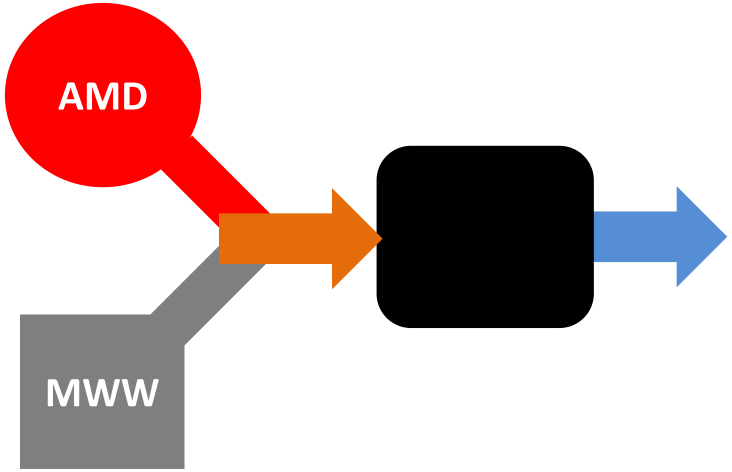
Expanding possibilities for the co-treatment of mine drainage with municipal wastewater



William Strosnider, Benjamin Roman, Charles Spellman Jr., Joseph Goodwill, Travis Tasker

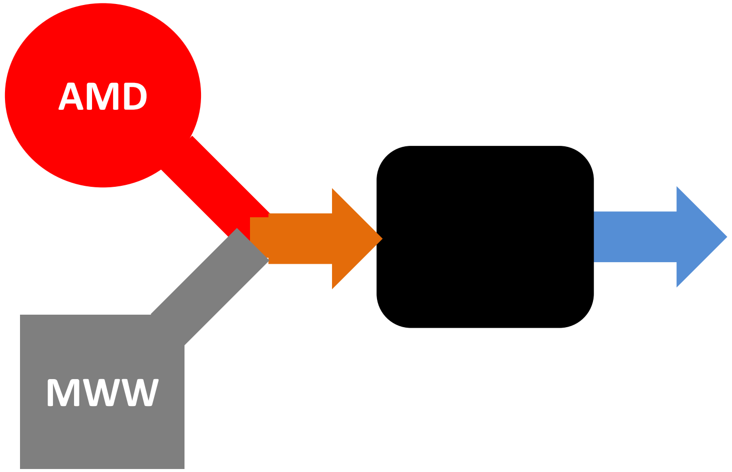
Baruch Institute for Marine and Coastal Sciences, School of the Earth, Ocean, and Environment, University of South Carolina
Office of Surface Mining Reclamation and Enforcement
The Narragansett Bay Commission
University of Rhode Island, Hope, 1892
Saint Francis University, Founded 1847

Overview

1. What is co-treatment?
2. Why co-treatment?
3. History
4. Recent studies
5. Current needs

What is Co-Treatment?

- Simultaneous treatment of two waste streams
  - Acid Mine Drainage (AMD)
  - Municipal Wastewater (MWW)



Background

- MWW treatment requires:
  - BOD processing
  - Nutrient removal
  - Pathogen removal
- Passive AMD treatment can require:
  - Metal
    - Oxidation
    - Reduction
    - Sorption
    - Precipitation
  - Alkalinity dosing/generation
  - Oxygen stripping

Synergistic

AMD provides

- e^- acceptors
  - DO
  - Sulfate
  - Metals
- Coagulants
  - Fe
  - Al
- Disinfectants
  - pH
  - Metals

MWW provides

- e^- donors (Complex)
  - DO stripping
  - Sulfate reduction
  - Metal reduction
- Nutrients (N:P)
  - DO stripping
  - Sulfate reduction
  - Metal reduction
- Alkalinity
- Sorbents

Synergistic

<u>AMD provides</u>

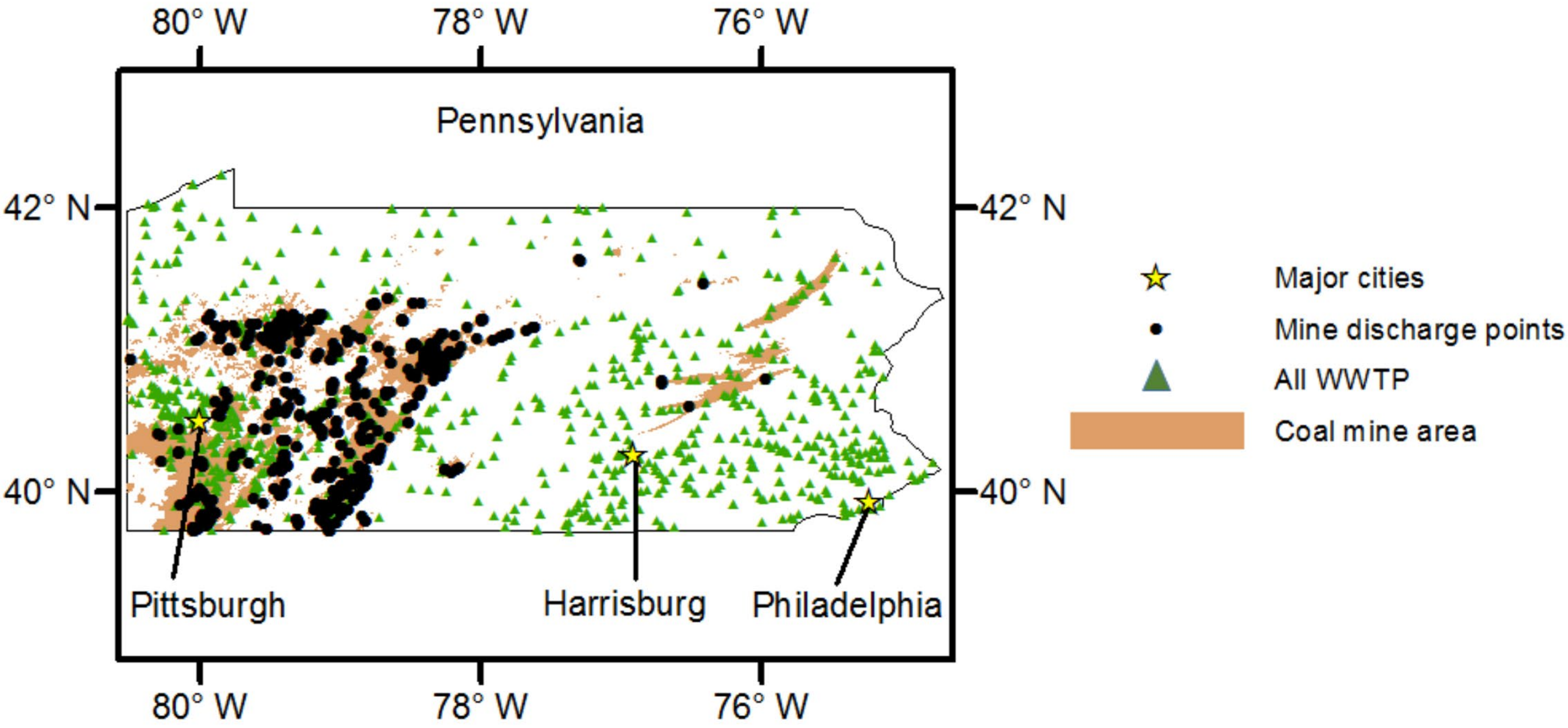
- e^- acceptors
  - DO
  - Sulfate
  - Metals
- Coagulants
  - Fe
  - Al
- Disinfectants
  - pH
  - Metals

<u>MWW provides</u>

- e^- donors (Complex)
  - DO stripping
  - Sulfate reduction
  - Metal reduction
- Nutrients (N:P)
  - DO stripping
  - Sulfate reduction
  - Metal reduction
- Alkalinity
- Sorbents

Bonus: *both waste streams are low in pollutants which are high in the other*

Example Opportunity: PA



Origins

- First proposed by Roetman (1932) for pathogen removal
- Co-Treatment of relatively weak AMD (net alkaline, low Fe) and secondary MWW (Johnson and Younger, 2006)
- Serendipitous improvement of water quality when high-strength AMD accidentally pumped to MWW evaporation pond (McCullough et al. 2008)

Two Paths

<u>“Passive”</u>

Kleinmann *et al.* (2021)

<u>“Active”</u>

TetraTech

Two Paths

"Passive"

Kleinmann *et al.* (2021)

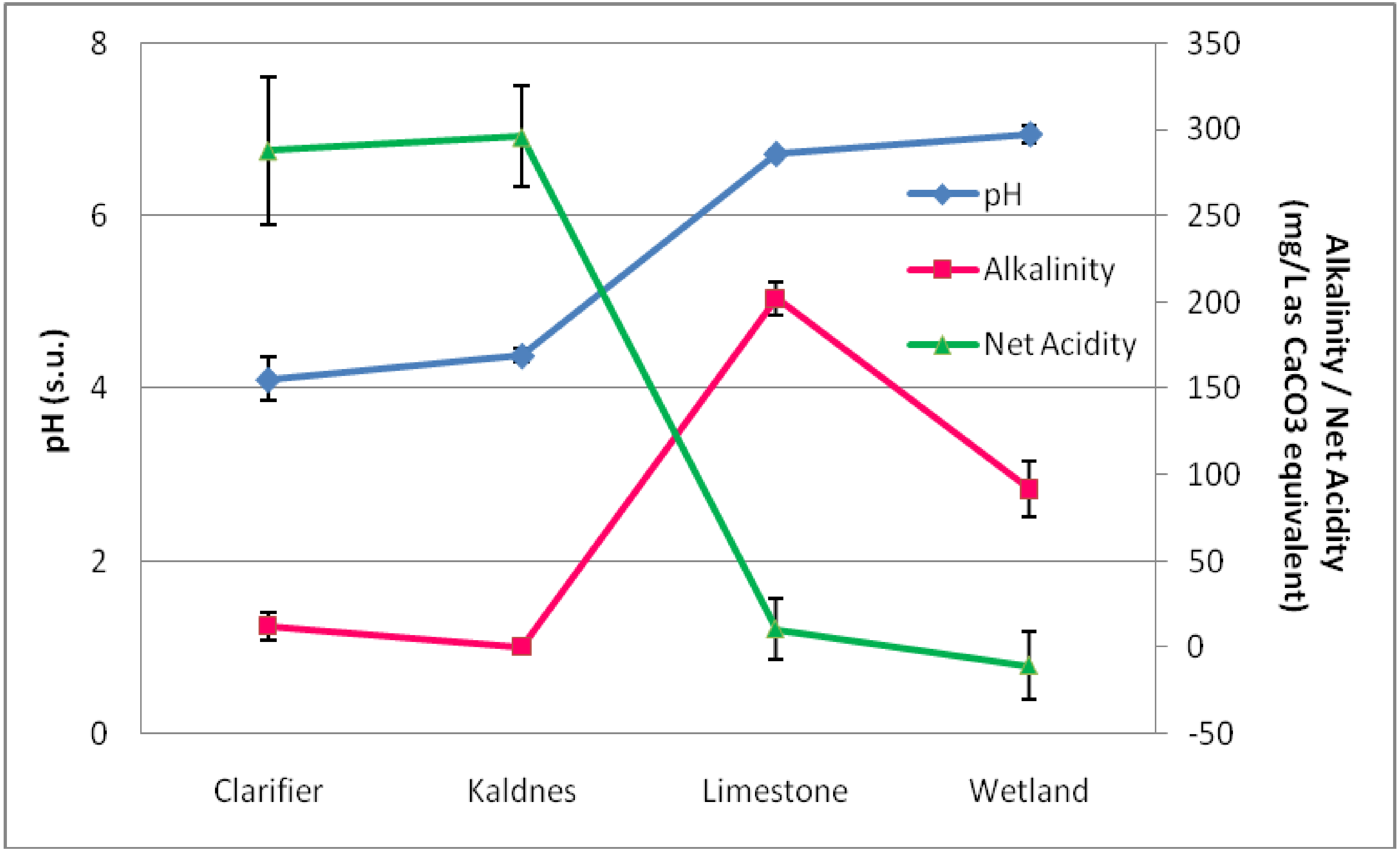
"Active"

TetraTech

Multi-Stage Flow-through:
Proof of concept

- MWW
  - 265 mg/L BOD
  - 11.5 mg/L phosphate
- AMD
  - pH 2.6
  - 1620 mg/L acidity
  - 410 mg/L Zn
  - 290 mg/L Fe
  - 49 mg/L Al

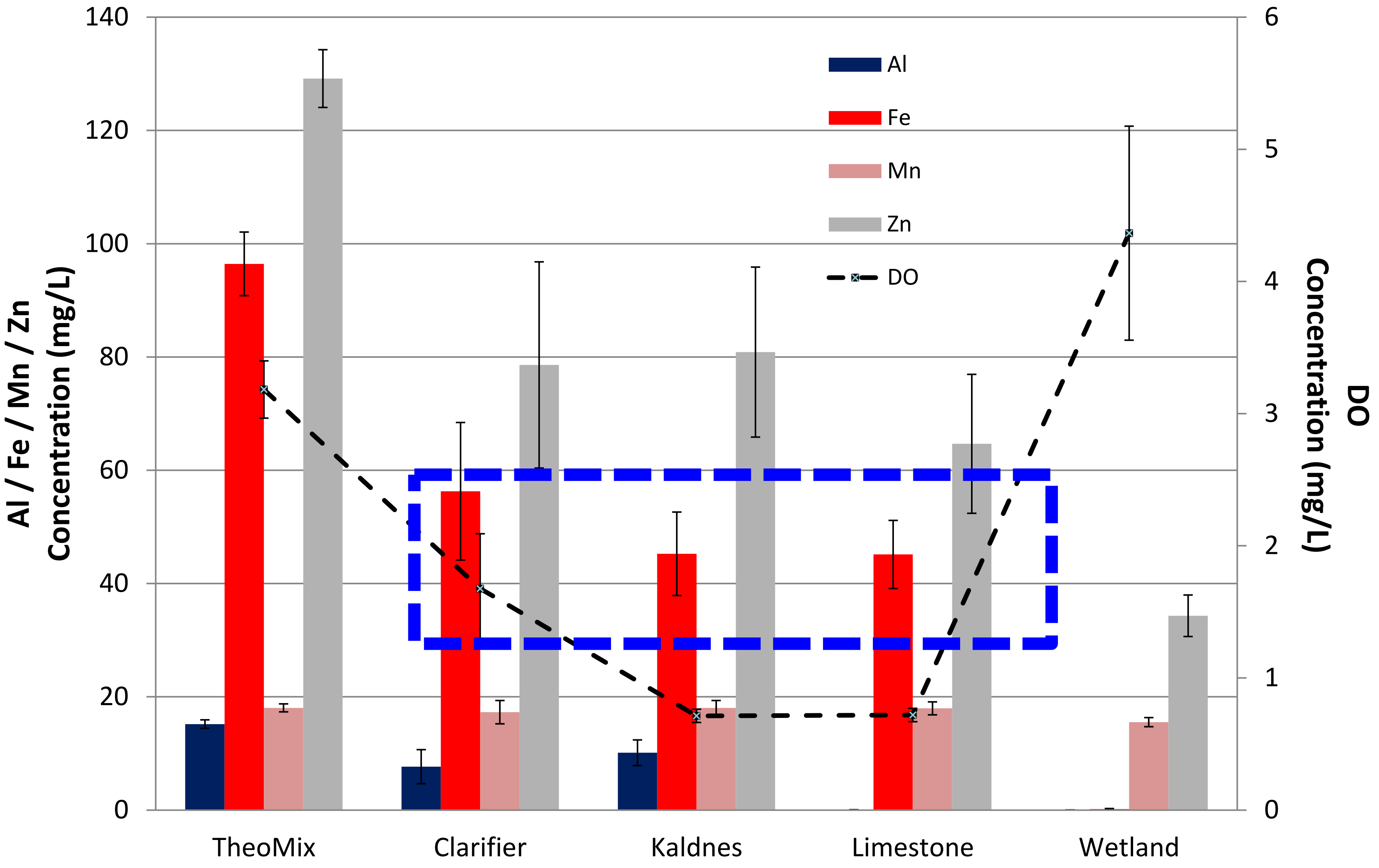
Net-Acid to Net Alkaline



Sulfate Reduction

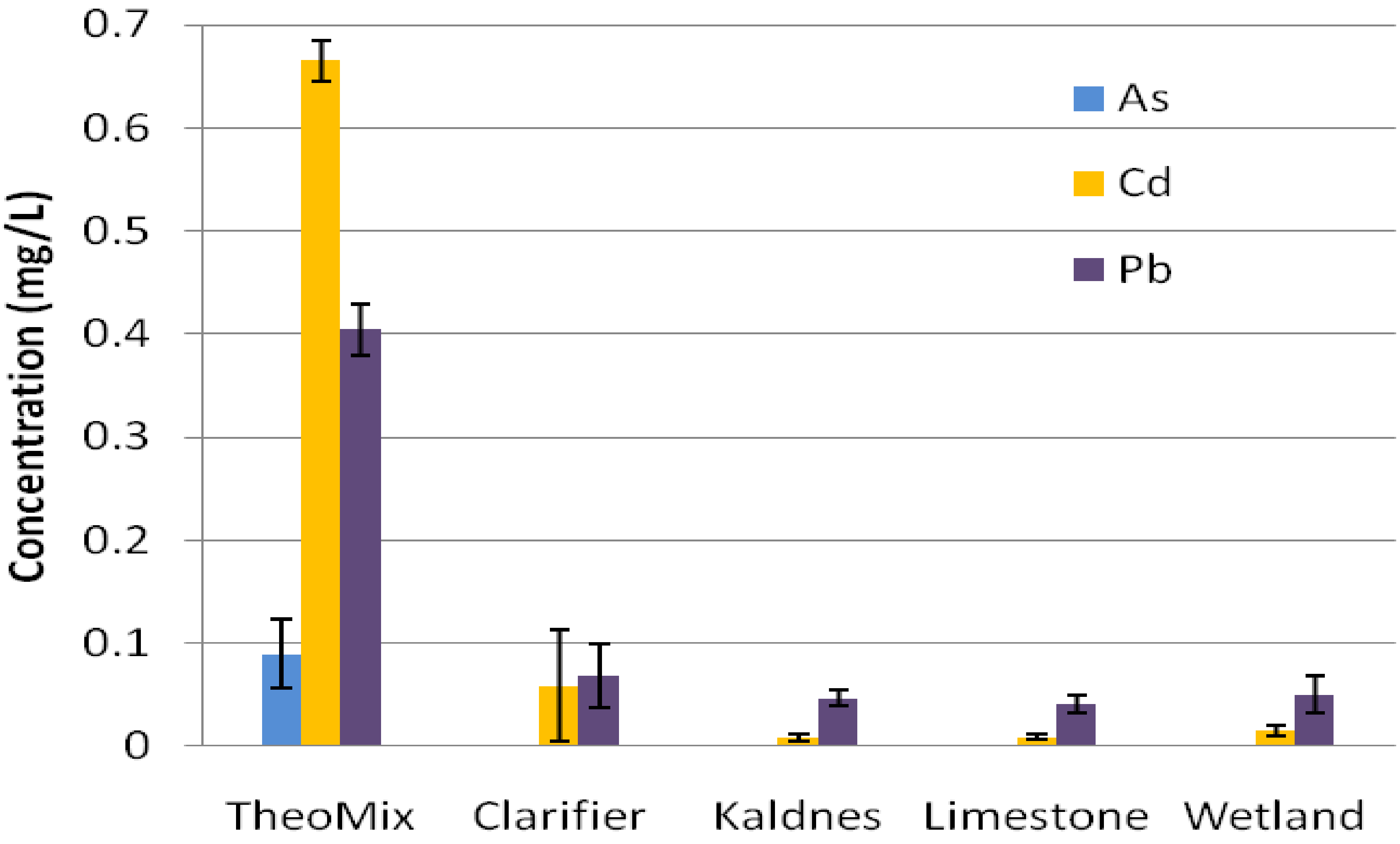
- Our system: **0.56 mol/m^3-d**
- **> ~0.3 mol/m^3-d:** optimal field conditions from mesocosm and full scale reactors
- **< ~3 mol/m^3-d:** simplified AMD with refined electron donors

Fe Behaved



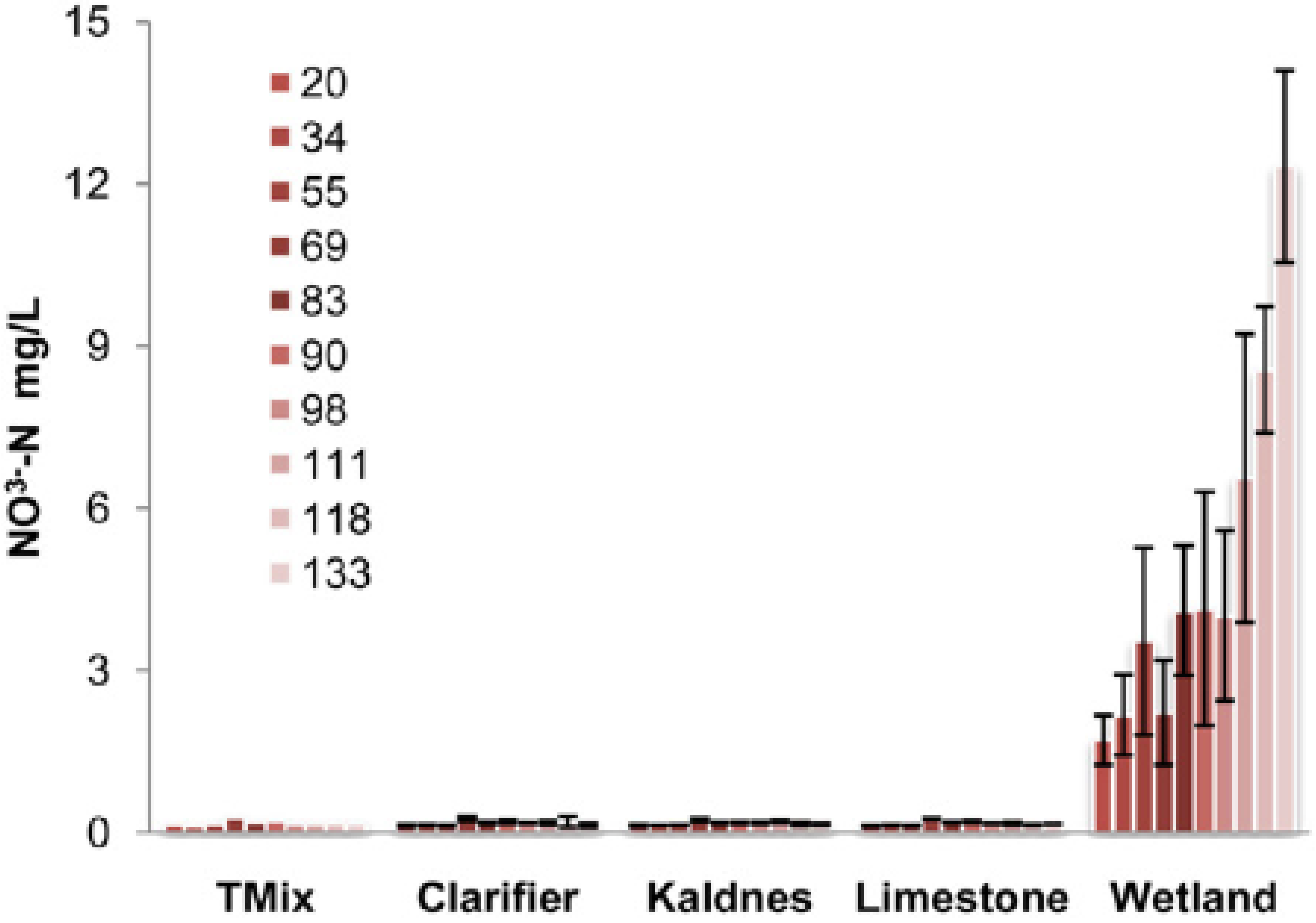
Al / Fe / Mn / Zn
Concentration (mg/L)
140
120
100
80
60
40
20
0
6
5
4
3
2
1
0
DO
Concentration (mg/L)
Al
Fe
Mn
Zn
DO
TheoMix
Clarifier
Kaldnes
Limestone
Wetland

Broad Removal

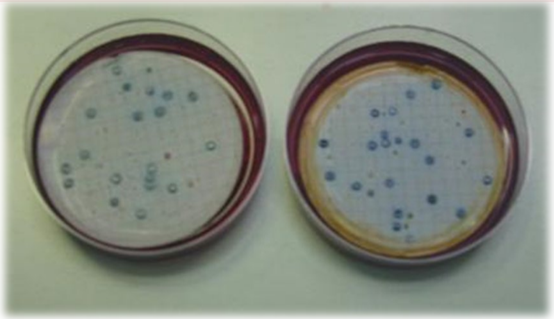


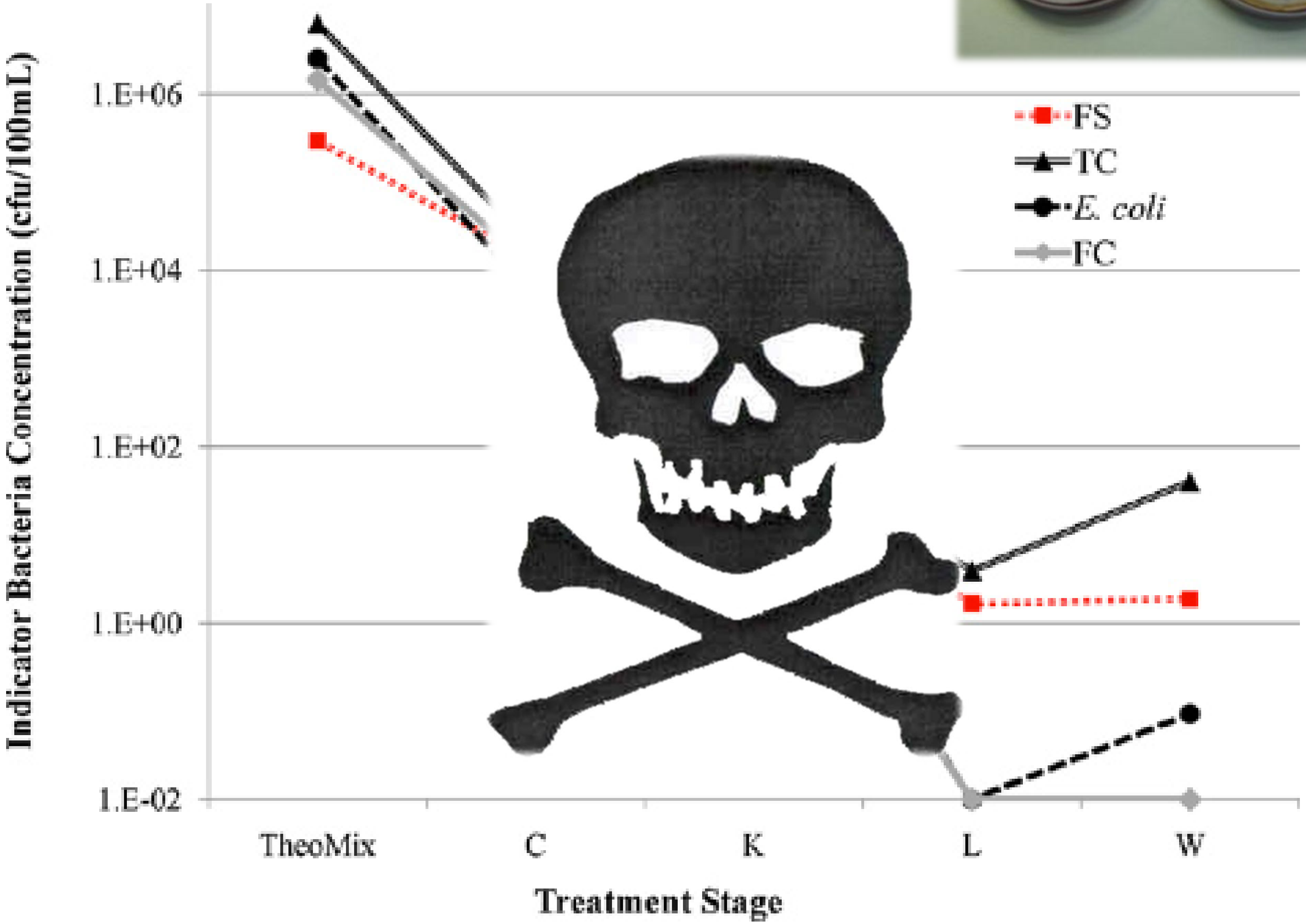
Wastewater Constituents

- BOD
  - 175 to <2 mg/L
- PO_4
  - 7.7 to <0.75 mg/L
- Nitrification?


15
12
9
6
3
0
NO3⁻-N mg/L
20
34
55
69
83
90
98
111
118
133
TMix
Clarifier
Kaldnes
Limestone
Wetland

Indications…

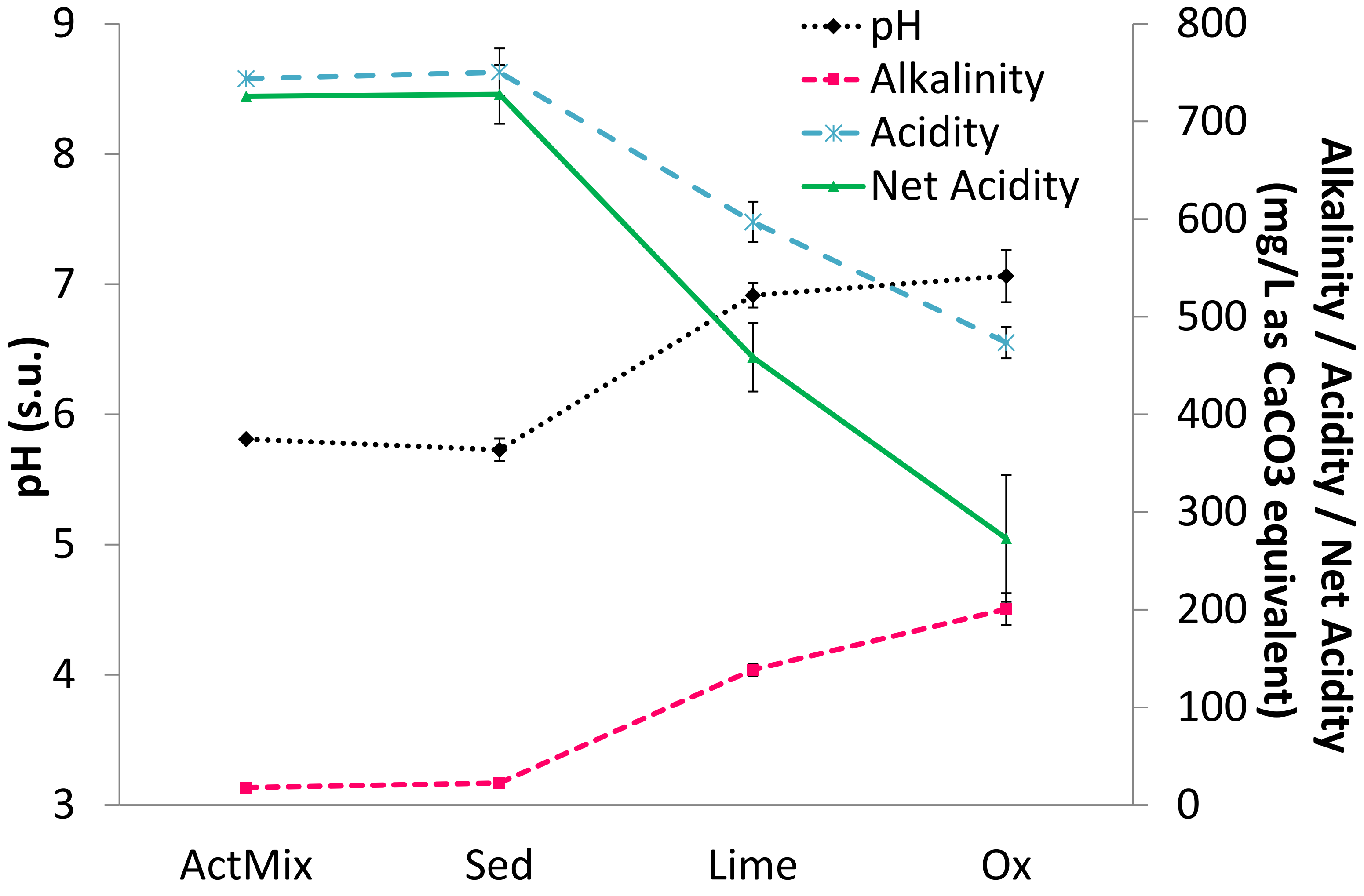


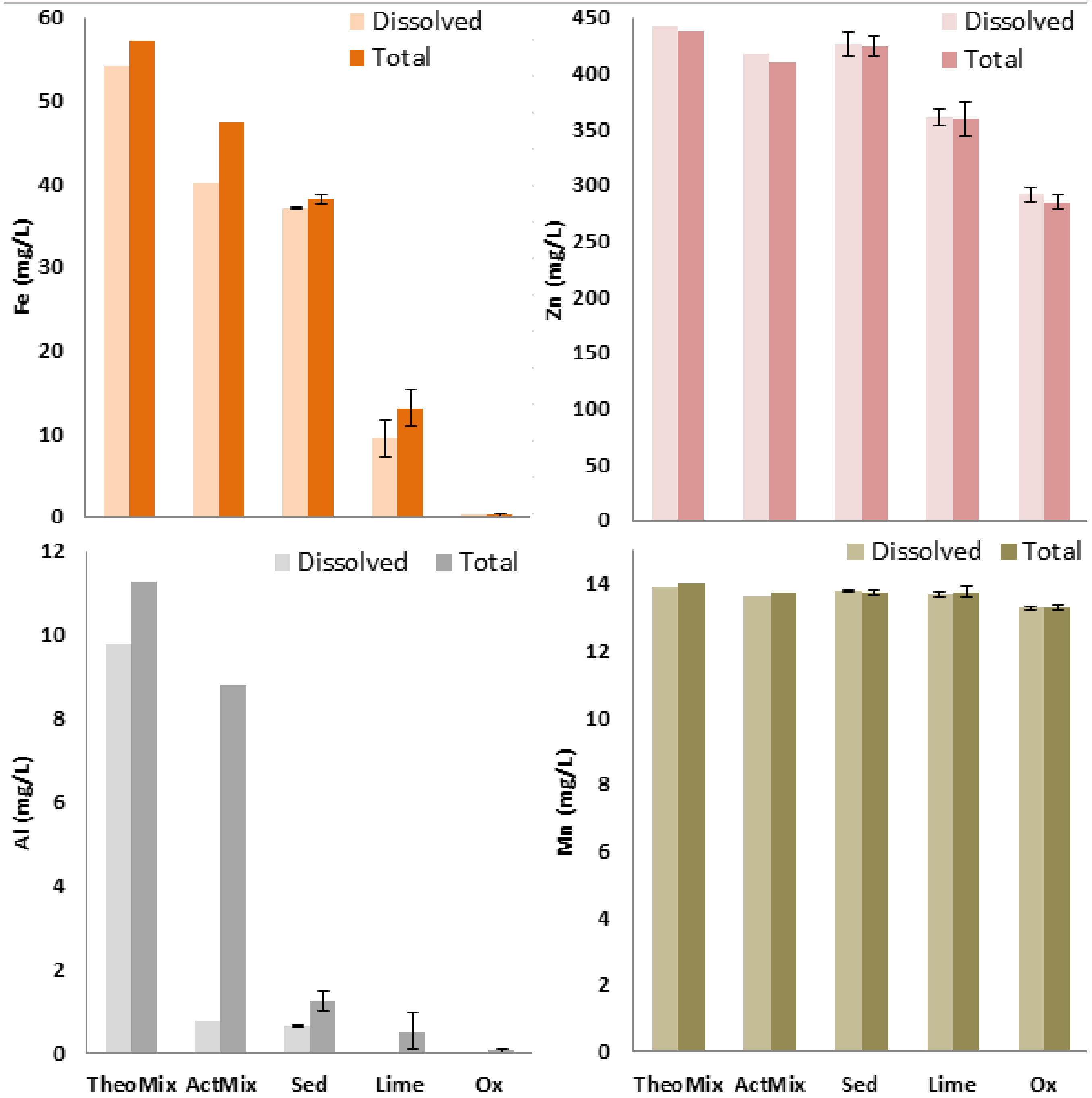


Multi-Stage Batch Reactor Co-Treatment, Potosí:
Real MWW and AMD, In-situ

- MWW
  - High-strength
  - pH 9.0
  - 38 mg/L phosphate
- AMD
  - pH 3.6
  - 1080 mg/L acidity
  - 550 mg/L Zn
  - 68 mg/L Fe
  - 12 mg/L Al
  - 17 mg/L Mn

Multi-Stage Batch Reactors





Dissolved
Total
Fe (mg/L)
60
50
40
30
20
10
0
Zn (mg/L)
450
400
350
300
250
200
150
100
50
0
Al (mg/L)
12
10
8
6
4
2
0
Mn (mg/L)
14
12
10
8
6
4
2
0
TheoMix
ActMix
Sed
Lime
Ox

More "Passive" Work

- Deng and Lin (2013)
- Wang et al. (2021)
- Masindi et al. (2022a,b)
- Younger and Henderson (2014)

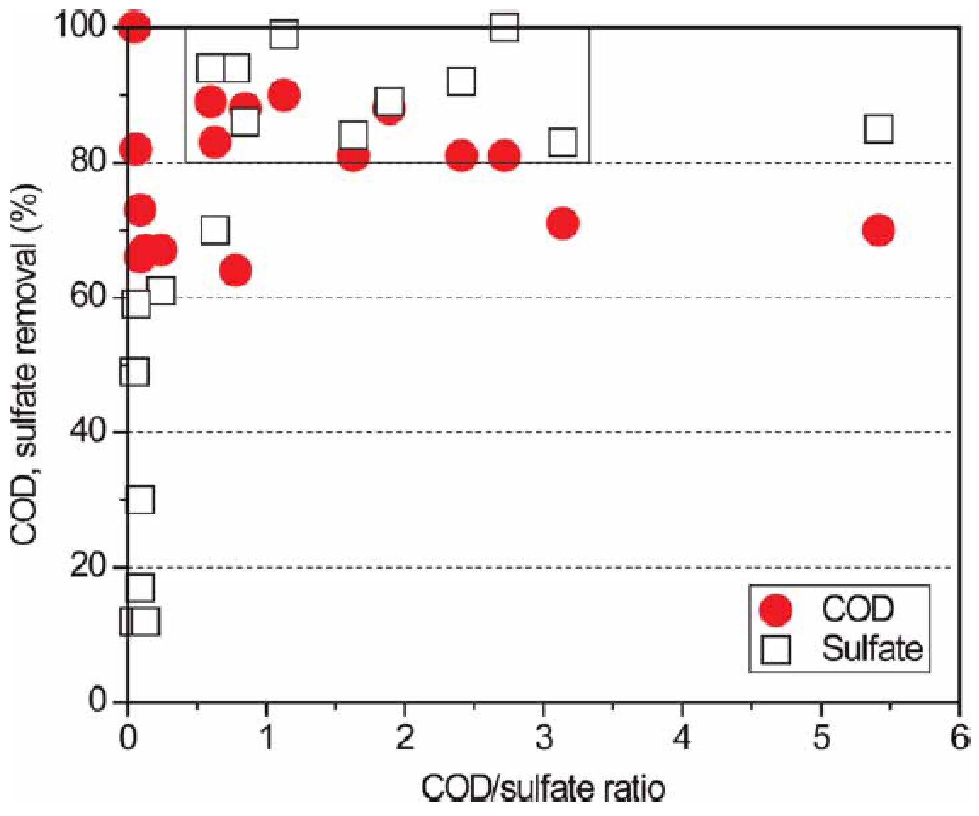
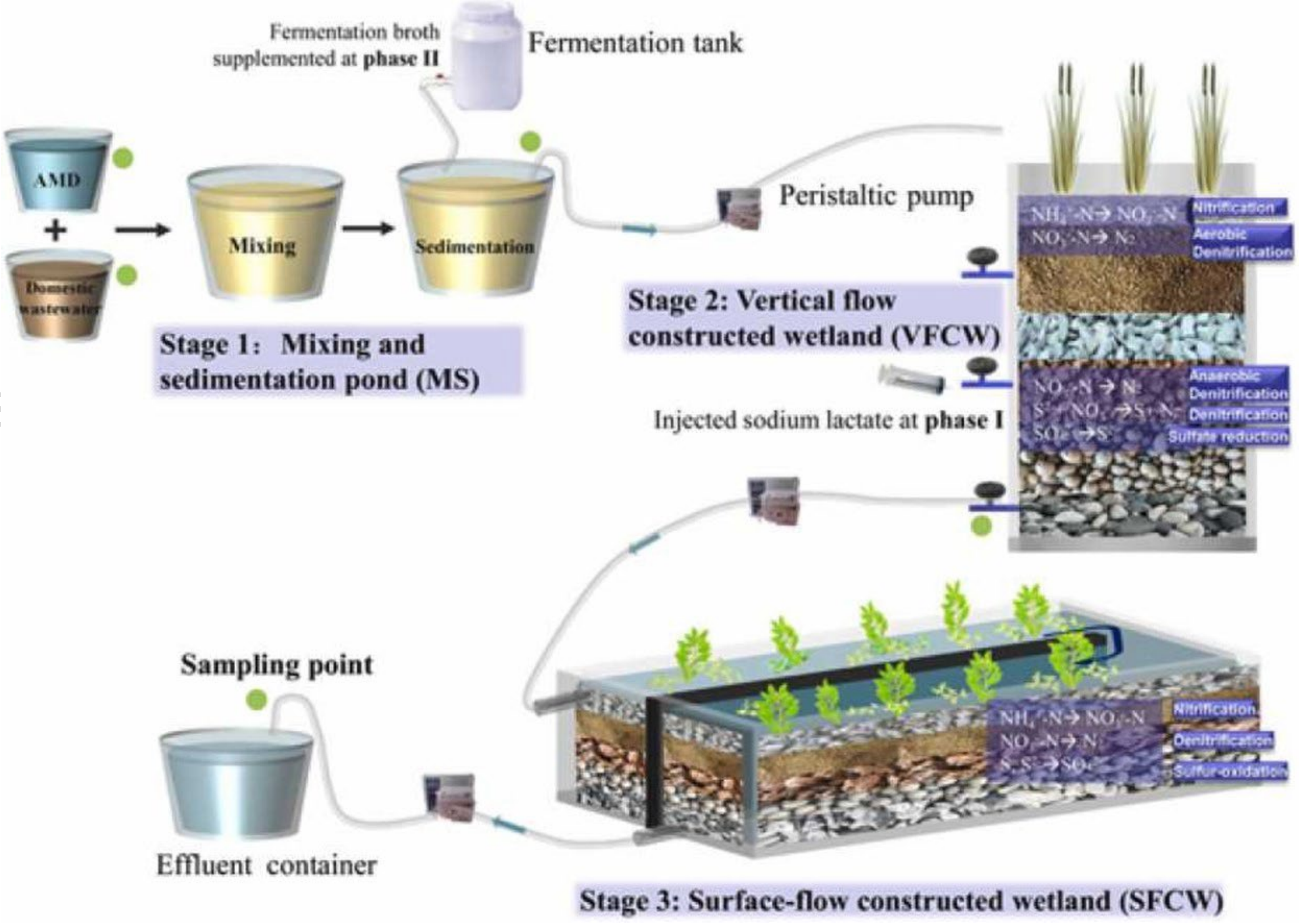


Figure 4 | COD and sulfate removal efficiency of the biological treatment as a function of COD/sulfate concentration ratio.

More "Passive" Work

- Deng and Lin (2013)
- Wang et al. (2021)
- Masindi et al. (2022a
- Younger and Henders



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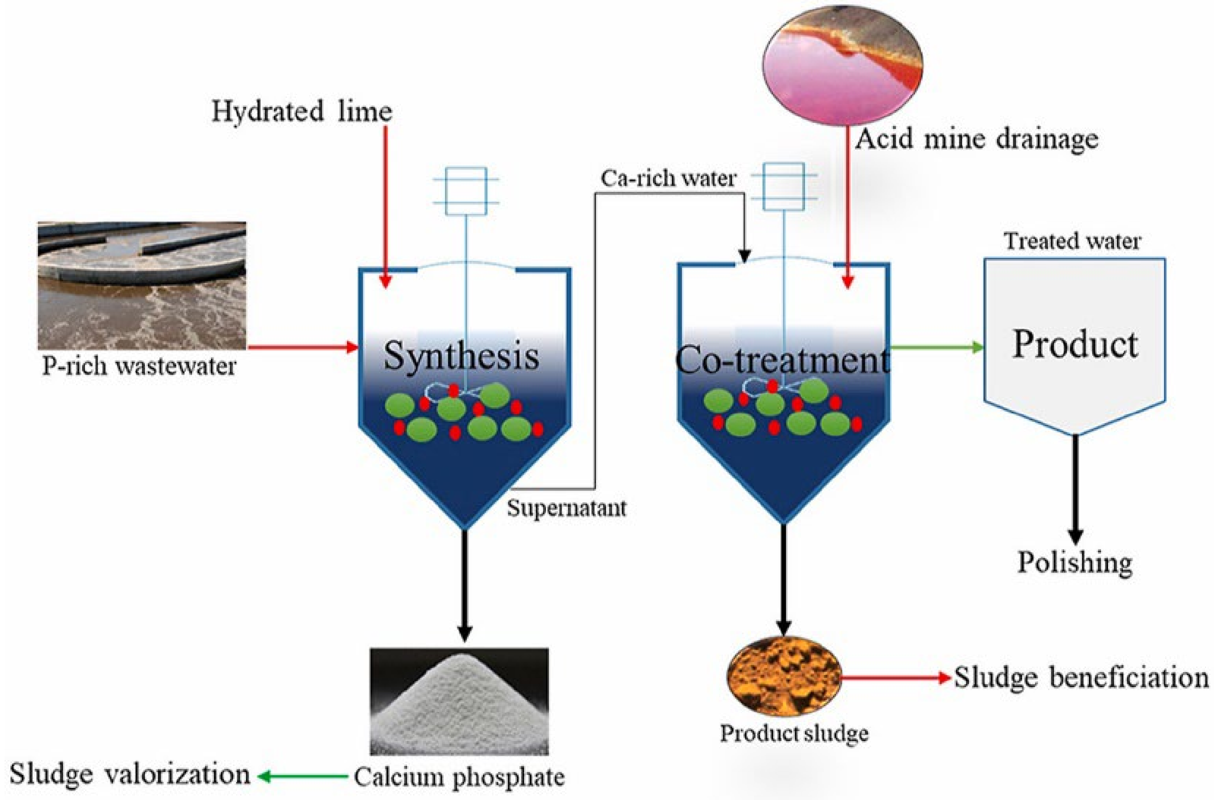

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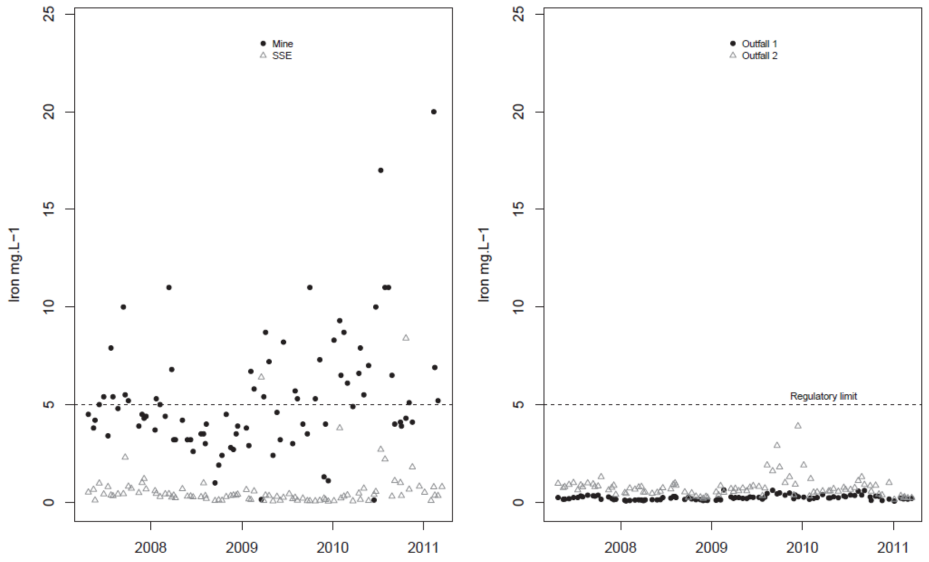
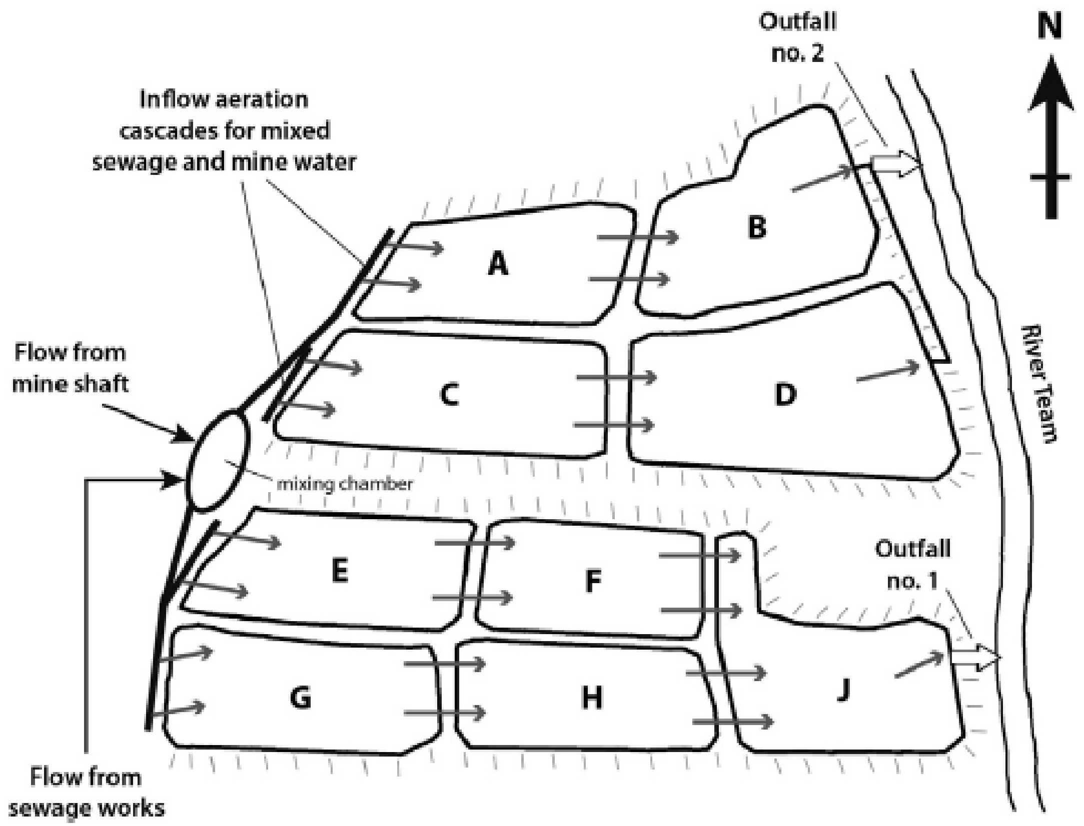




Two Paths

"Passive"

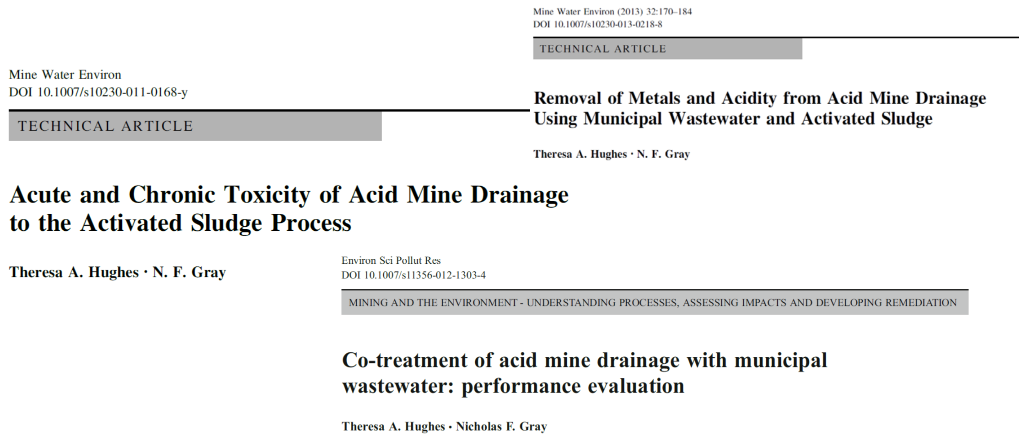
Kleinmann *et al.* (2021)

"Active"

TetraTech

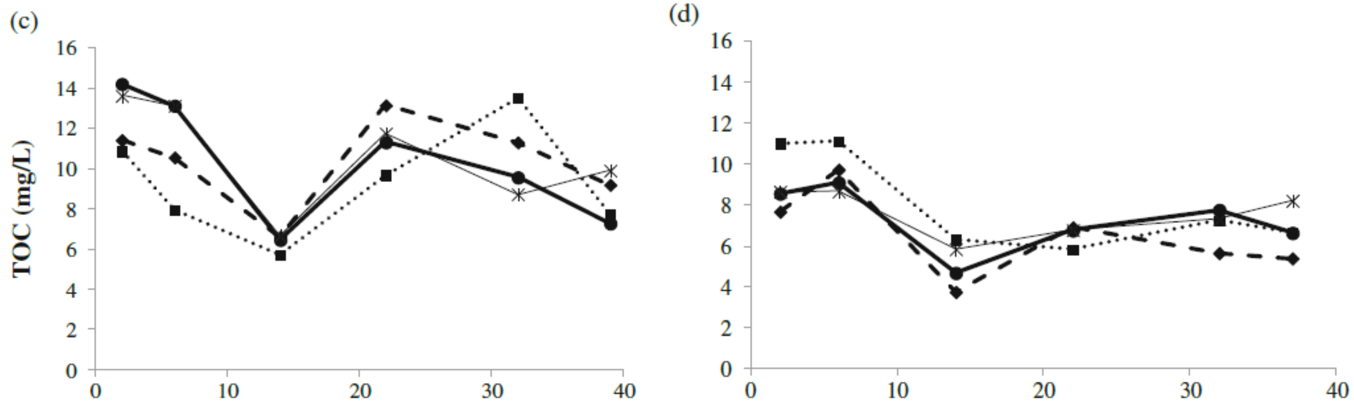
Trailblazers

- Theresa Hughes and Nicholas Gray
  - Trinity College, Ireland
- Traditional activated sludge context
  - High ratios with little impact
  - Efficient metals removal
  - Efficient MWW processing (except N)
- Immediately applicable

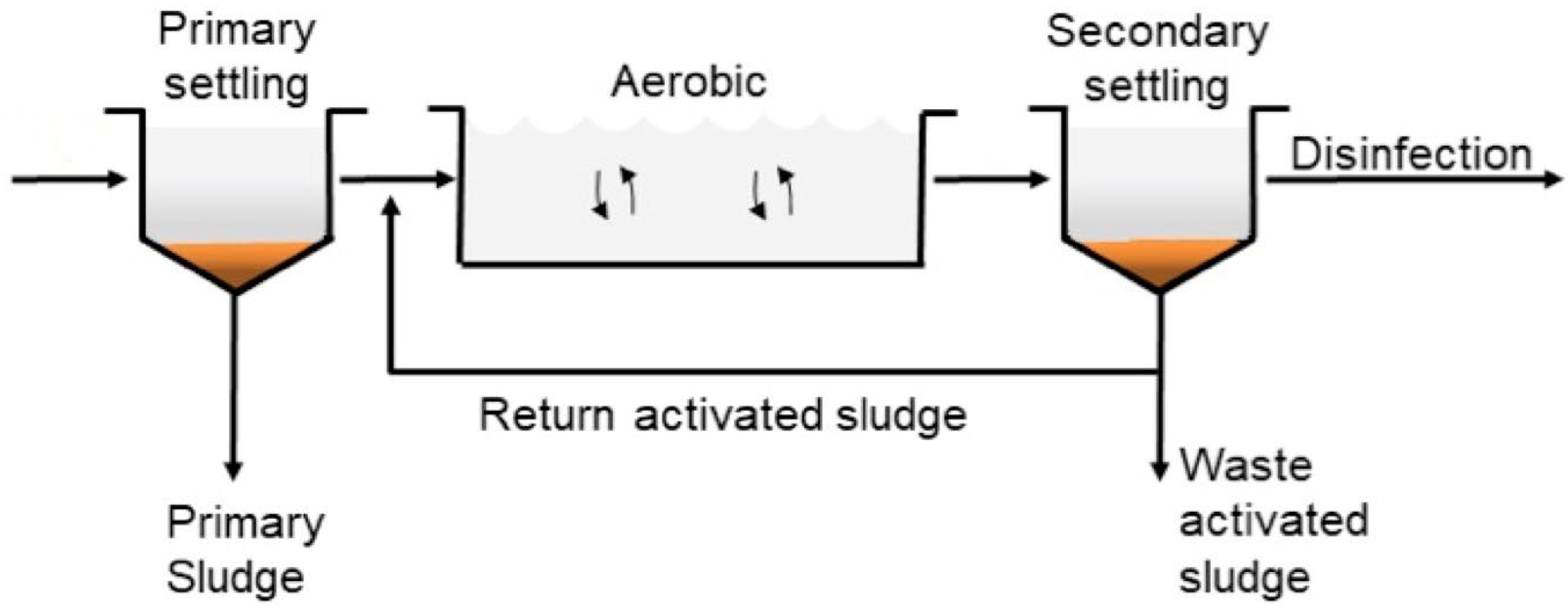

Mine Water Environ (2013) 32:170–184
DOI 10.1007/s10230-013-0218-8
TECHNICAL ARTICLE
Removal of Metals and Acidity from Acid Mine Drainage Using Municipal Wastewater and Activated Sludge
Theresa A. Hughes · N. F. Gray

Mine Water Environ
DOI 10.1007/s10230-011-0168-y
TECHNICAL ARTICLE
Acute and Chronic Toxicity of Acid Mine Drainage to the Activated Sludge Process
Theresa A. Hughes · N. F. Gray

Environ Sci Pollut Res
DOI 10.1007/s11356-012-1303-4
MINING AND THE ENVIRONMENT - UNDERSTANDING PROCESSES, ASSESSING IMPACTS AND DEVELOPING REMEDIATION
Co-treatment of acid mine drainage with municipal wastewater: performance evaluation
Theresa A. Hughes · Nicholas F. Gray

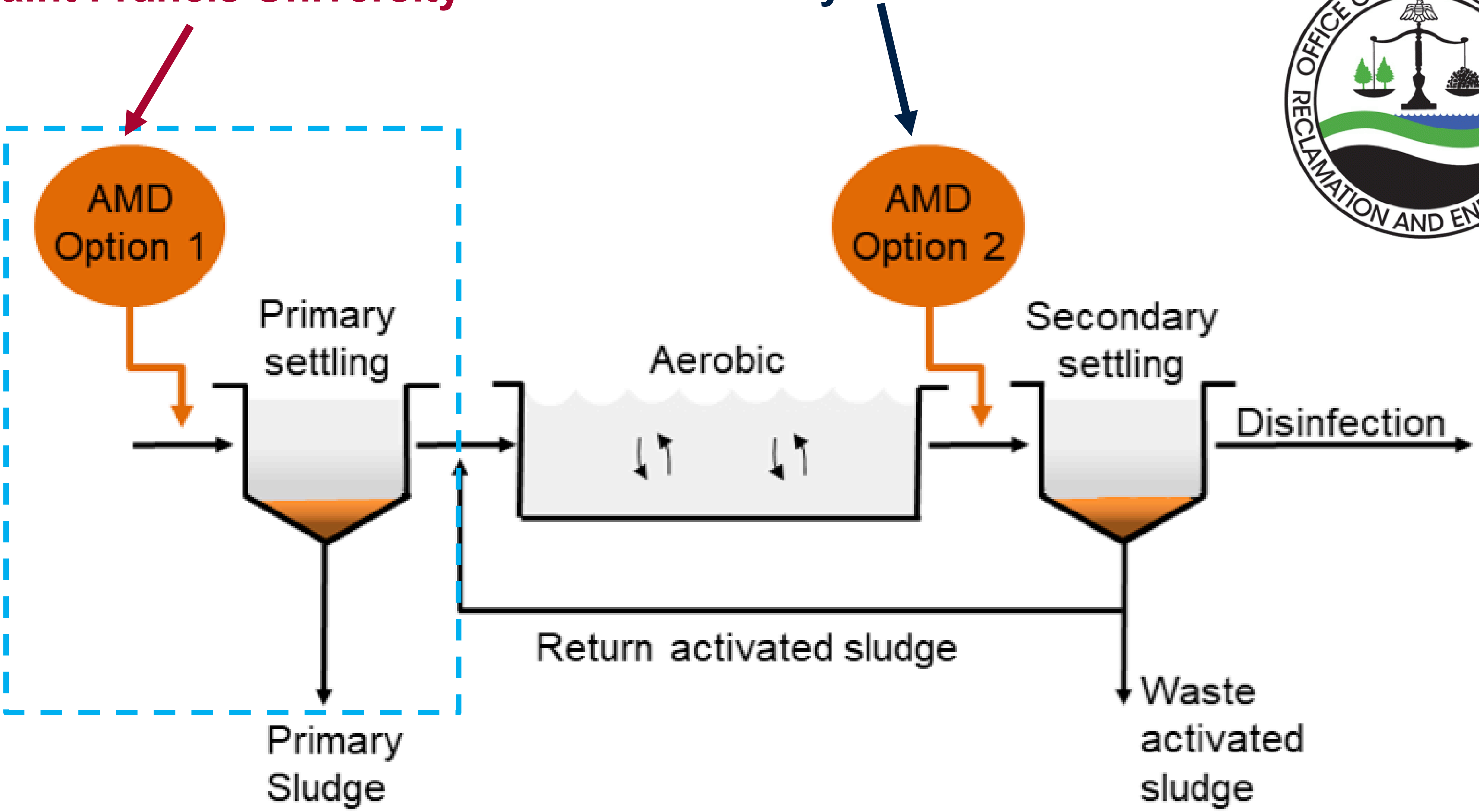


Conventional Activated Sludge



Saint Francis University

University of Rhode Island



Three Distinct Discharges

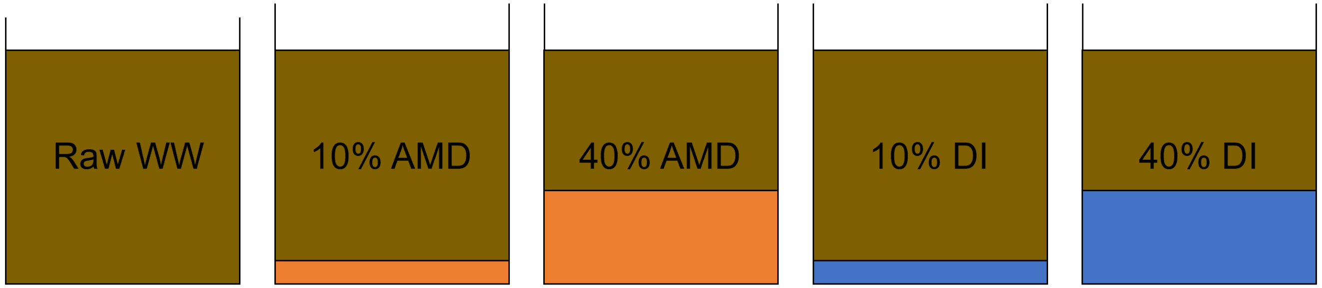
Constituent	Average ± *Standard Deviation*
pH	3.22 ± *0.05*
Iron (mg/L)	**8.67 ± *7.04***
Aluminum (mg/L)	**13.8 ± *1.01***
Calcium (mg/L)	69.0 ± *7.62*

Constituent	Average ± *Standard Deviation*
pH	4.42 ± *0.31*
Iron (mg/L)	**60.6 ± *4.65***
Aluminum (mg/L)	0.43 ± *0.11*
Calcium (mg/L)	25.3 ± *0.91*

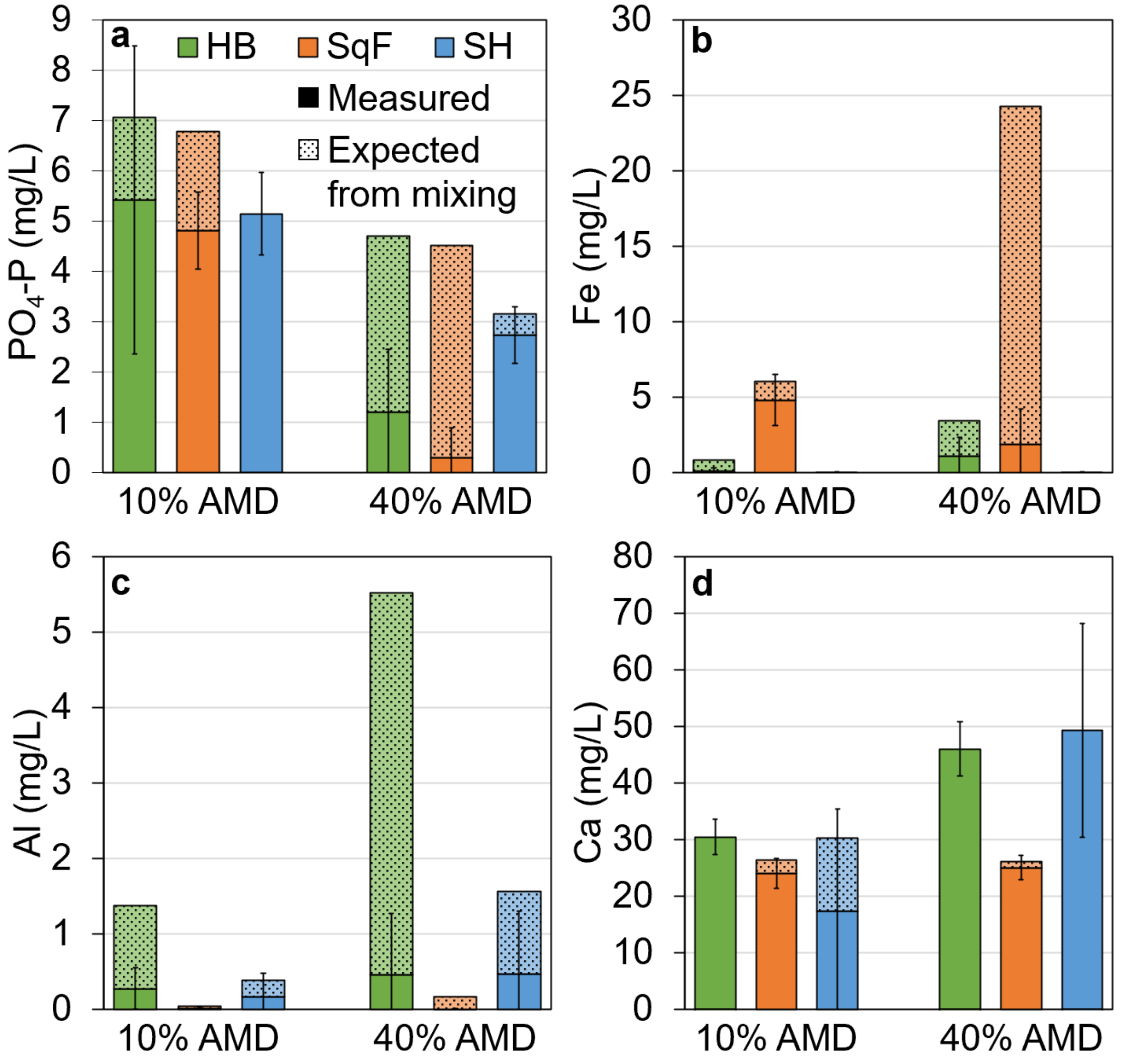
Constituent	Average ± *Standard Deviation*
pH	4.01 ± *0.03*
Iron (mg/L)	Below Detection
Aluminum (mg/L)	**3.92 ± *0.91***
Calcium (mg/L)	85.2 ± *7.49*

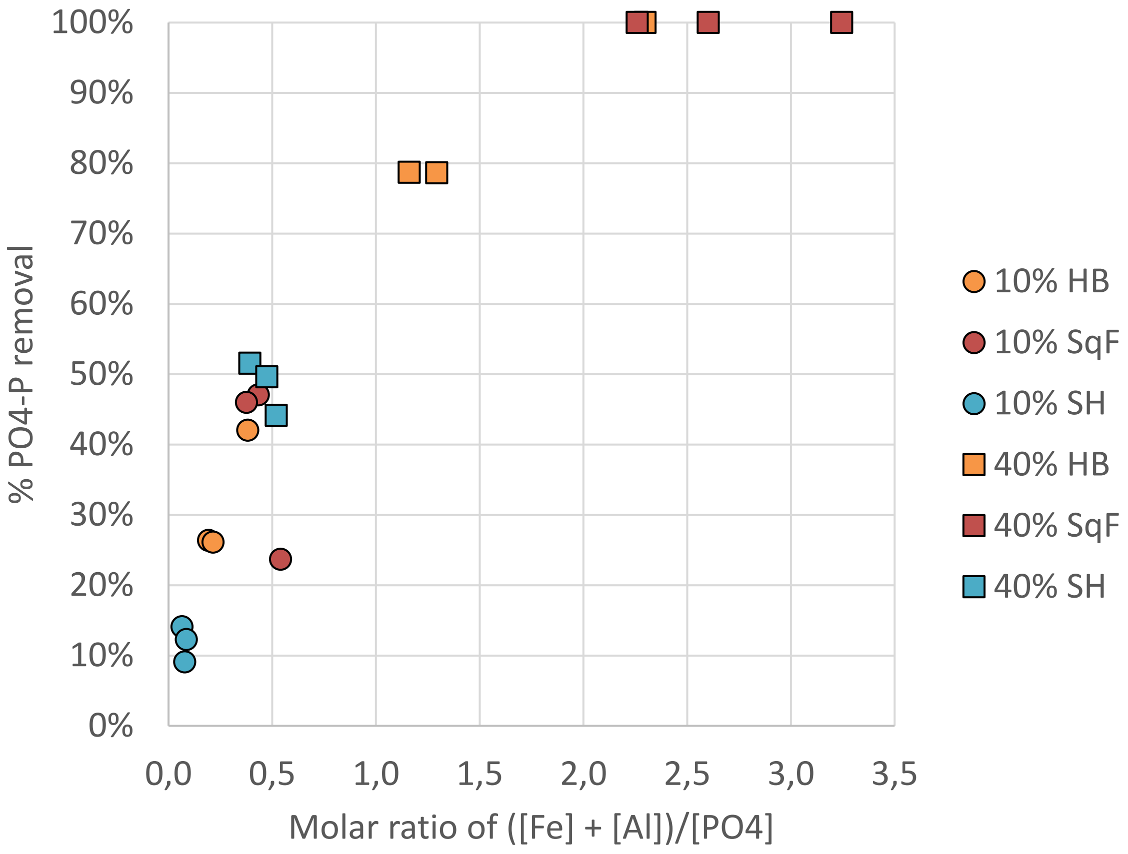
Simulating Primary Clarification

- Mixed for 2 minutes
- Settled for 2 hours, supernatant analyzed
- BOD removal rates - HACH BOD Trak II respirometers

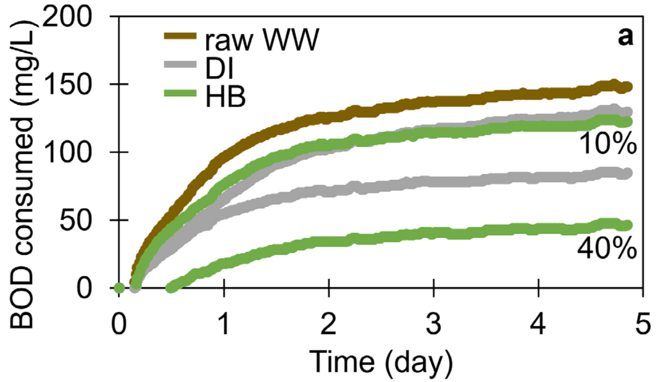


Iron Driving Phosphorus Removal

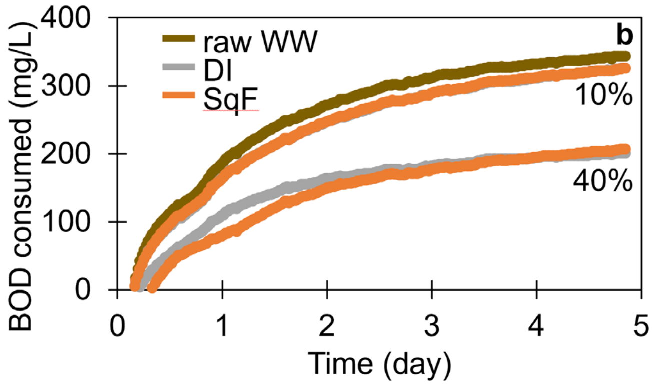




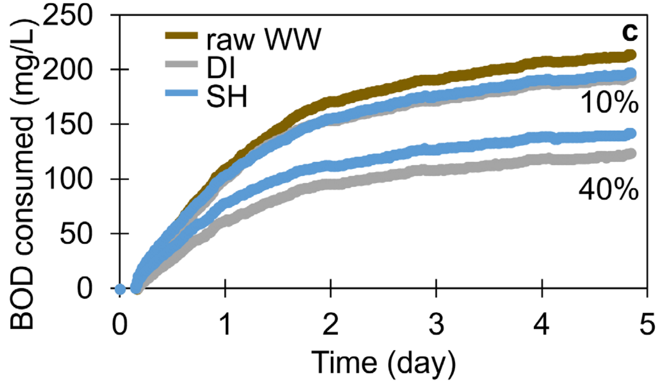
BOD Relatively Unaffected



Reactor	*k* (day^{-1})	UBOD (mg/L)	pH
raw WW	1.00	146	7.81
10% DI	0.69	134	7.72
10% HB	0.95	123	7.09
40% DI	0.98	83.6	7.52
40% HB	0.40	56.1	6.22

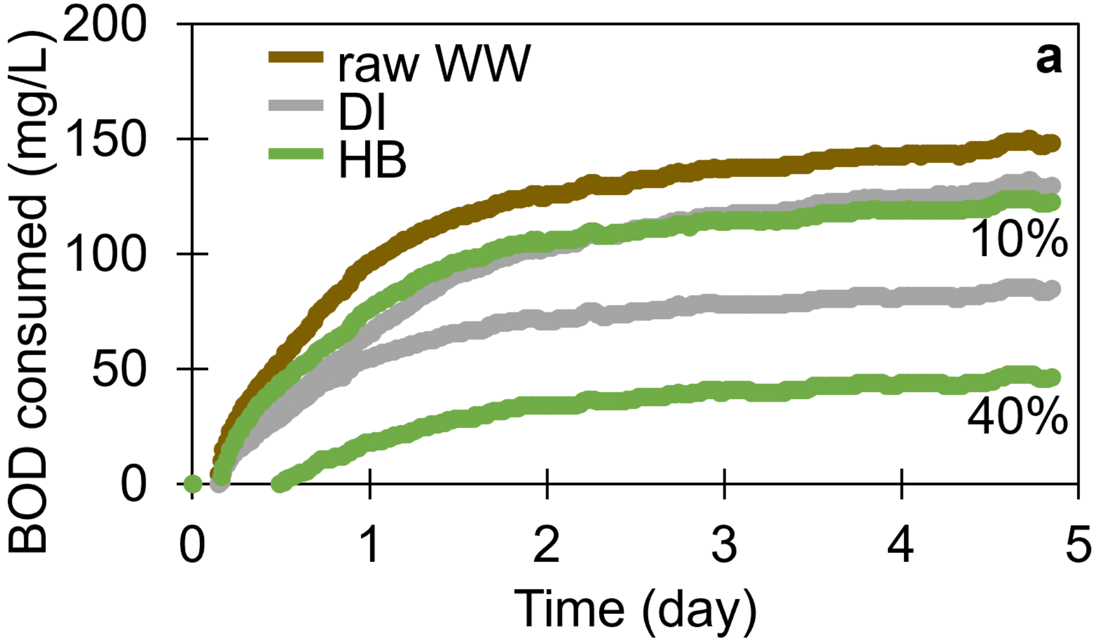


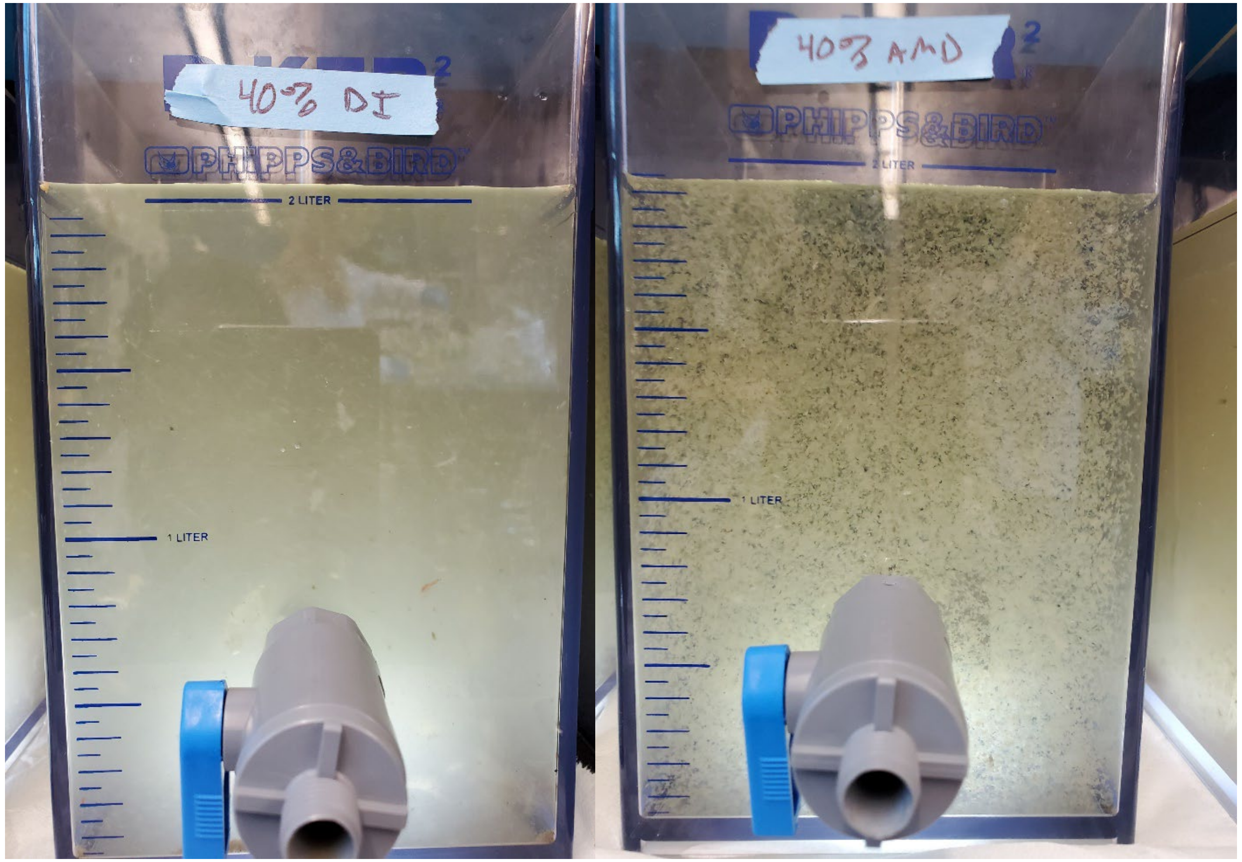
Reactor	*k* (day^{-1})	UBOD (mg/L)	pH
raw WW	0.74	351	8.45
10% DI	0.65	338	8.44
10% SqF	0.65	338	7.75
40% DI	0.72	208	8.40
40% SqF	0.45	236	6.98



Reactor	*k* (day^{-1})	UBOD (mg/L)	pH
raw WW	0.67	223	7.90
10% DI	0.69	200	7.88
10% SH	0.70	203	7.44
40% DI	0.64	128	7.92
40% SH	0.73	145	6.88

Sweep Coagulation

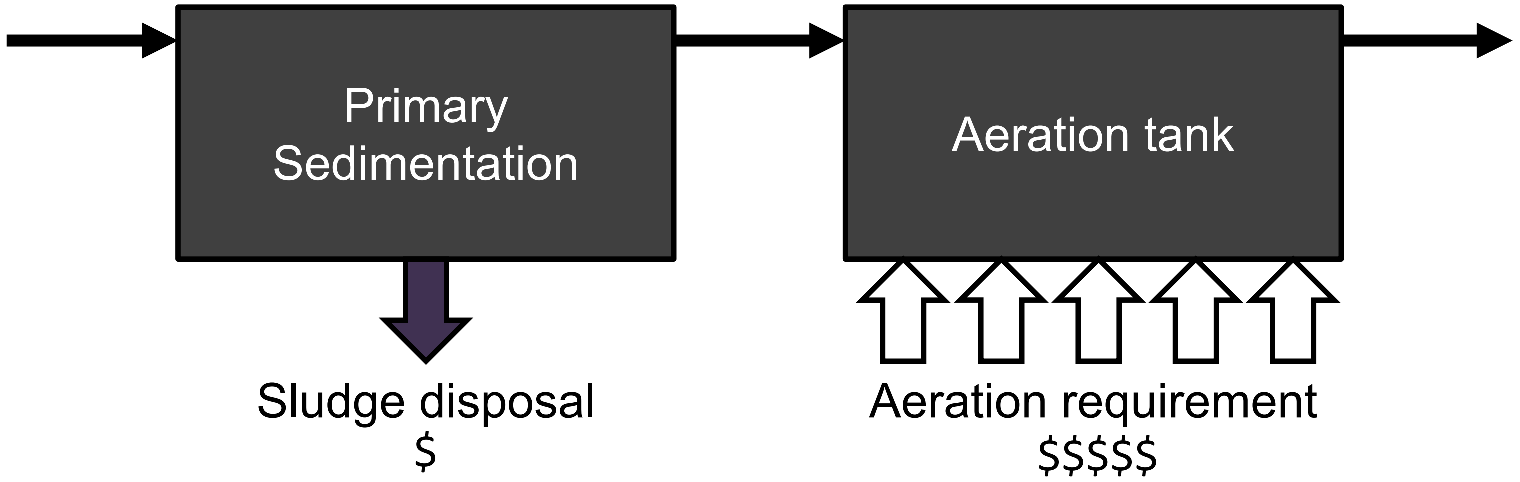




Reduced Aeration, Additional Sludge

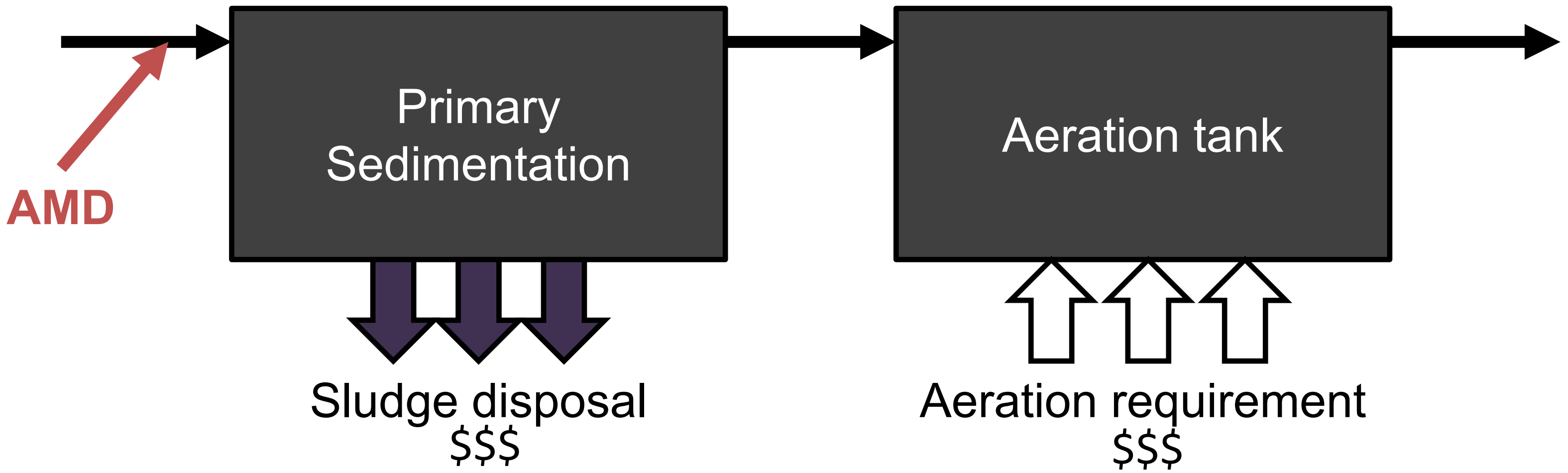
Energy requirements for a WWTP:

- ~50% for aeration
- ~10% for sludge pumping

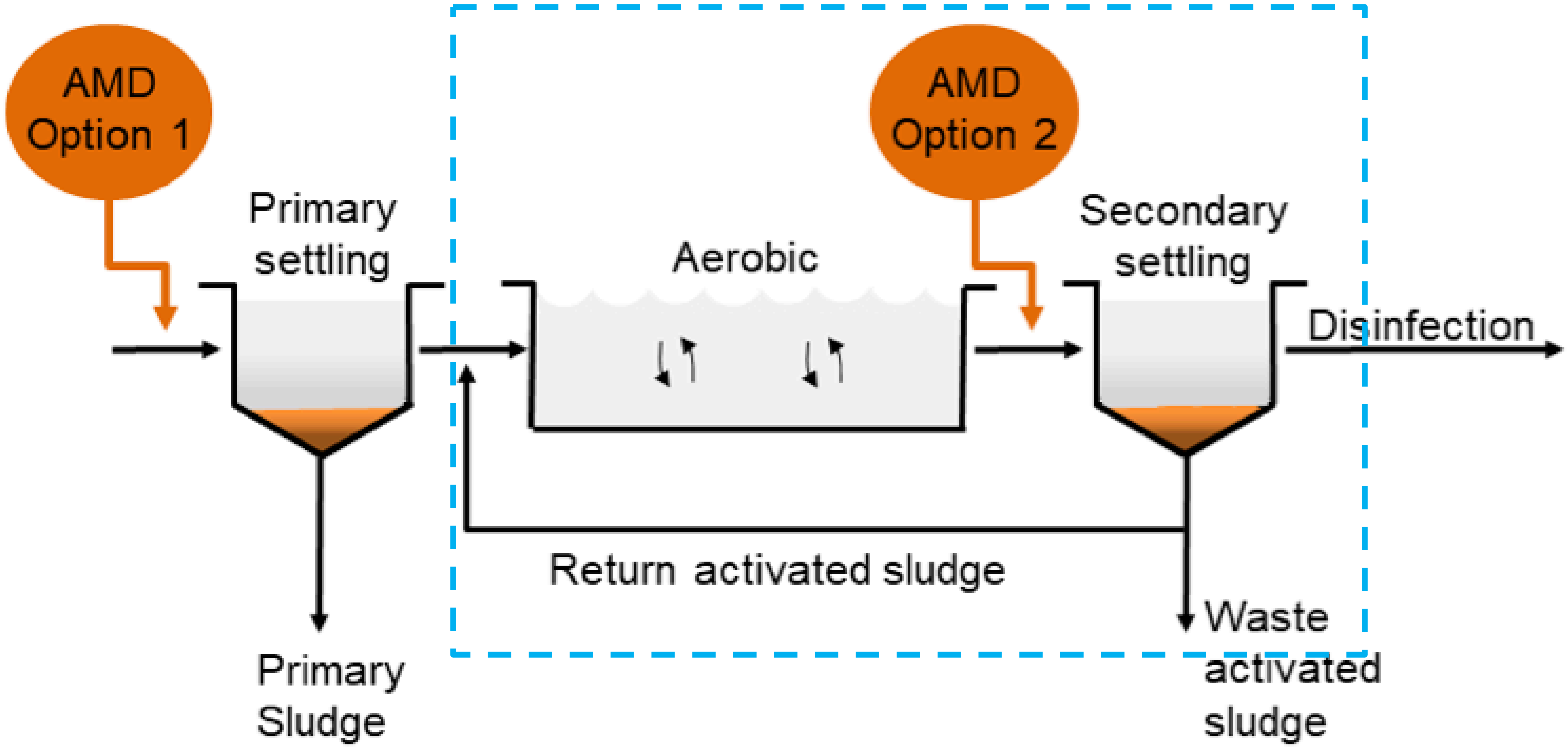


Changes from adding AMD:

- **Increased sludge generation** in primary clarifier
- **Reduced aeration requirement** from BOD being removed in clarifier by sweep coagulation

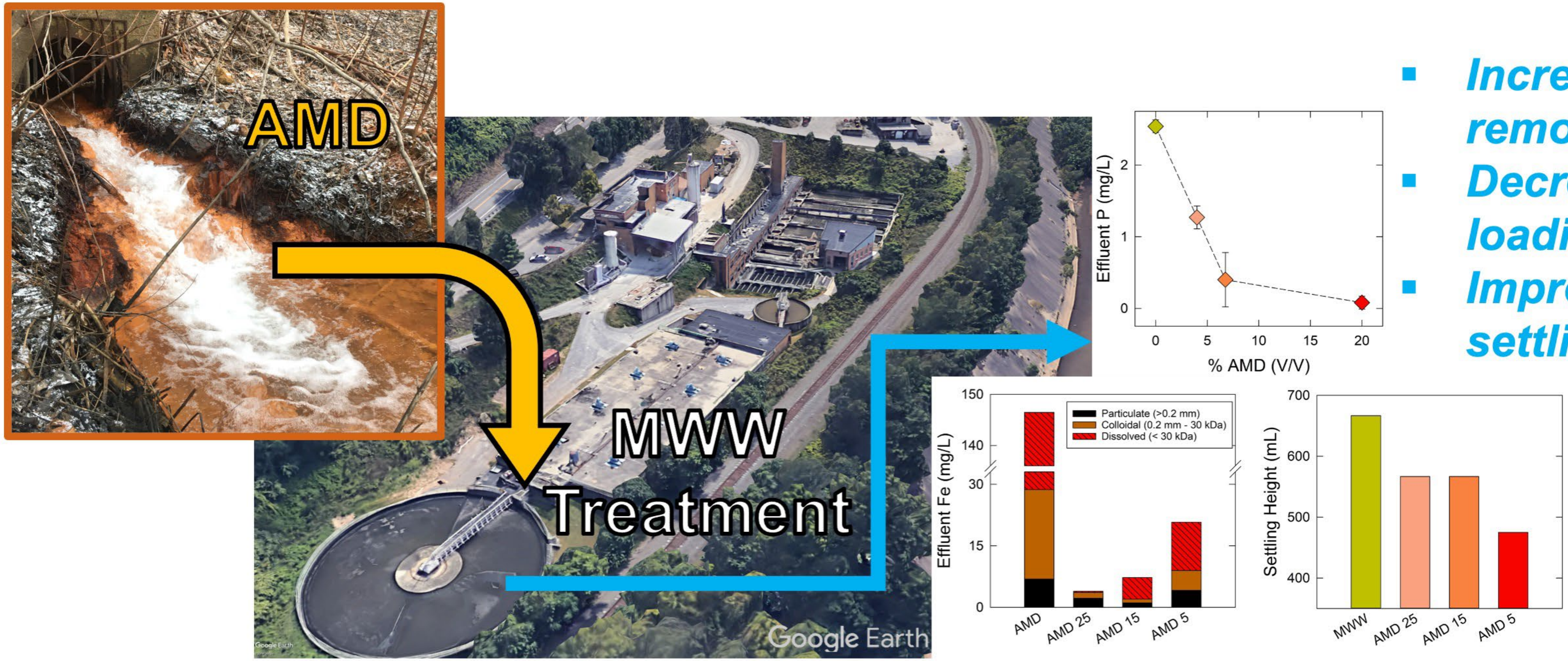


Co-Treatment Options at a WWTP



Hypothesis

- Adding small ratios of AMD (~10%) to secondary MWW treatment processes may improve some treatment rates.

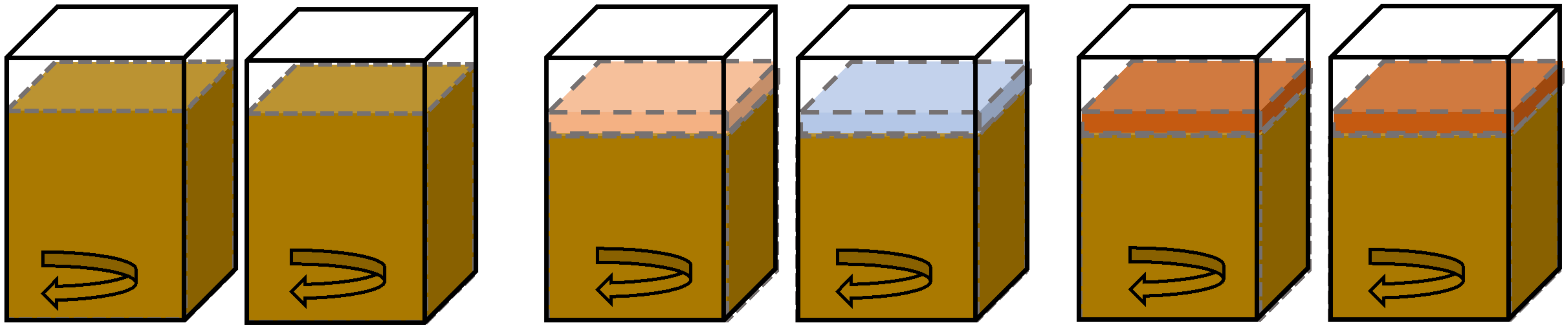


- *Increased PO_4 removal*
- *Decreased Fe loading*
- *Improved settling*

Figure from Spellman et al., 2020

Trials

Baseline Monitoring | **Phase I Co-Treatment** | **Phase II Co-Treatment**



No co-treatment "baseline", after 30 days of start-up.
14 days

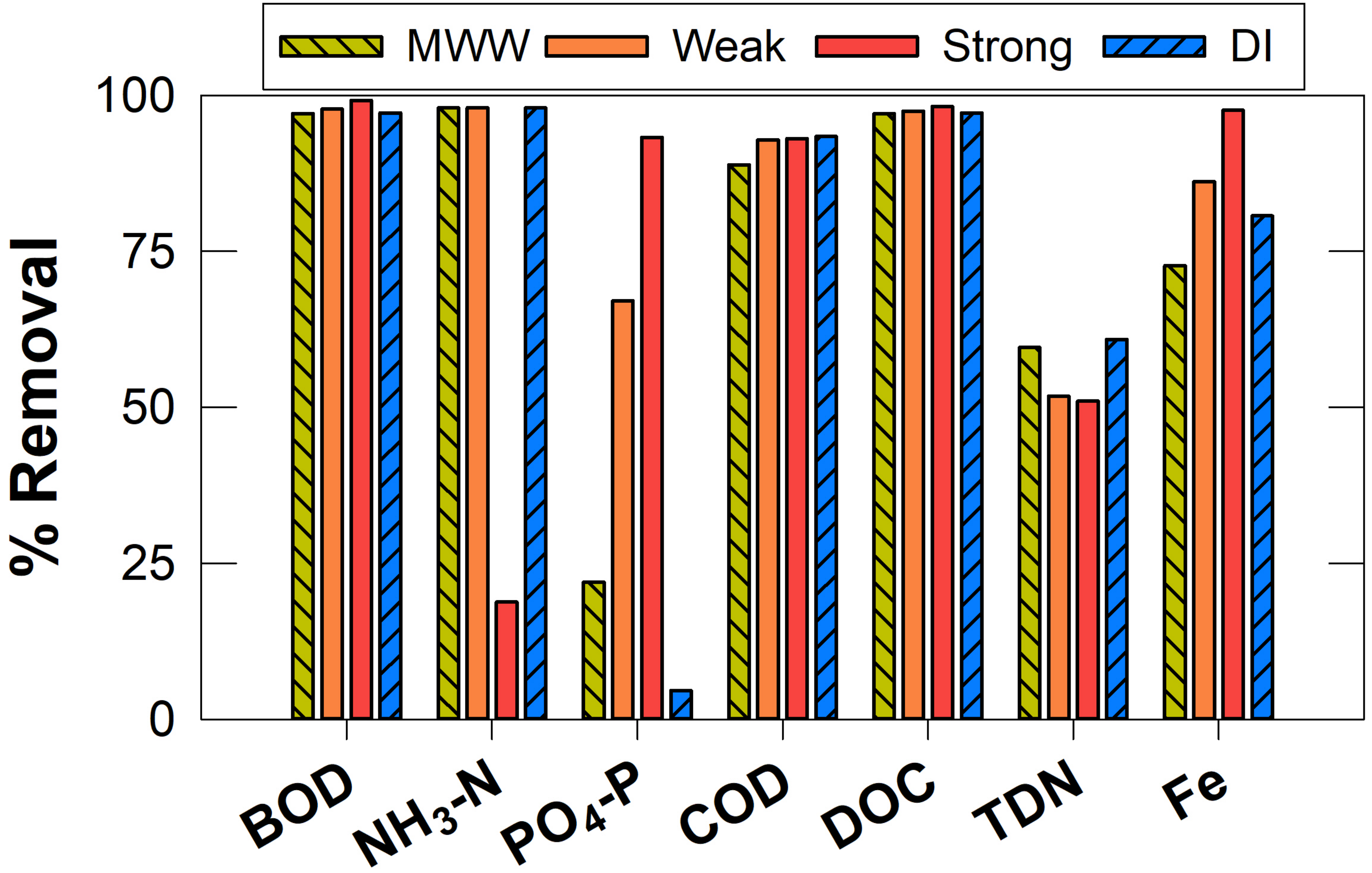
Add <u>Weak AMD</u> (1:10) to SBR1 & DI water (1:10) to SBR2.
40 days

Add <u>Strong AMD</u> (1:10) to SBR1 & <u>Strong AMD</u> (1:10) to SBR2.
40 days

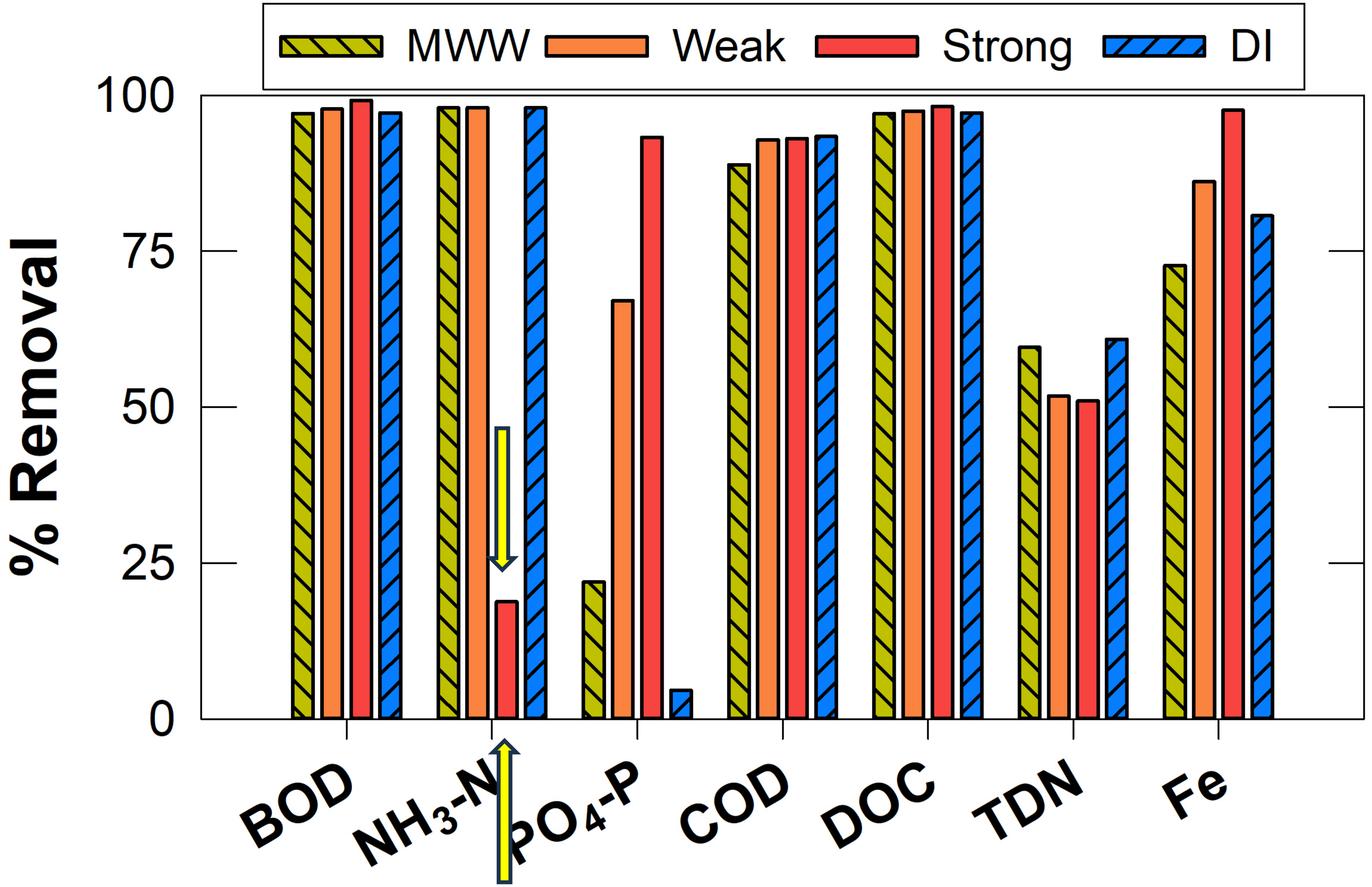
***Weak AMD* Acidity:** *87 mg/L as $CaCO_3$*

***Strong AMD* Acidity:** *720 mg/L as $CaCO_3$*

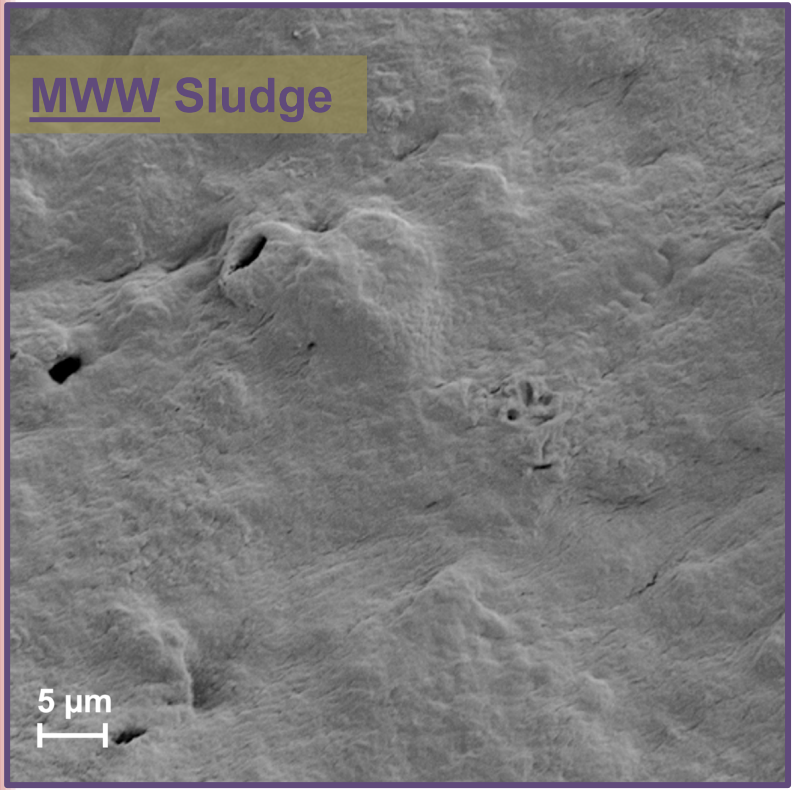
Pollutant Removal

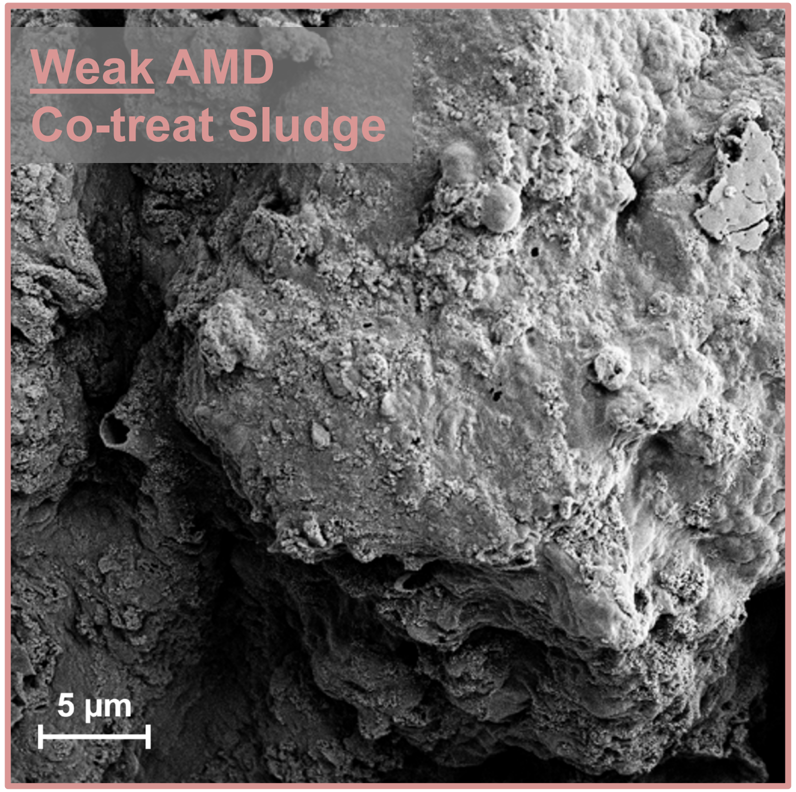


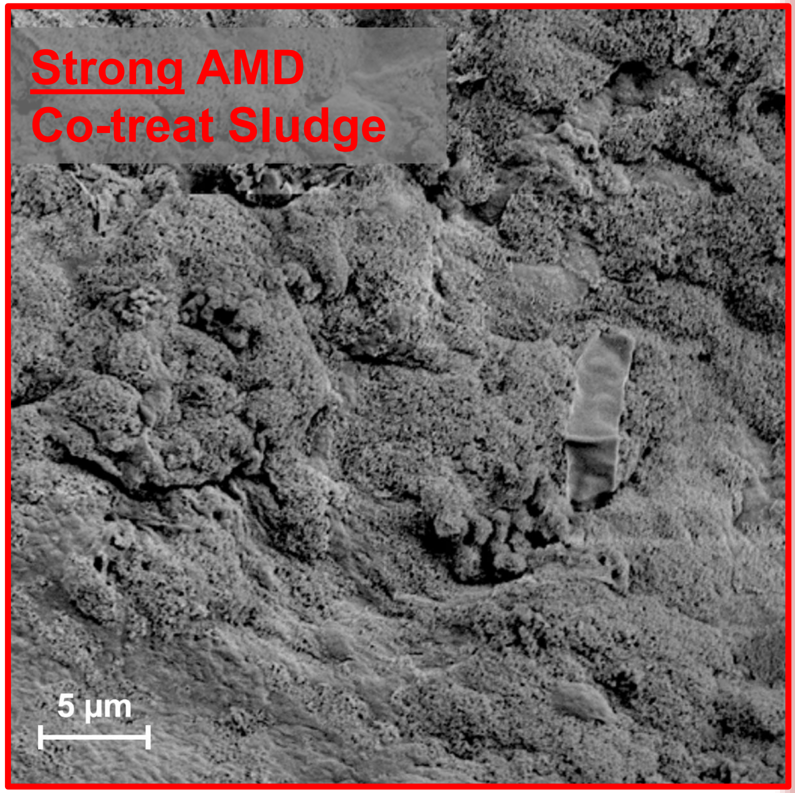
Pollutant Removal



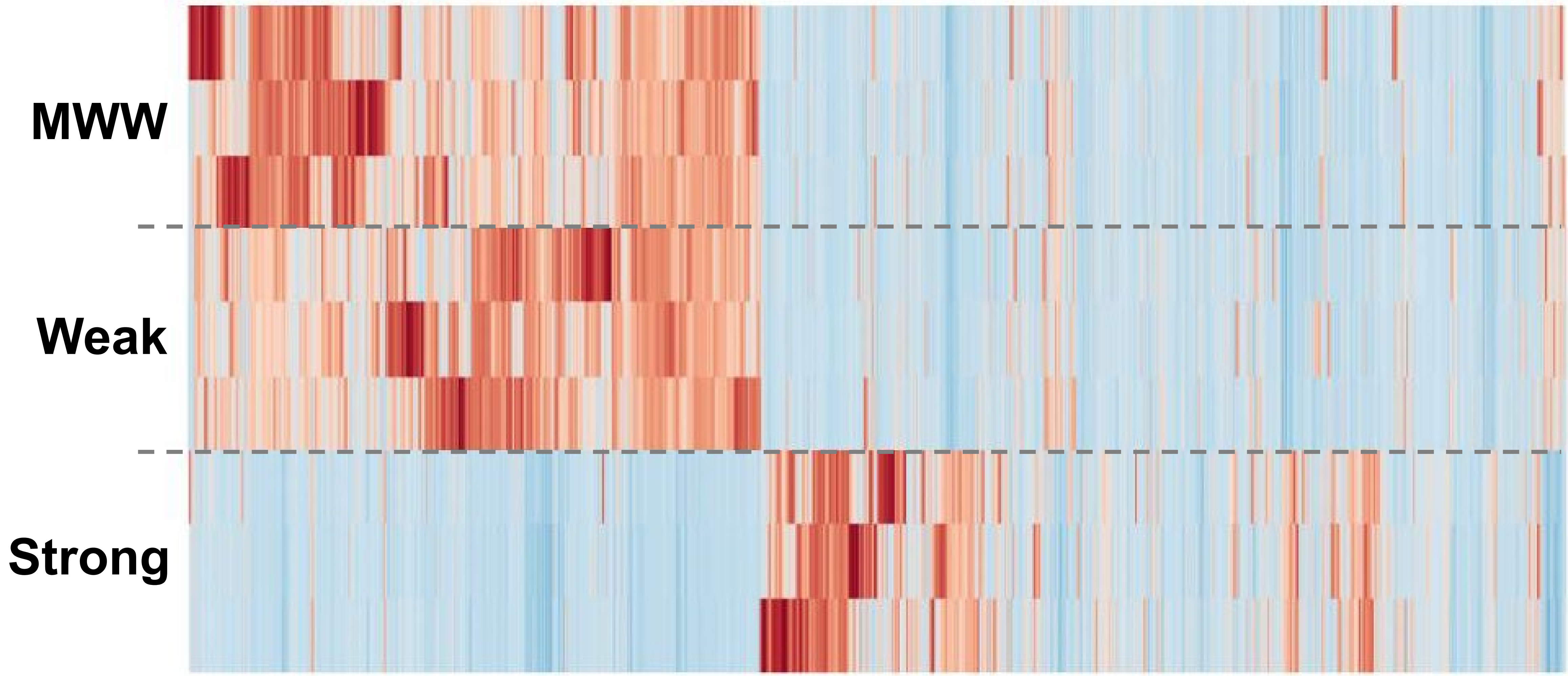
Sludge Characteristics







Microbial Diversity



Results

- Positives
  - Enhanced PO_4 removal
  - Inactivation of pathogens
  - Decreased BOD & TSS
  - Improved sludge settling
- Potential impacts
  - Increased effluent Fe
  - Decreased pH
  - Inhibited denitrification
  - Microbial diversity impact
- Co-treatment appears feasible
  - Especially PO_4-limited facilities
  - Lower chemical cost
  - But must manage **loading**

Remaining Questions/Considerations

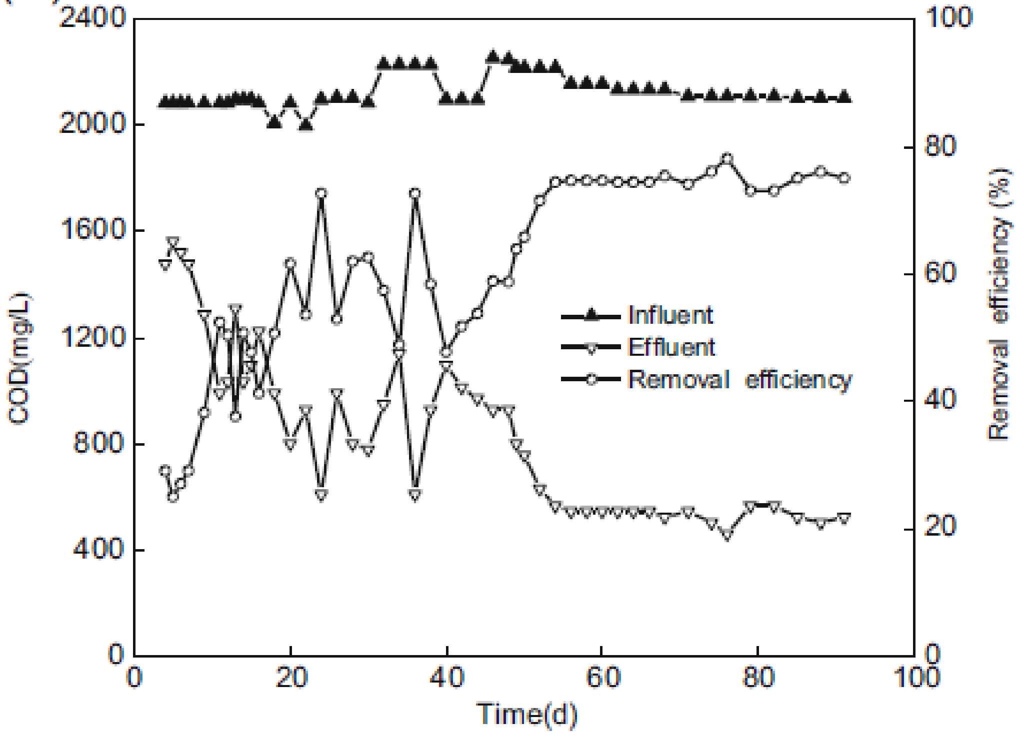
- Life-cycle assessment
  - *Can WWTP co-treatment be a sustainable alternative?*
- Cost Feasibility
  - *How does co-treatment compare to separate, tertiary MWW treatment and active AMD treatment systems?*
  - *Preliminary cost analysis suggests co-treatment more cost effective*

Estimated Co-treatment Lifetime Savings:	
vs Active AMD Treatment only	*$1,175,000*
vs AMD + New PO_4 Treatment	*$29,985,000*

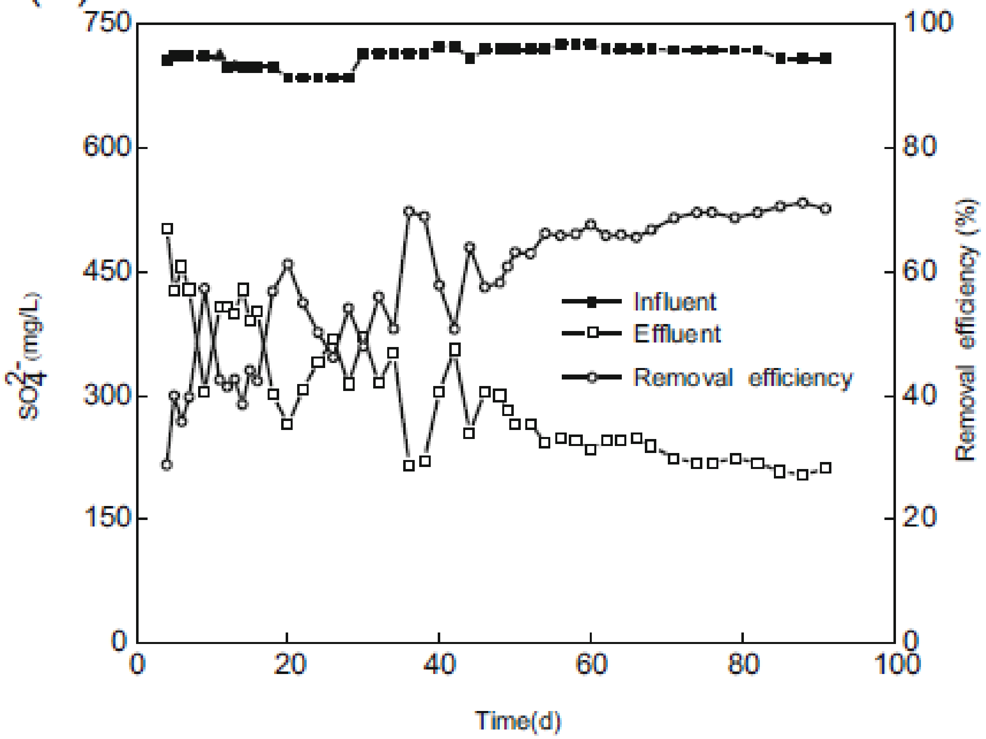
Further "Active" Work

- See Zhou et al. (2020)
  - Upflow anaerobic sludge blanket reactor (landfill leachate + AMD)

(a)



(b)



Conclusions

- Passive and Active co-treatment remains promising
  - High-efficiency treatment of nearly all constituents of interest is possible
  - Wastes as mutual resources

- Need:
  - Field pilots and full-scale systems (ambitious regulators)
    - Optimization, refined design/operational guidance

¡Thank You!