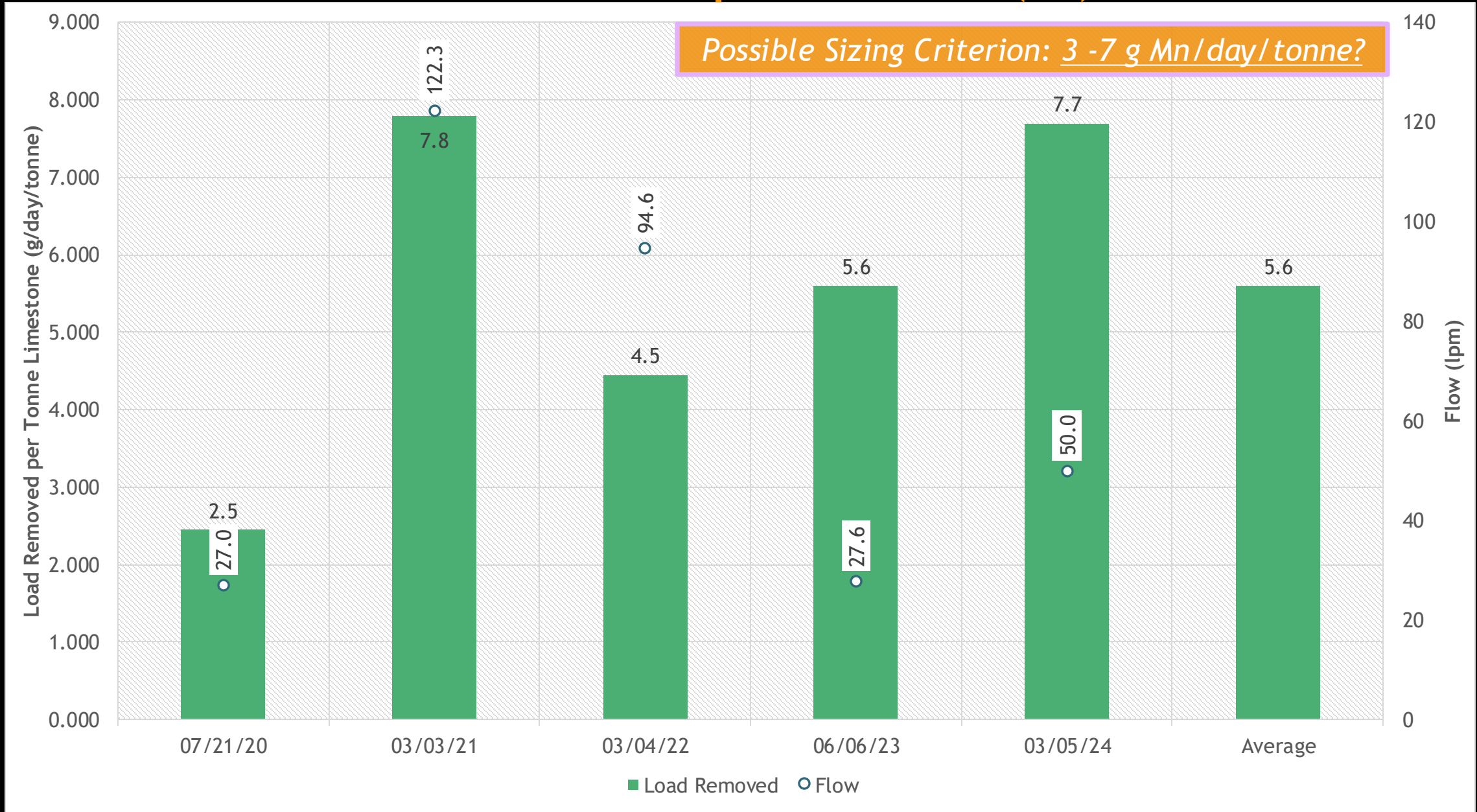
HFLB Manganese Load with Average



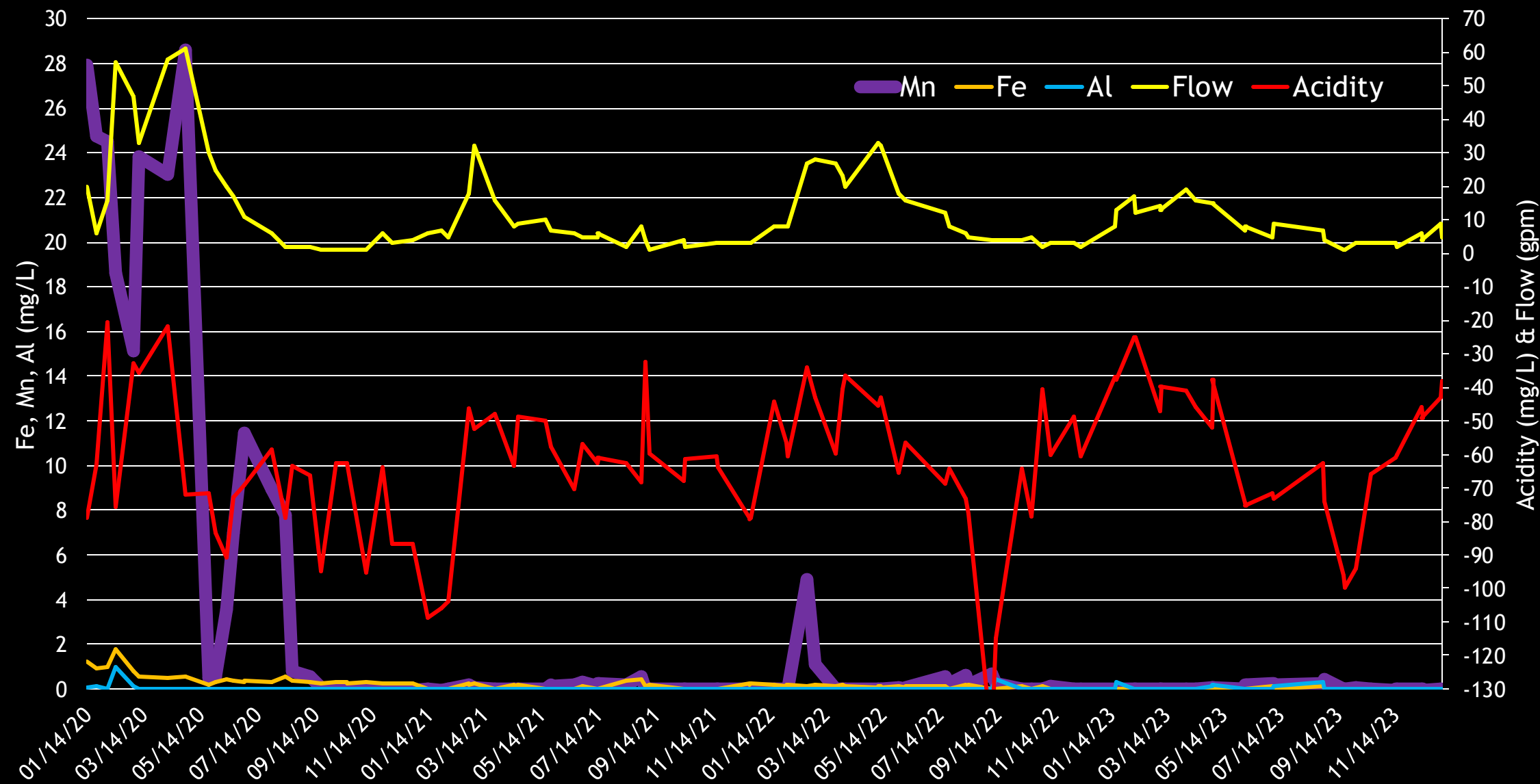
HFLB Mn Load Removal per Tonne (SI)



AFVFP Mn Load Removed per Tonne (SI)



Effluent Characteristics (2020 - 2023)



AFVFP Cleaned & Agri Drain Fixed 3/9/22



AFVFP Cleaned & Agri Drain Fixed 3/9/22



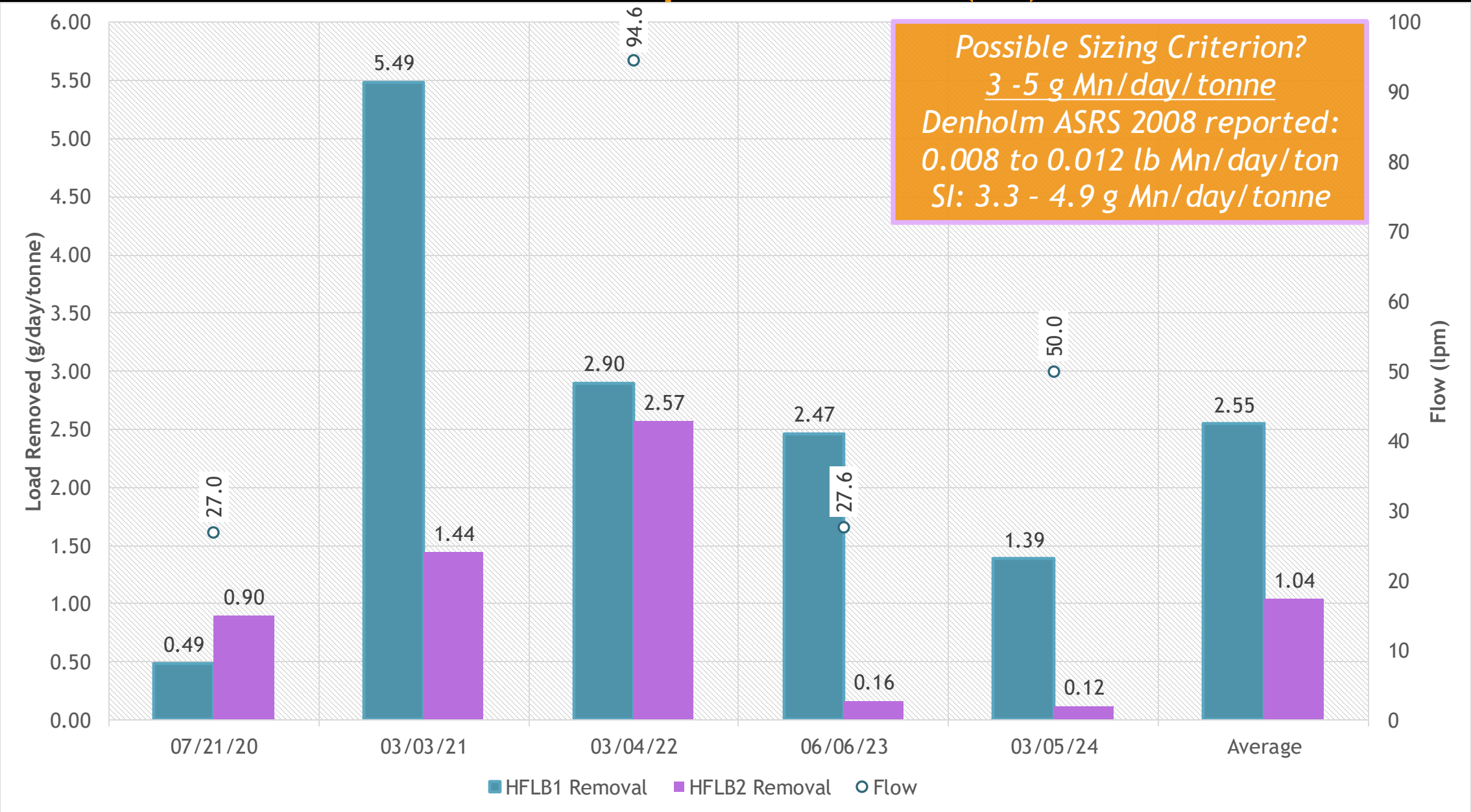
AFVFP Cleaned 1/26/24 (~6 hour for 250 tons)



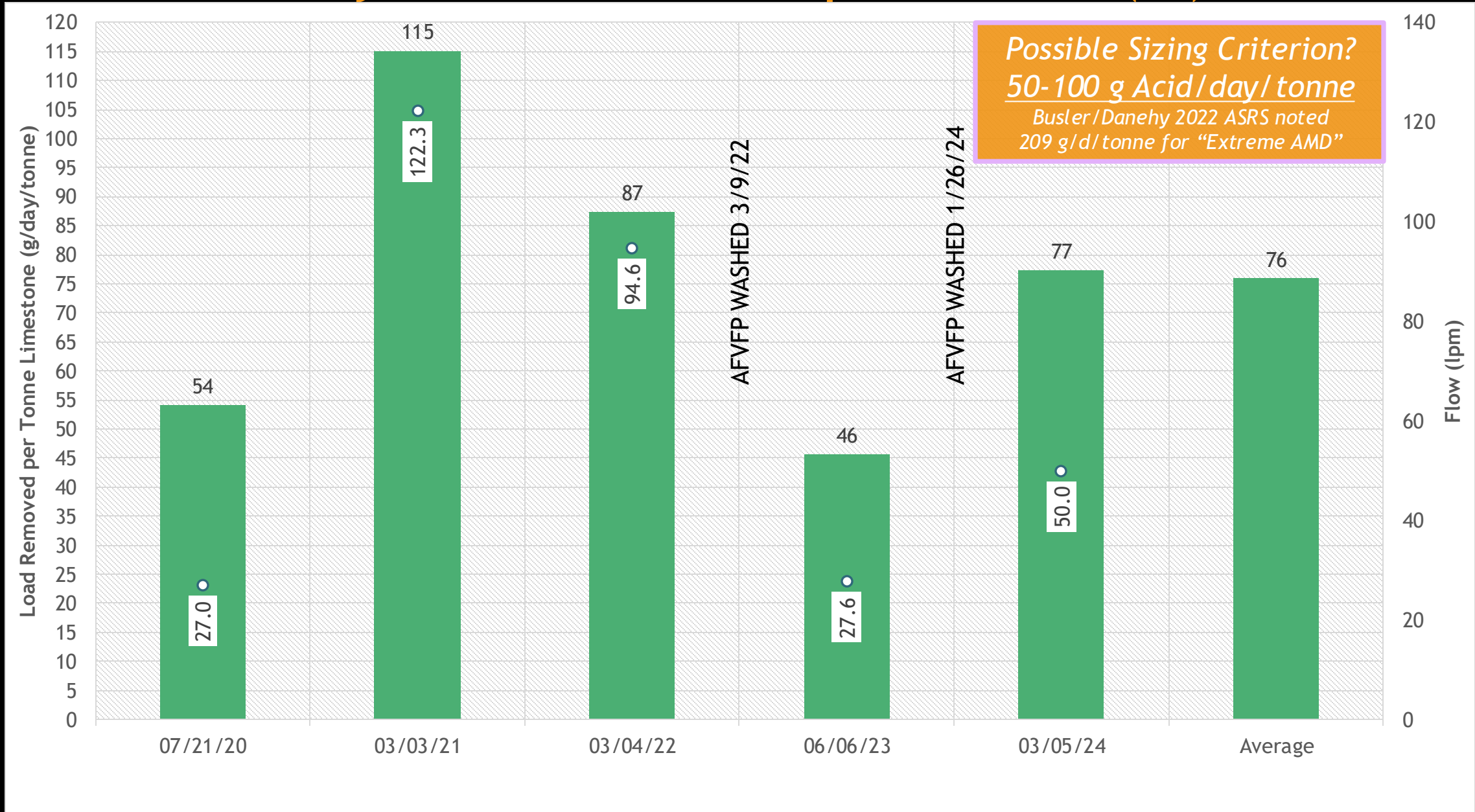
Concluding Thoughts

1. We need more science to confirm.
2. Need a guideline for sequential acid removal.
3. Can we develop a “simple” sizing criteria?
 1. AFVFP: 50-100 g acidity/d/tonne (need more science!)
 2. HFLB: 3-7 g Mn/day/tonne (need more science!)
4. These results need to be PHREEQ-N-Modeled.
 1. Sorption needs to be explored and understood.
5. Actual “Seasoned” Limestone Void Space: 25%

HFLB Mn Load Removal per Tonne (SI)



AFVFP Acidity Load Removed per Tonne (SI)



Thank you!

BioMost, Inc. expresses our gratitude to the operator for being willing to allow us to share this data.

Questions?

