Comparison of Pollutant Removal Rates for Three Limestone-Only Autoflushing Vertical Flow Ponds

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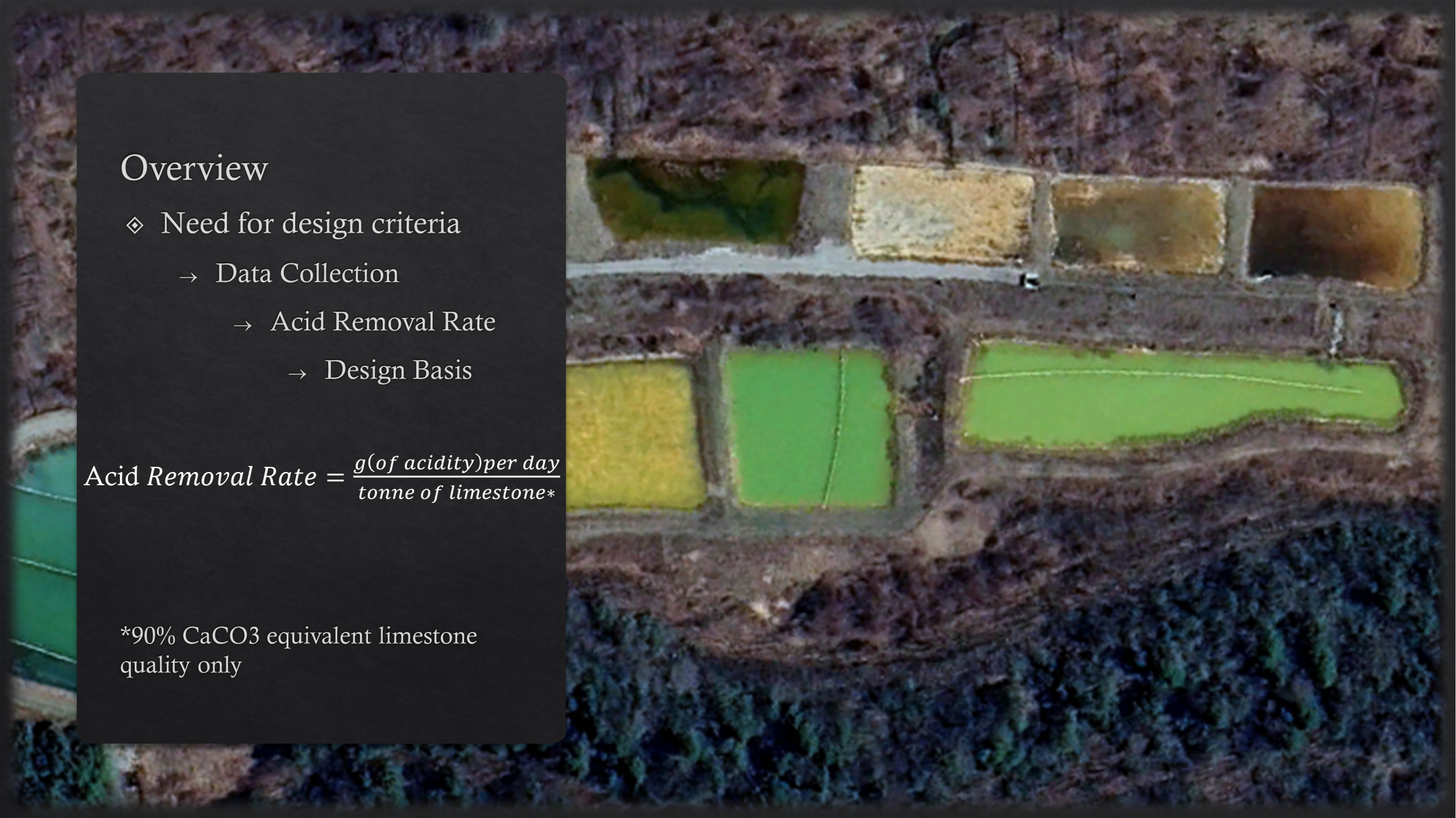


Overview

- Need for design criteria
  - → Data Collection
    - → Acid Removal Rate
      - → Design Basis

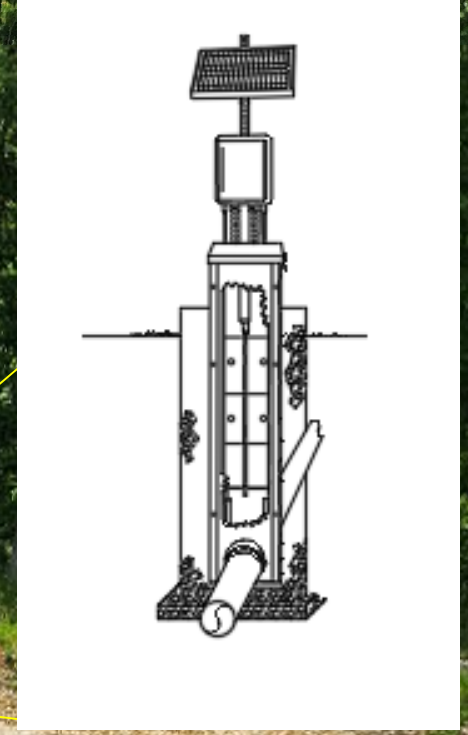
$$\text{Acid } Removal\ Rate = \frac{g(of\ acidity) per\ day}{tonne\ of\ limestone*}$$

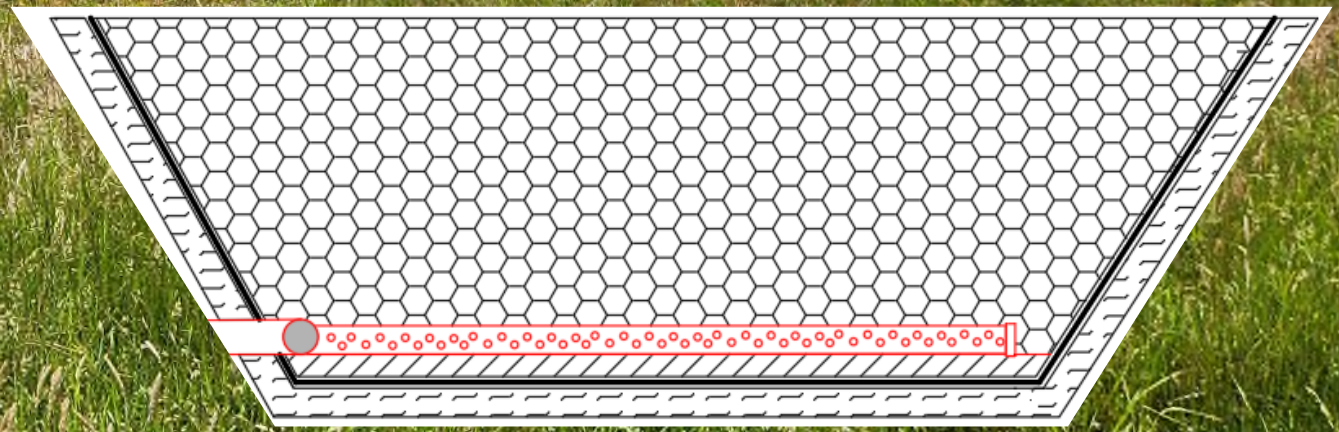
*90% $CaCO_3$ equivalent limestone quality only

Overview

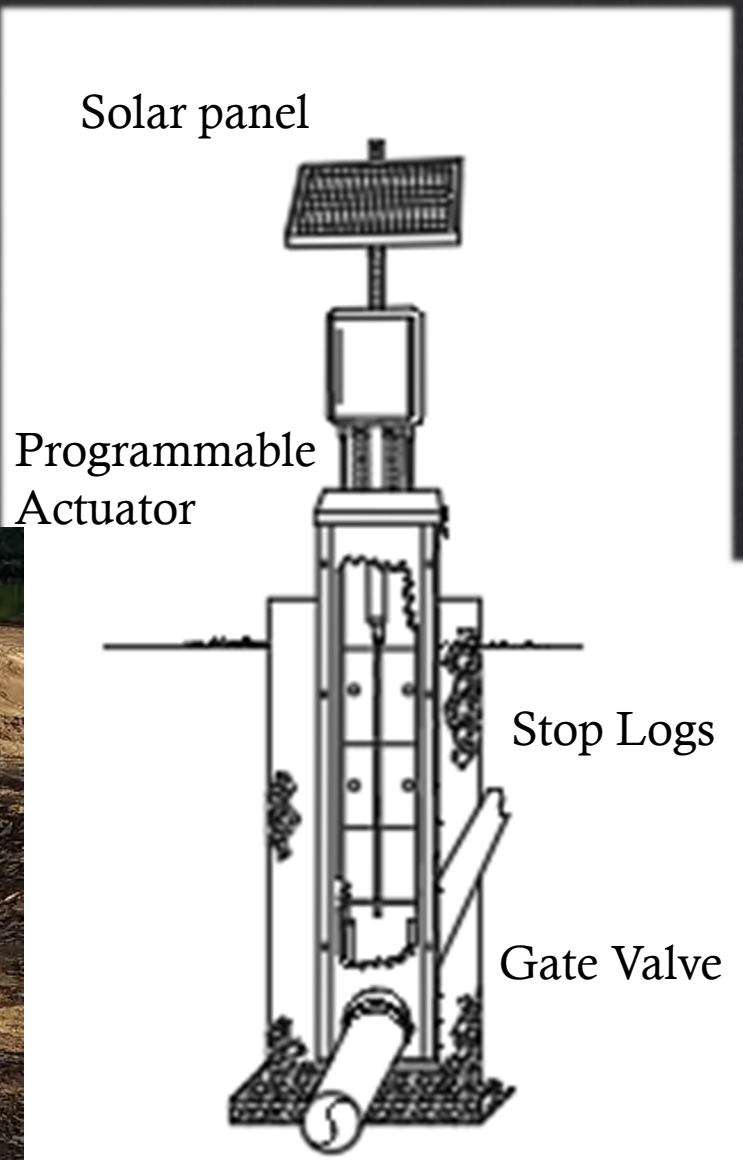
- Data Collection Methods
  - Telemetry
  - As-Builts
  - Water Quality Data

- How to use the AFVFP data
  - Gradual vs. Rapid Fill
  - Flush frequency (12hr, 9hr, 6hr)





The Guts:
Auto Flushing Vertical Flow Ponds (AFVFPs)



The Sites

Neal Run • Oven Run B • Muscavitch

The Sites

Neal Run

TIF

(1) 635 Tonne LS AFVFP

SP, (1) 1678 Tonne LS AFVFP, TIF 2

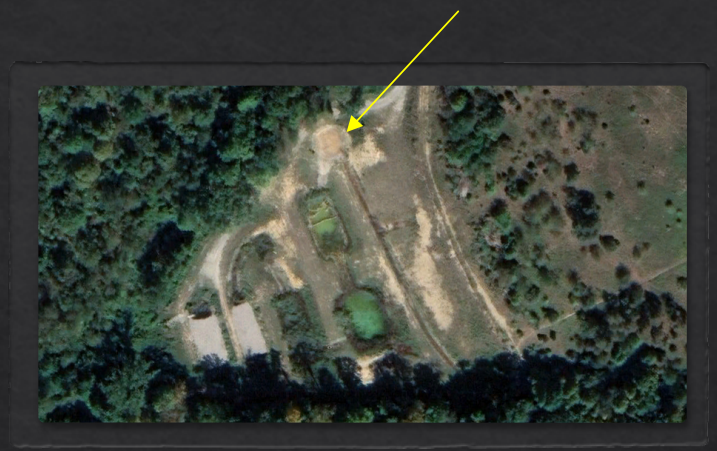
Oven Run B

Collection Moat

Holding Pond

(3) 2722 Tonne LS AFVFP

SP (3), JVFP (2)



Muscavitch

French Drain Collection

TIF

227 Tonne LS AFVFP

SP (2), JVFP , WL, HFLB (2)

The Treatment Material: Limestone Quality

- Design considering limestone (LS) $CaCO_3$ %.
  - Measured as $CaCO_3$ calcium carbonate equivalent (CCE); 1:1 ratio of acid to CCE
- Source Quality Confirmation

$$How\ much\ stone\ do\ we\ need? = Consumed\ Stone + Retention\ Reservoir$$

$$How\ much\ stone\ will\ be\ consumed?? = \frac{Acid\ Load\ * Lifespan}{Purity\ of\ Limestone}$$

$$\frac{(10\ tonnes\ Acid\ per\ year * 20\ years)}{90\%\ CaCO3\ Limestone} = 222\ tonnes\ of\ Limestone\ Consumed$$

$$"Retenetion\ Reservoir"\ Factors: Max.FLow\ *\ Desired\ Retention\ Time\ *\ Limestone\ Void\ Spac\ *\ LS\ Bulk\ Density$$

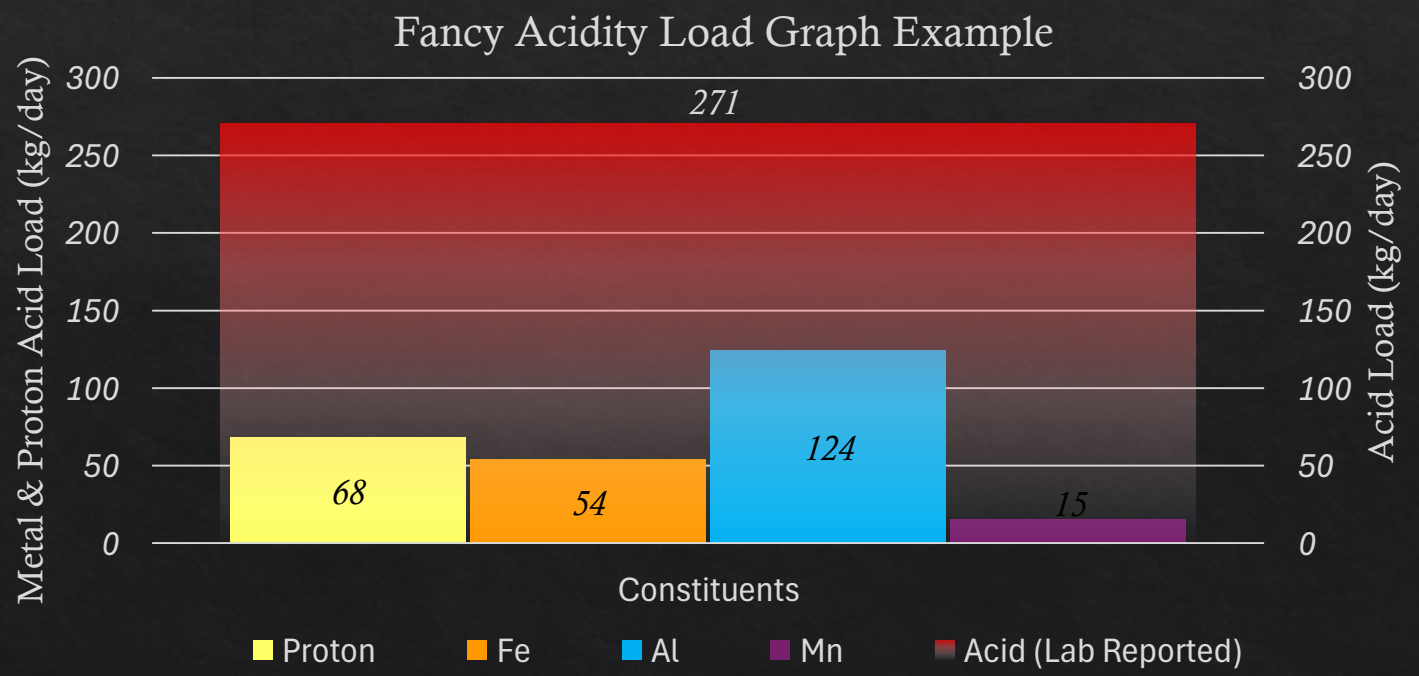
PROCEDURE FOLLOWED: ASTM C 1271 (Modified)

Oven Run B Stone Reuse Analysis

	TOTAL ANALYSIS (Dry)	
INTENSITY OF FIZZ	STRONG	
CALCIUM CARBONATE	95.12	%
MAGNESIUM CARBONATE	2.56	%
CALCIUM CARBONATE EQUIVALENT	98.33	%

The Need for Data: Calculating Acid Load

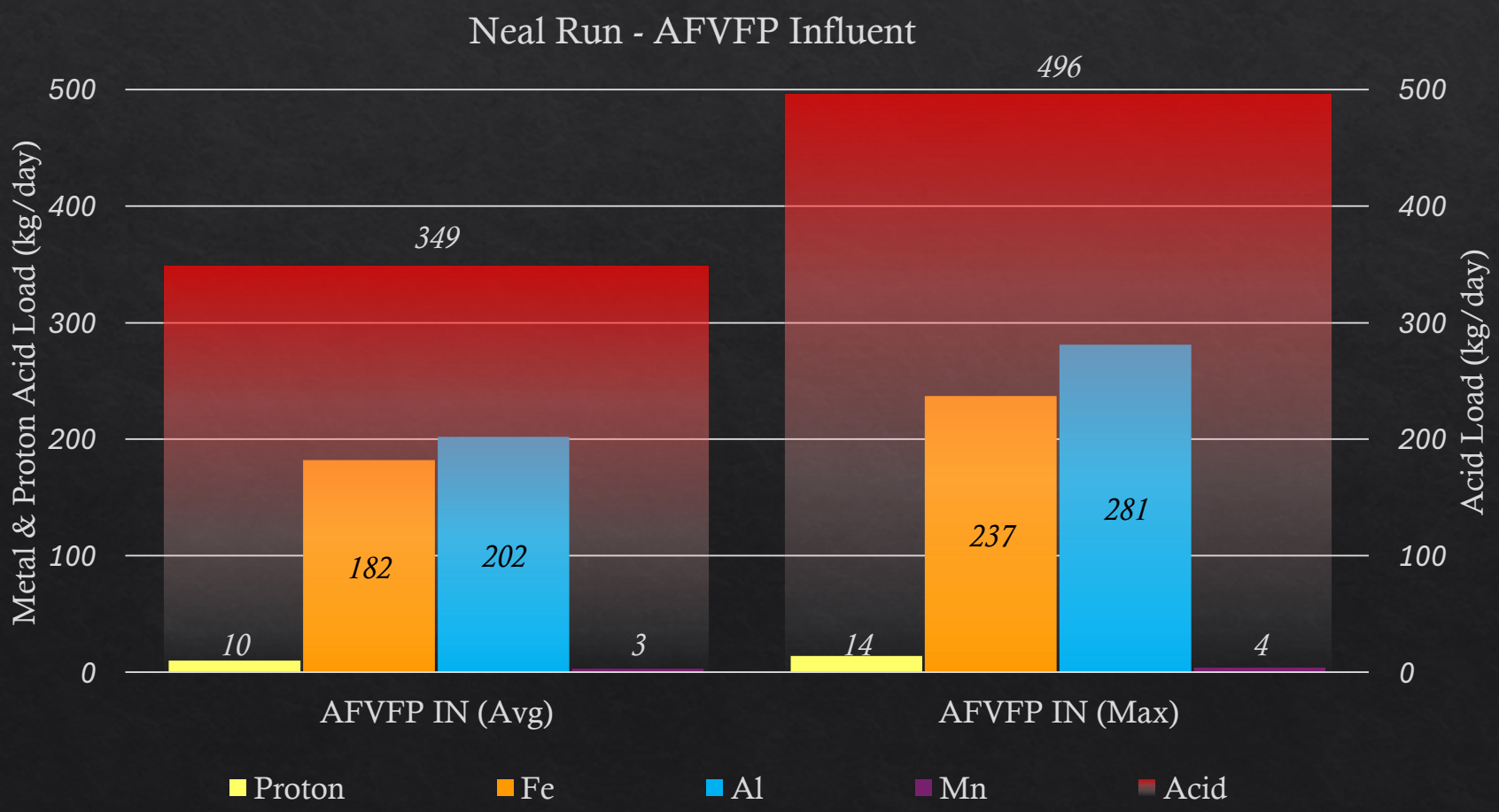
- Load refers to kg/day (lb/day)
- Proton Acidity Load + Sum of Metal Acidity Load = Total Acid Load
- Calculated Acidity does not always = Lab Reported Acidity
- Assuming all iron is Ferric (2.83 mg/L acid per mg/L Fe)



271 ≠ 261

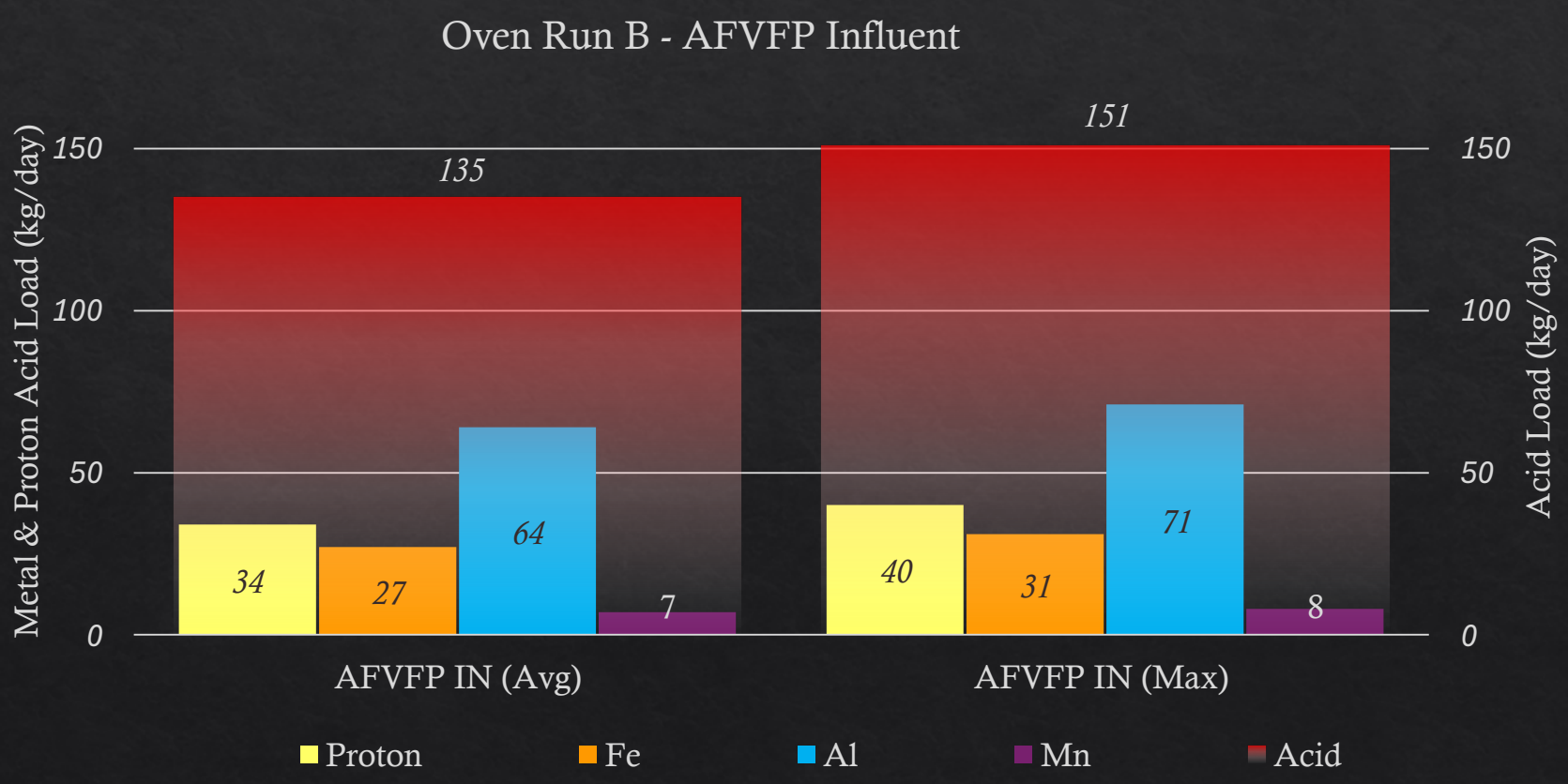
Water Quality: Neal Run

RAW	Average	Min	
pH	2.7	2.4	
	Average	**Max**	**Units**
Flow	1.1	1.8	L/s
	18.1	28.5	GPM



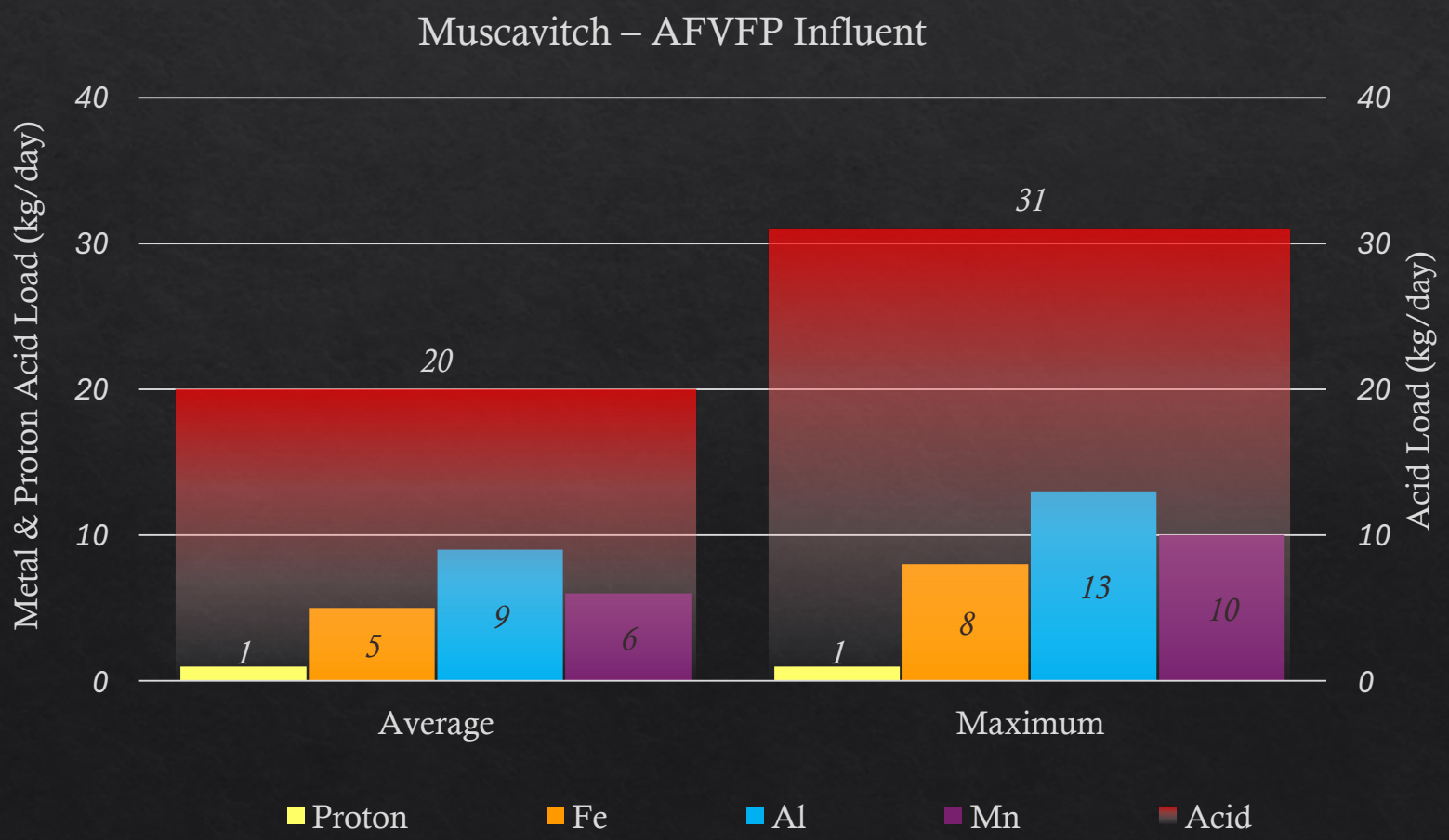
Water Quality: Oven Run B

	Average	Min	
pH	3.2	3.7	
	Average	**Max**	**Units**
Flow	6.1	6.5	L/s
	97	103	GPM



Water Quality: Muscavitch

	Average	Min	
pH	3.7	3.2	
	Average	**Max**	**Units**
Flow	1.1	2.0	L/s
	18	32	GPM



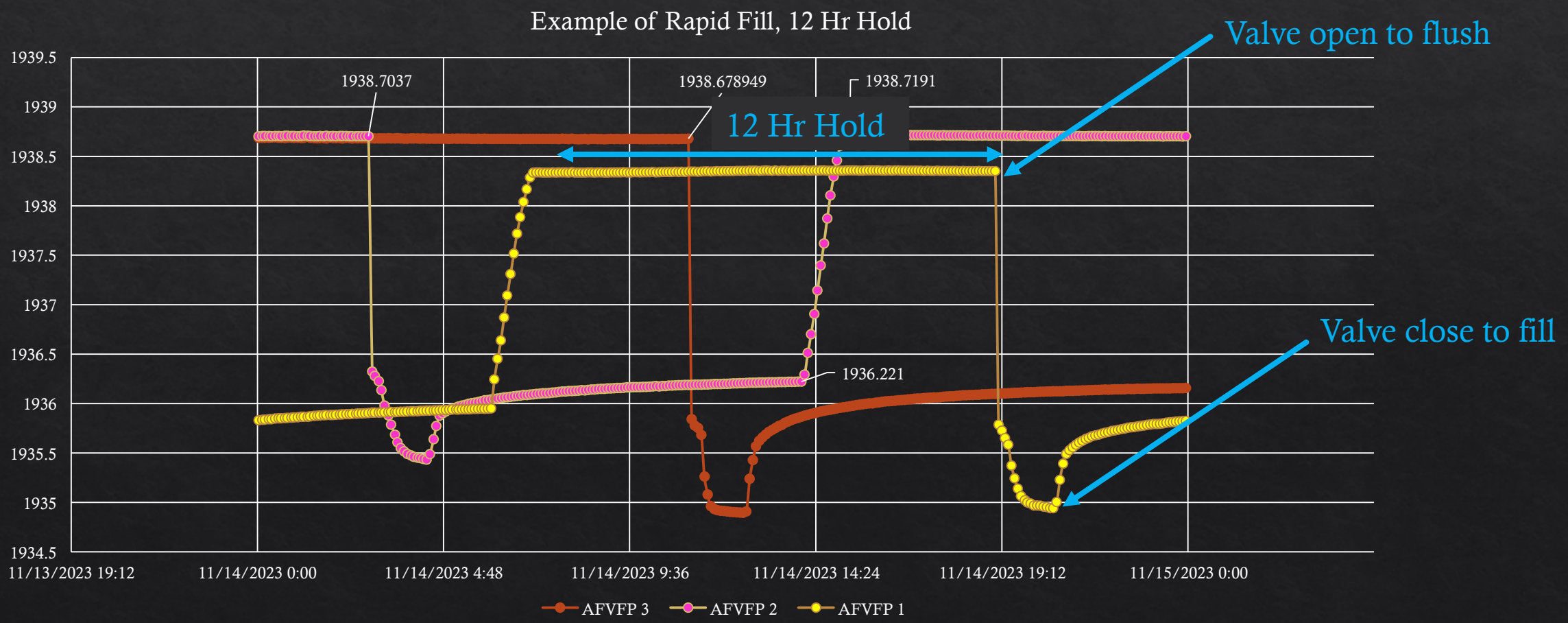
Acid Removal Rate Calcs

- Acid Removal = Acid Load IN –Acid Load OUT
- g/day/tonne
- We've used this style for sizing criteria before! Just not for Limestone only AFVFPs
  - Jenning Style Vertical Flow Ponds
    - Acid Removal/CY of Organic Media
    - lb/day/CY
    - Danehy 2022 ASRS
  - Wetlands
    - Metal Removal/meter^2 of Wetland
    - g/day/m^2
    - Hedin 1990 ASRS (JASMR)

Neal Run AFVFP (635 tonne LS)

Use of Telemetry

- Telemetry Setup: https://www.asrs.us/events/webinars/
- Water elevation from telemetry data at time of flush/fill



Use the Telemetry, Luke!

- Download telemetry data and identify flush elevations

Top of stone from As-Built Survey

Elev. Of Water in AFVFP
1941.00
1940.90
1940.80
1940.70
1940.60
1940.50
1940.40
1940.30
1940.20
1940.10
1940.00
1939.90
1939.80
1939.70
1939.60
1939.50
1939.40

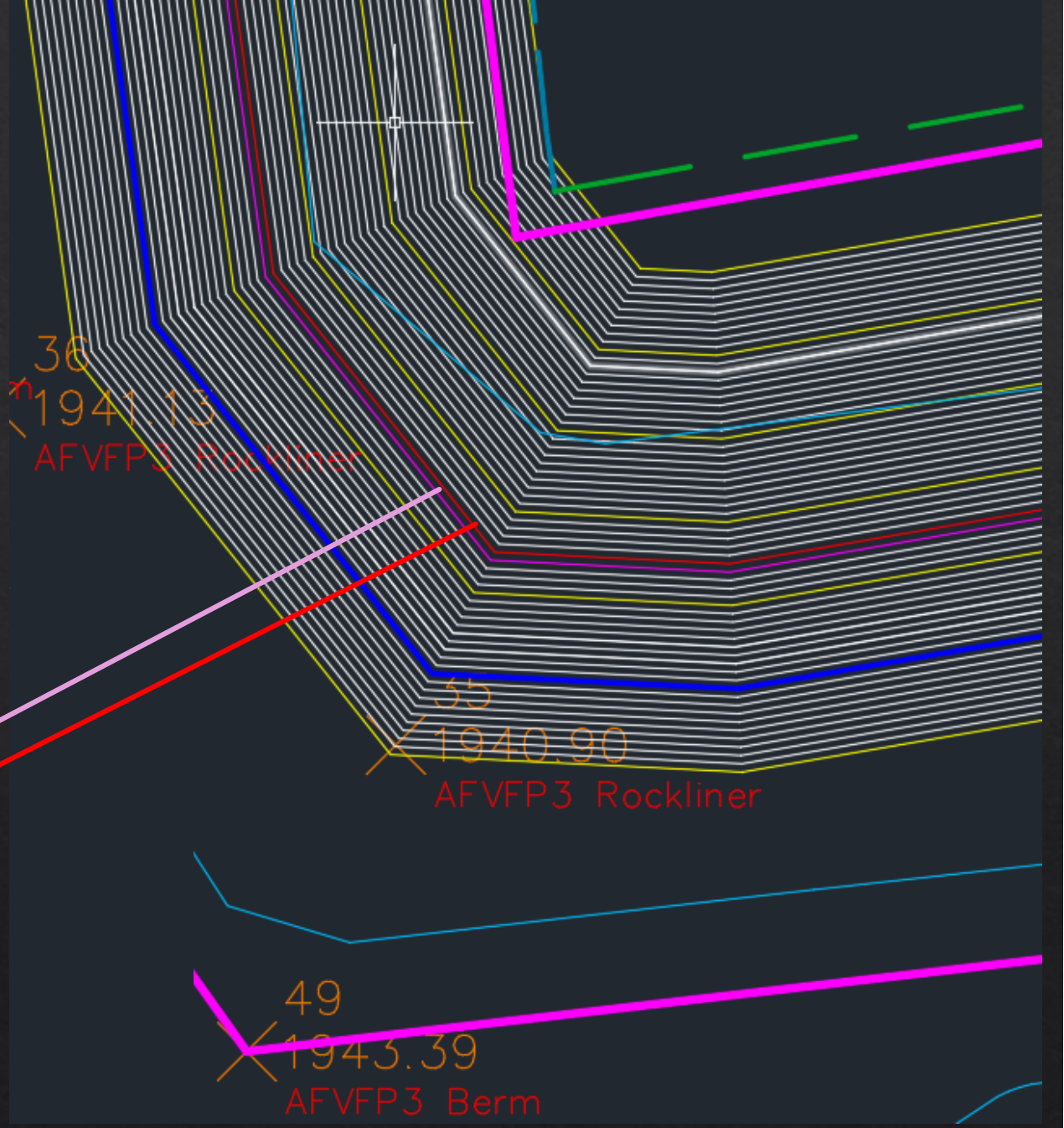
Water level in stone at initiation of flush

The Tower of Power at Oven Run B

Use the Telemetry, Luke!

- Use As-Built survey elevations to determine an area of stone at flush elevations.

Elev. Of Water in AFVFP	Area per As Built (sf)	Tot Volume at Elev. (Cuft)
1941.00	13058.8	1305.88
1940.90	12965.1	1296.51
1940.80	12871.7	1287.17
1940.70	12778.6	1277.86
1940.60	12685.8	1268.58
1940.50	12593.3	1259.33
1940.40	12501.1	1250.11
1940.30	12409.1	1240.91
1940.20	12317.5	1231.75
1940.10	12226.2	1222.62
1940.00	12135.1	1213.51
1939.90	12044.3	1204.43
1939.80	11953.9	1195.39
1939.70	11863.7	1186.37
1939.60	11773.8	1177.38
1939.50	11684.2	1168.42
1939.40	11594.9	1159.49

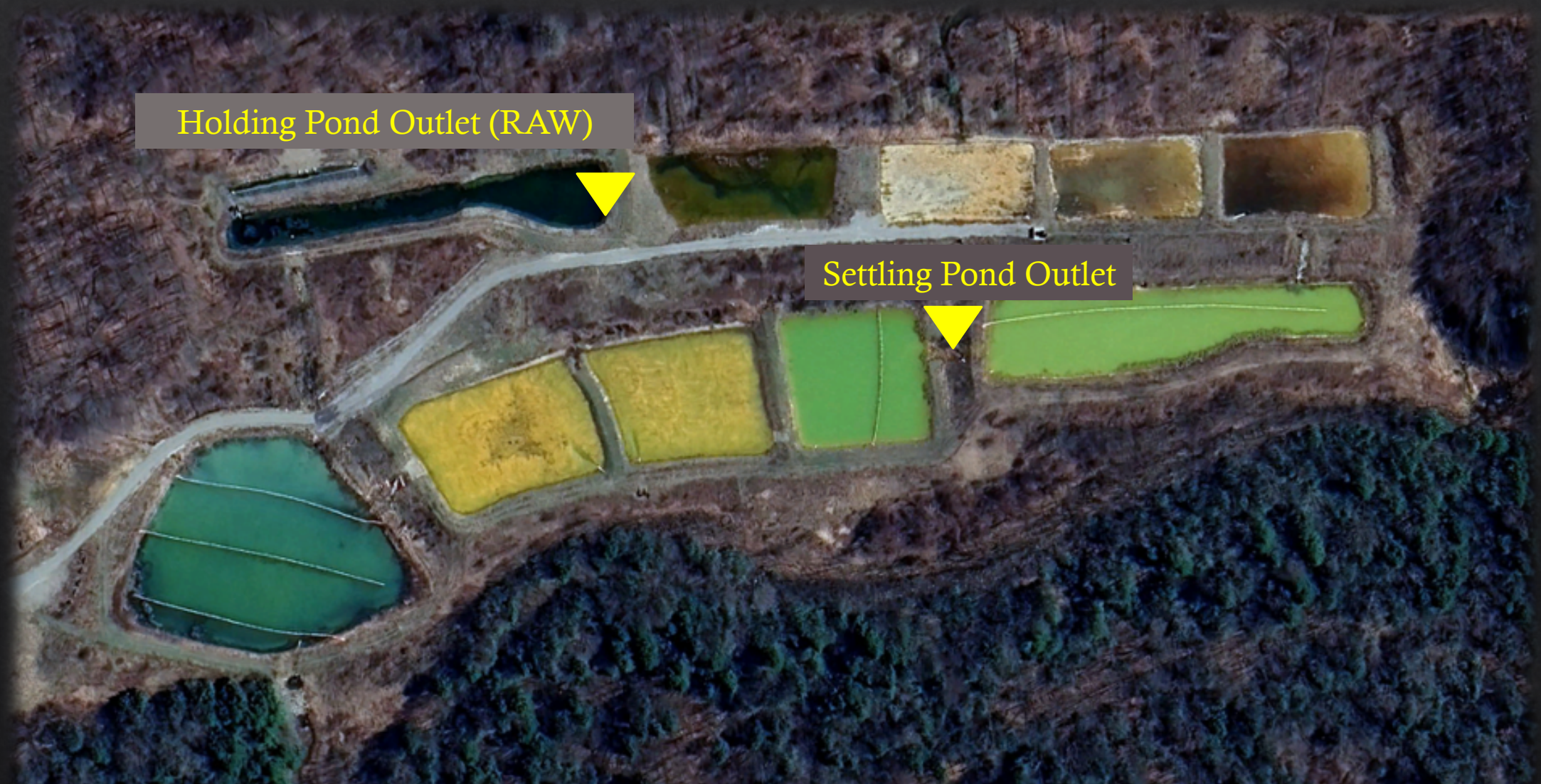


Use the Telemetry, Luke!

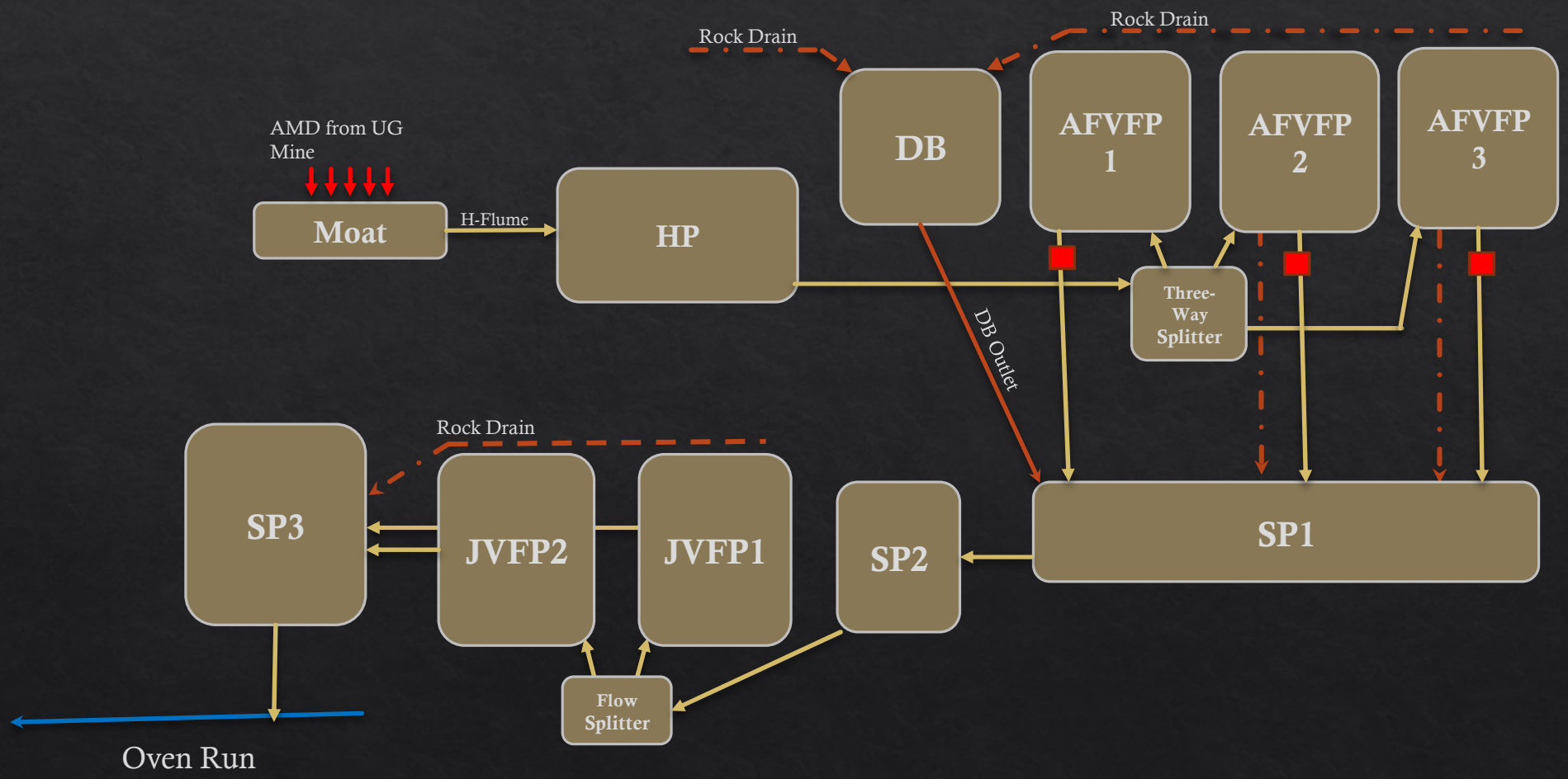
- Consider Void Space
  - Calculated! Not theory. Yay science
  - Volume per section – Water within void space = Stone within layer
- Calculated volume of stone to the 10ths of feet (every .03 meters)

Elev. Of Water in AFVFP	Area per As Built (sf)	Tot Volume at Elev. (Cuft)	Water within Layer Void Space (CuFt)	Water within Layer (gal)	Stone within Layer (CY)	Stone within Layer (ton)		
1941.00	13058.8	1305.88	326.47	2442.32	48.4	65.3		
1940.90	12965.1	1296.51	324.13	2424.80	48.0	64.8		
1940.80	12871.7	1287.17	321.79	2407.33	47.7	64.4		
1940.70	12778.6	1277.86	319.47	2389.92	47.3	63.9		
1940.60	12685.8	1268.58	317.15	2372.56	47.0	63.4		
1940.50	12593.3	1259.33	314.83	2355.26	46.6	63.0		
1940.40	12501.1	1250.11	312.53	2338.02	46.3	62.5		
1940.30	12409.1	1240.91	310.23	2320.81	46.0	62.0		
1940.20	12317.5	1231.75	307.94	2303.68	45.6	61.6		
1940.10	12226.2	1222.62	305.66	2286.61	45.3	61.1		
1940.00	12135.1	1213.51	303.38	2269.57	44.9	60.7		
1939.90	12044.3	1204.43	301.11	2252.59	44.6	60.2		
1939.80	11953.9	1195.39	298.85	2235.68	44.3	59.8		
1939.70	11863.7	1186.37	296.59	2218.81	43.9	59.3		
1939.60	11773.8	1177.38	294.35	2201.99	43.6	58.9	24 Hr (Gradual Fill; 12 hr hold)	
1939.50	11684.2	1168.42	292.11	2185.24	43.3	58.4	9hr max (Rapid Fill)	
1939.40	11594.9	1159.49	289.87	2168.54	42.9	58.0		

A Close Look at Oven Run B

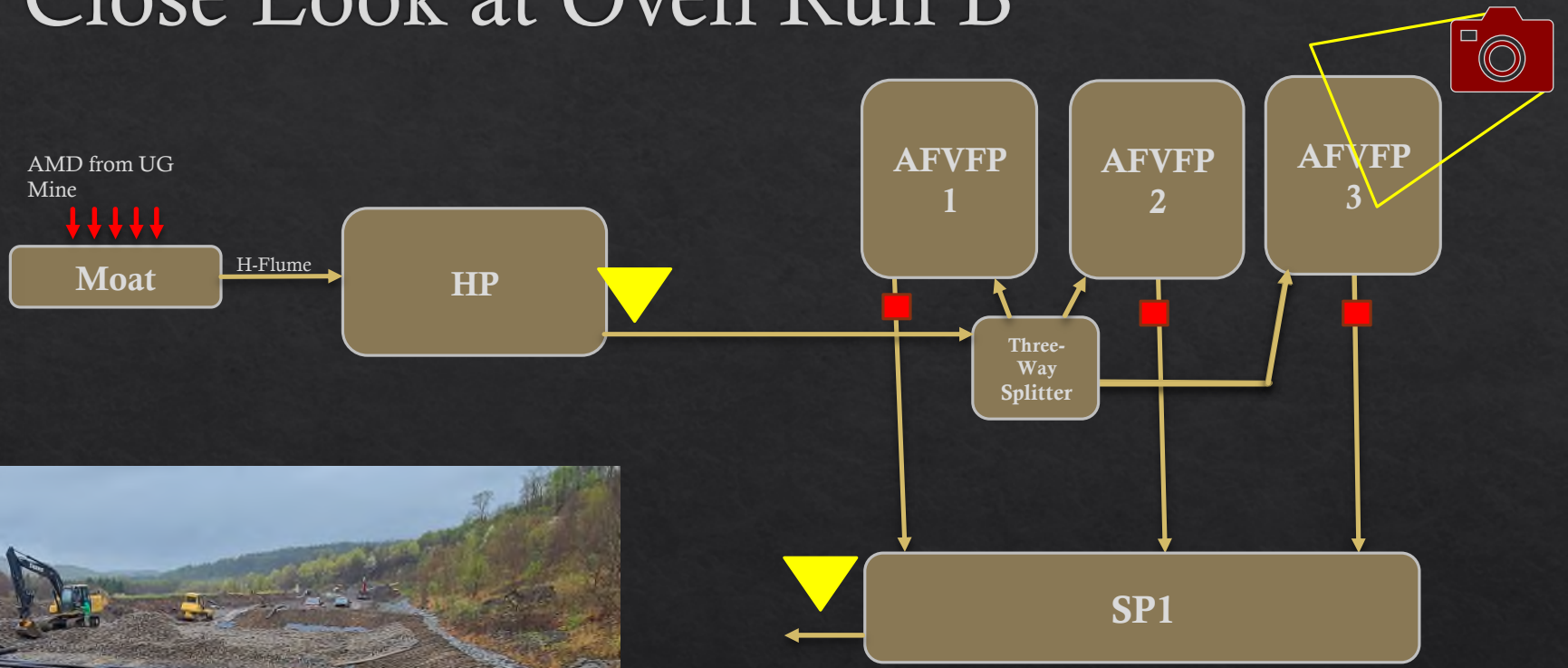


A Close Look at Oven Run B



HP – Holding Pond
DB - Dewatering Basin
AFVFP – Auto-Flushing Vertical Flow Pond
SP- Settling Pond
JVFP – Jennings Vertical Flow Pond

A Close Look at Oven Run B



HP – Holding Pond
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Oven Run B Results

	12 Hour Retention (Rapid Fill)	9 Hour Retention (Rapid Fill)	6 Hour Retention (Rapid Fill)	12 Hour Retention (Gradual Fill)	Units
Stone Used During Flush (All 3 AFVFPs)	3530	4230	3630	6006	Tonne
Field Measured Flow	87	103	86	100	GPM
	5.4	6.5	5.4	6.3	L/s
Acid Removed	104	114	87	90	kg/day
Acid Removal Rate*	30	27	24	15	g/day/tonne

2024 Fill Type and Hold Time Impacts on AFVFP Performance

*Underestimate as SP1 makes small amount of water

High Flow - Flow Through Mode

	12 Hour Retention (Rapid Fill)	Flow Through Mode**	Units
Stone Used During Flush (All 3 AFVFPs)	3530	9000	Tonne
Field Measured Flow	87	848	GPM
	5.4	53.6	L/s
Acid Removed	104	440	kg/day
Acid Removal Rate*	30	54	g/day/tonne

Considering the more work you give it the more it will do: Art Rose, 2004

*Underestimate as SP1 makes small amount of water.
**Flush 1X per day (12Hr hold time).

Acid Removal Rates per Site

Neal Run

Range: 79-351 g/day/tonne

Number of Events Sampled: 8

Oven Run B

Range: 15-30 g/day/tonne

Number of Events Sampled: 4

Muscavitch

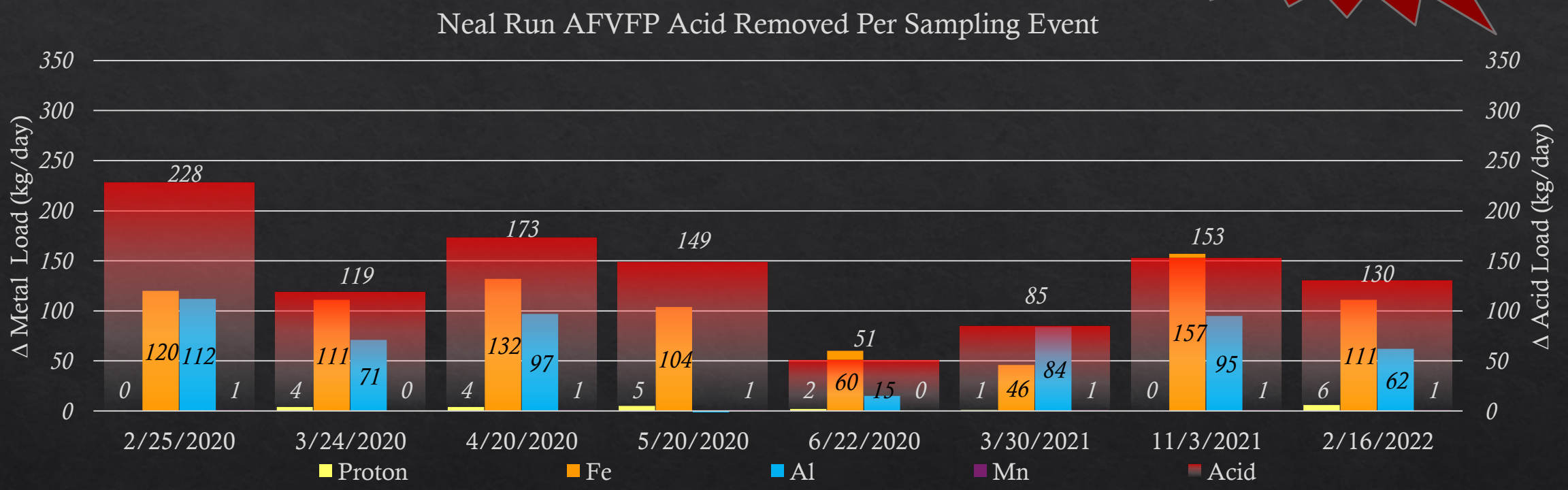
Range: 46-115 g/day/tonne

Number of Events Sampled: 5

Which do we use as our design basis?

Acid Removal by Event: Neal Run

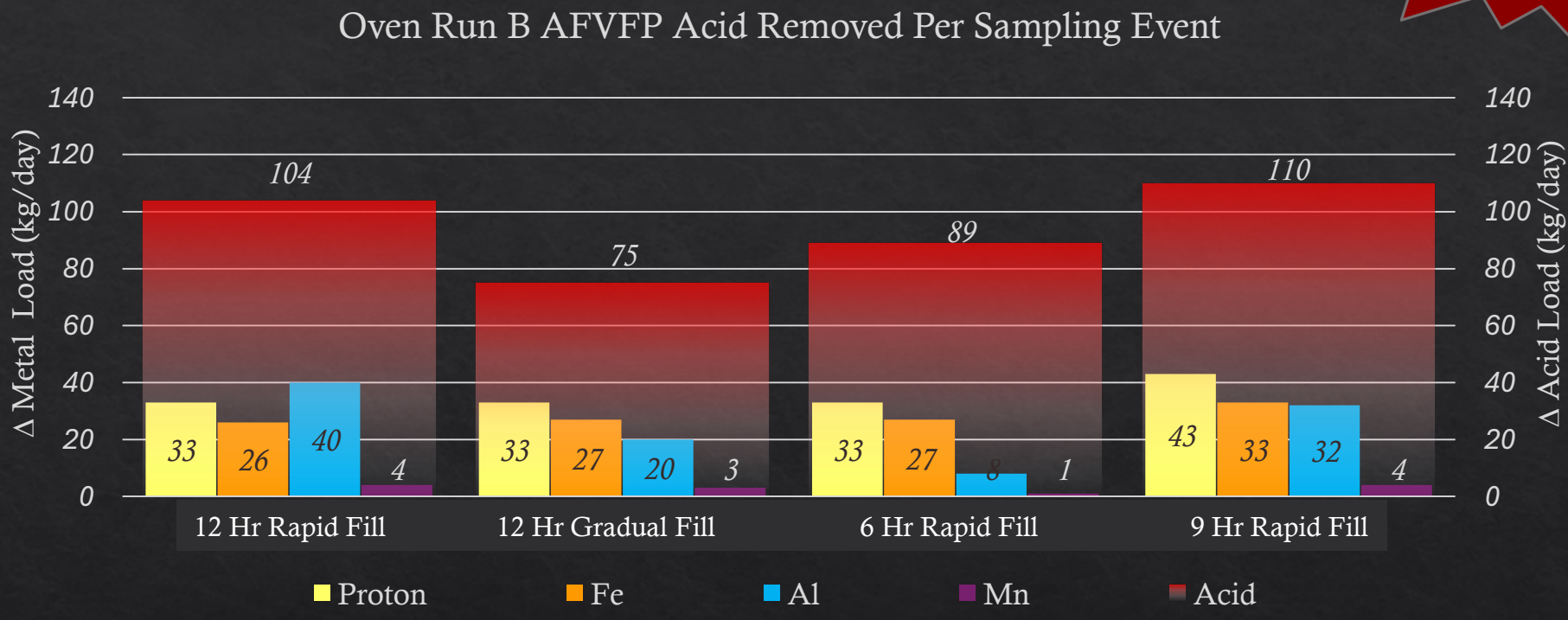
Assumes ALL Stone was used



Acid Removal Rate	351	184	267	230	79	131	235	201	**g/day/tonne**
Flow	1.1	1.8	1.4	0.9	0.5	0.6	0.9	1.8	**L/s**

Acid Removal by Event: Oven Run B

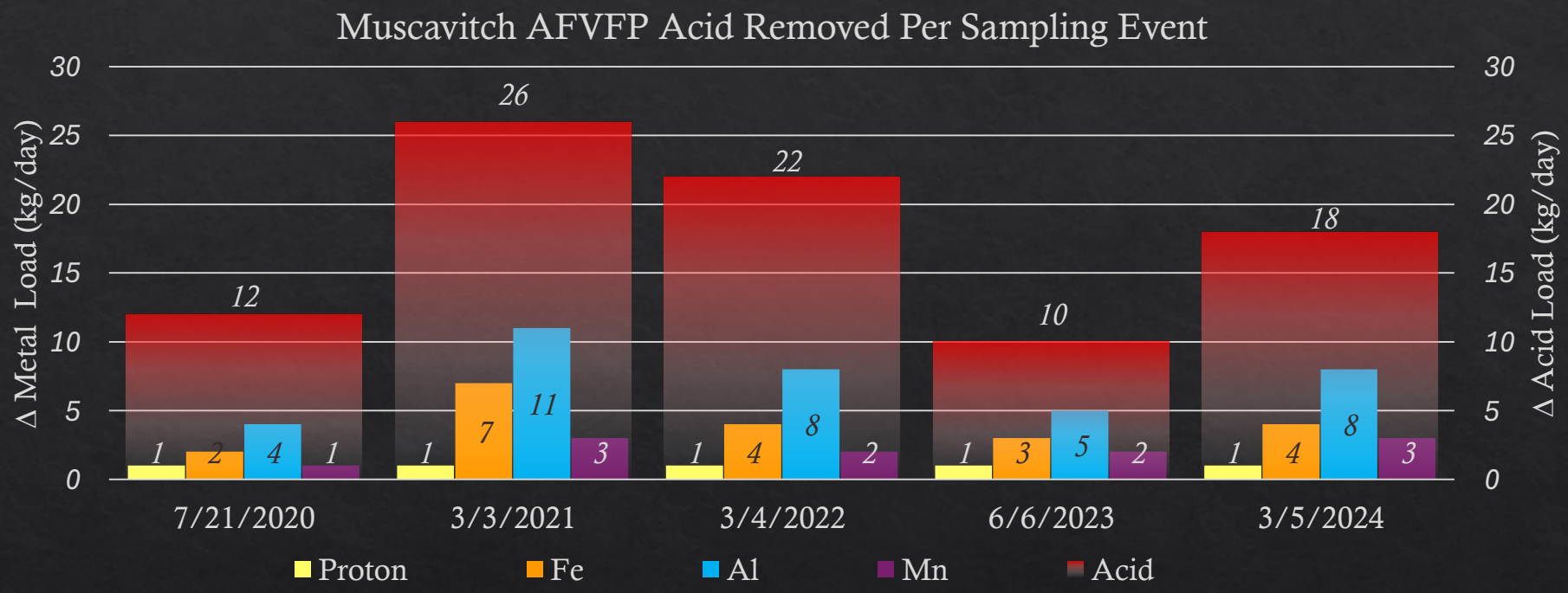
Exact stone use KNOWN



Acid Removal Rate	30	15	24	27	**g/day/tonne**
Flow	5.4	6.3	5.4	6.5	**L/s**

Acid Removal by Event: Muscavitch

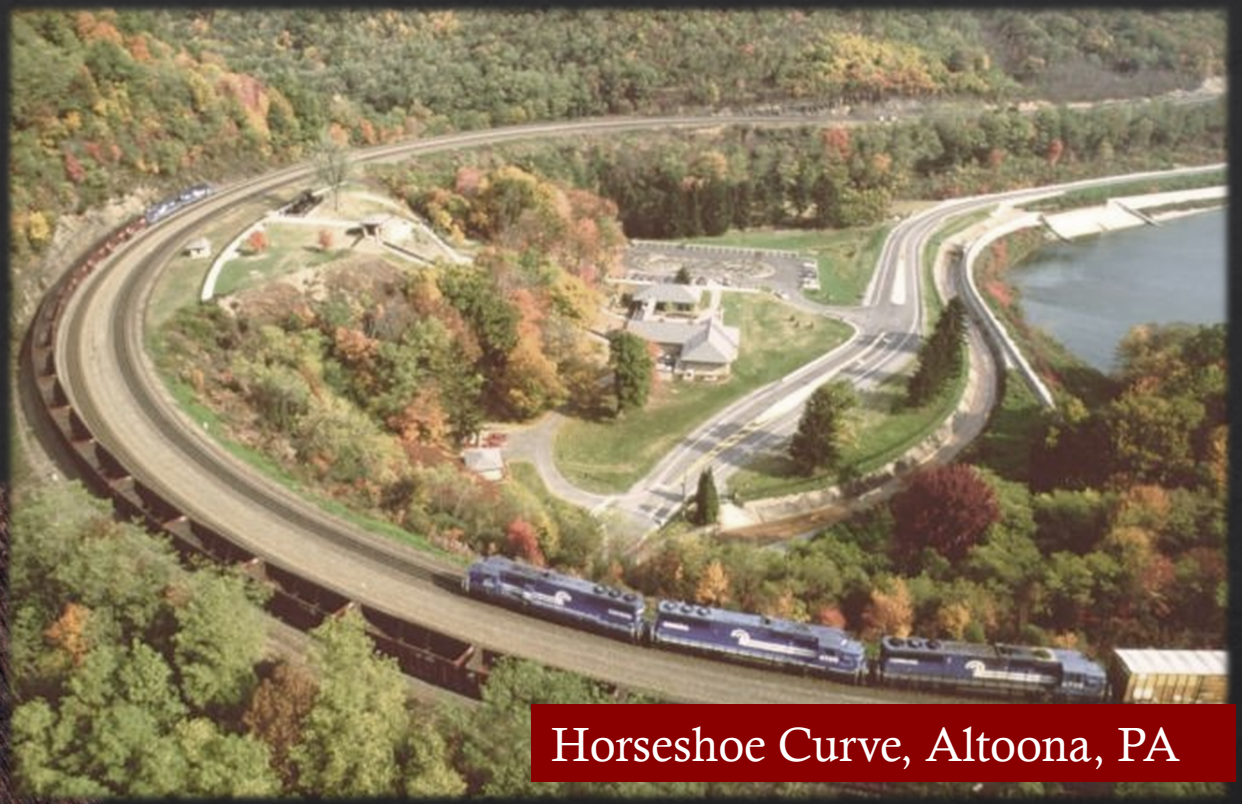
Assumes ALL Stone was used



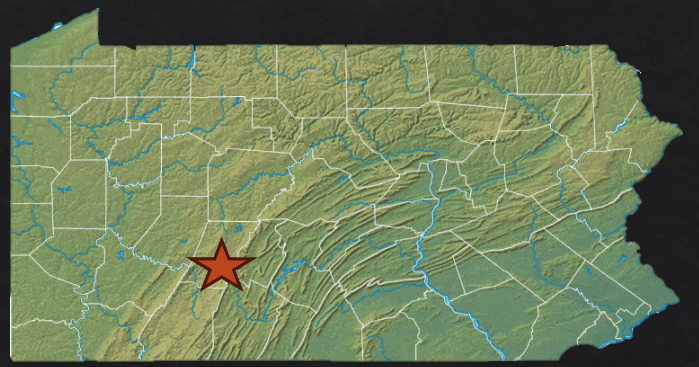
Acid Removal Rate	19	40	34	16	27	**g/day/tonne**
Flow	0.5	2.0	1.7	0.5	0.8	**L/s**

Acid Removal Rate Used for Design

- Spaghetti Hole
  - Improve Acid Neutralization
  - Large existing Vertical Flow Pond (SAPS)



Horseshoe Curve, Altoona, PA



Design with Acid Removal Rate

- Remember:
  - Use good water quality data (measure the flow)
  - Specify High CaCO3 stone

$$How\ much\ stone\ do\ we\ need? = Consumed\ Stone + Retention\ Reservoir$$

$$Consumed\ stone\ = \frac{Acid\ Load\ (AVG)\ \ * Lifespan}{Purity\ of\ Limestone\ \%}$$

$$"Retenetion\ Reservoir"\ = Acid\ Load\ (MAX)\ /\ Removal\ Rate$$

Design with Acid Removal Rate

Spaghetti Hole: Supporting Water Quality Data			
	Average	Max	**Units**
Acid Load	44	126	**Kg/day**
Flow	6	21	L/s
	90	340	GPM

Expected Measurable Alkalinity: 30mg/L
Desired Δ Acidity Load =
(30mg/L+ CCE of Avg. Acid mg/L) * Avg. Flow

Design Lifespan: 20 years

Acid Removal Rate Used: 30 g/day/tonne*

Design Method	**Consumed Stone**	**Retention Reservoir**	**Total Stone To Buy**
"Old Way"	= Avg Flow Rate * Retention Time * Desired Δ Acid * Limestone Purity	=Max Flow * Retention Time * Void Space * LS Bulk Density	= Consumed Stone + Retention Reservoir Stone
"Acid Removal Rate Way"	= Avg Acid Load (kg/day)* Design Lifespan (years) / Limestone Purity (%)	= Max Acid Load / Acid Removal Rate	

**Used 12 Hr Rapid Fill from Oven Run B.*

Design with Acid Removal Rate

Spaghetti Hole: Supporting Water Quality Data			
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Acid Load	44	126	**Kg/day**
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Design Lifespan: 20 years

Acid Removal Rate Used: 30 g/day/tonne*

Design Method	**Consumed Stone**	**Retention Reservoir**	**Total Stone To Buy**
"Old Way"	265 tonne	3040 tonne	3305 tonne
"Acid Removal Rate Way"	356 tonne	4200 tonne	4556 tonne

25% more

**Used 12 Hr Rapid Fill from Oven Run B.*

Muscavitch Stone Wash 2024

Future Work: More Systems = More Data

McIntire

AFVFP with a Siphon

Dream Mountain

Neely, Butte, 2025 Presentation

2024 Fill Type and Hold Time Impacts on AFVFP Performance

Summary and Recommendations

1. The more work you give it, the more work it can do. (based on Art Rose ASRS 2004)
2. Choose an Acid Removal Rate (g/day/tonne) based on influent maximum measured acid load.
   - Calculate and add the consumed stone as: acid load x Design Life / limestone purity
3. AFVFPs are Self Cleaning!
   - Flushing typically removes: Aluminum > Iron > Manganese
   - Limestone will need to be cleaned periodically. (several years and variable!)
   - We recommend HDPE pipe for underdrain (harder to break)
4. Should consider multiple AFVFP -> SPs in Series if influent acidity about 150-200 mg/L or greater
   - Need to consider the source of acidity (pH, Fe, Al, Mn)
   - Mn acidity may be less readily removed
5. More research is needed!

6. Stay tuned to see how the Spaghetti Hole sizing criteria works!
   ASRS 2027!

Questions and Thanks

- Stream Restoration Incorporated
- Pennsylvania Department of Environmental Protection (PADEP)
  - Bureau of Abandoned Mine Reclamation(BAMR)
- Foundation for Pennsylvania Watersheds
- Aultmans Run Watershed for Restoring the Environment (AWARE)

Neal Run, 2015
Julie LaBar

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