Passive Treatment of Mn: Results from our Experimental Pilot System

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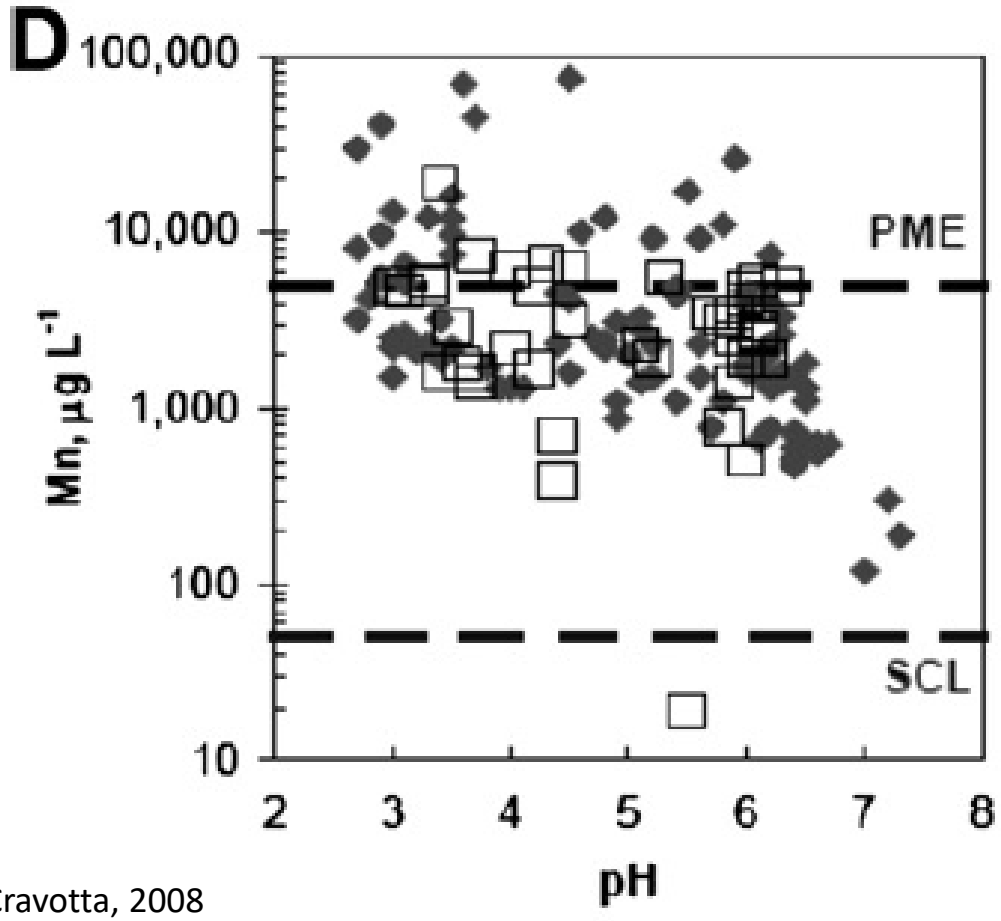
HedinEnvironmental

Manganese (Mn) in Mine Drainage

Contaminant Concentrations



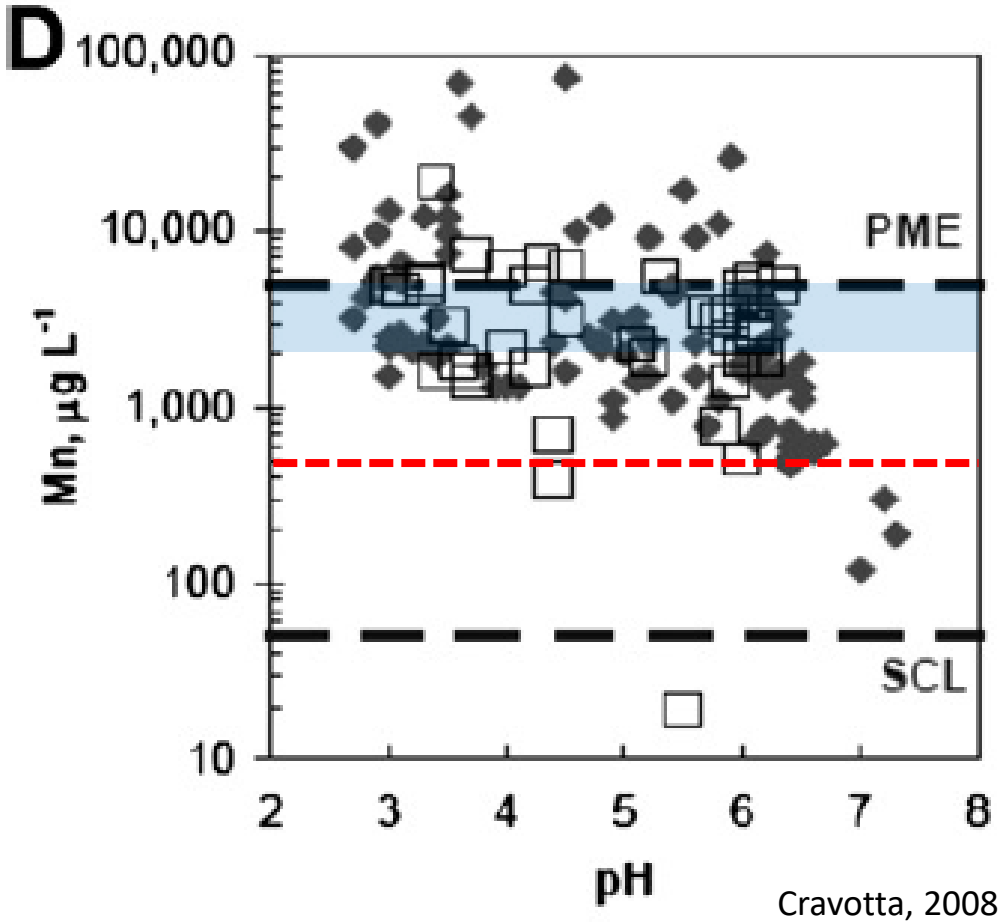
Cravotta, 2008

Removal

- Active
  - pH >10
    - Lime, sodium hydroxide
  - Oxidant
    - Potassium permanganate, ozone
- Passive
  - Wetlands (incomplete)
  - Aggregate beds (complete)

Why are we talking about Mn?

- Current PADEP Mn effluent limit
  - 2 to 5 mg/L
- Proposed PADEP Human Health criterion
  - 0.3 mg/L
- International mining limits
  - 0.3 - 0.5 mg/L

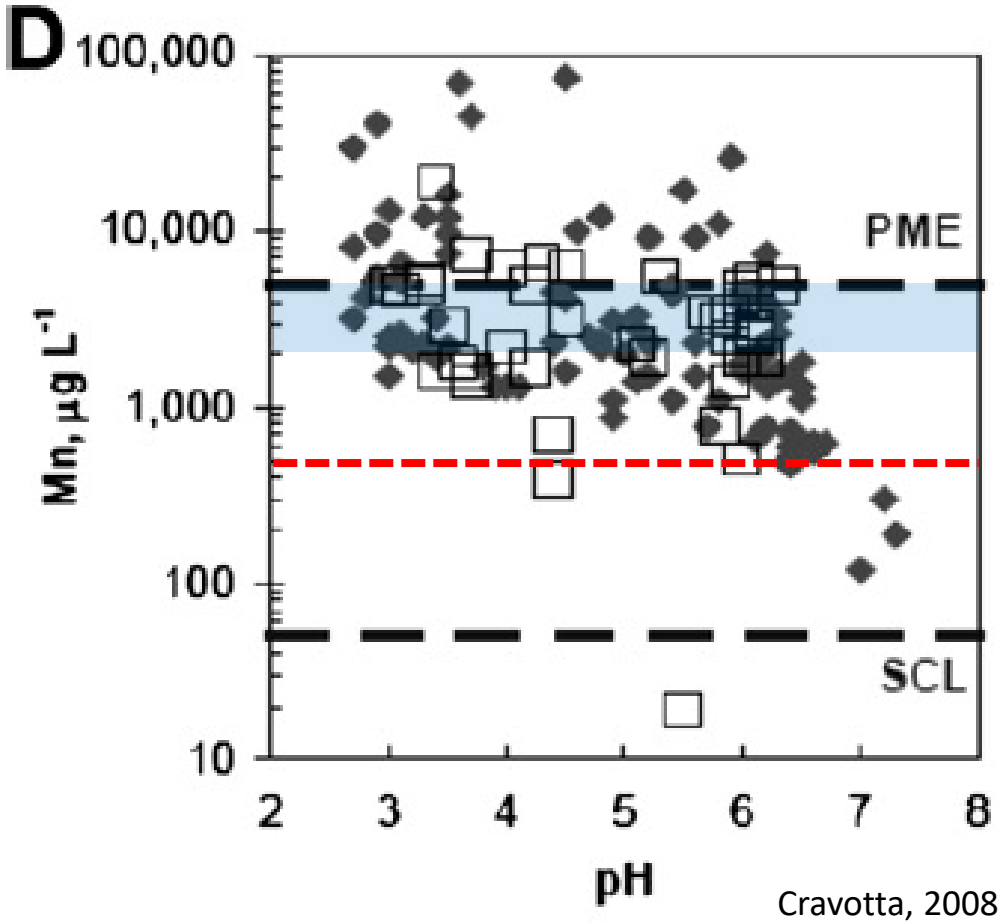


Cravotta, 2008

Reaction to Proposed 0.3 mg/L Limit

Industry response:

- Cost concerns
  - $137 to $143 million capital costs
  - $33 to $46 million per year in annual costs
- Passive treatment least costly treatment for low flows (<50 gpm)
- Passive treatment only applicable to low flows
  - Assumed retention time of 48 hours in aggregate beds

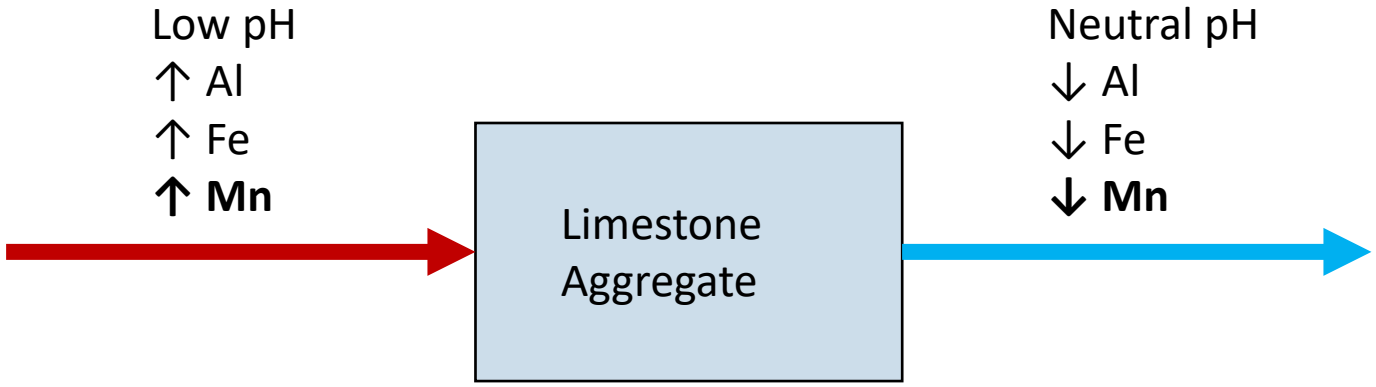


Cravotta, 2008

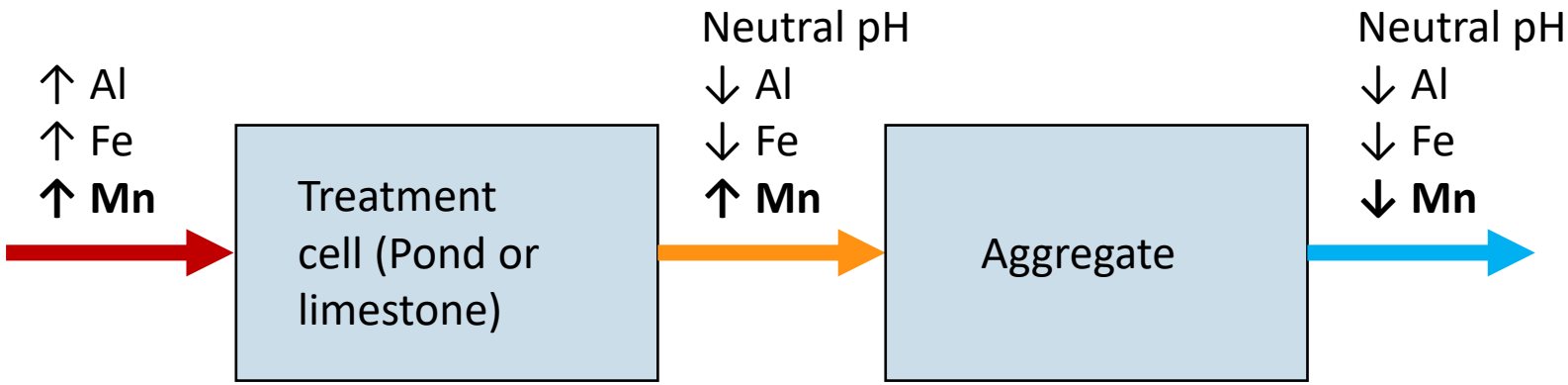
Goal: Passive Treatment is an Excellent Tool to Remove Mn to Proposed Mn Limits

- What kind of passive systems remove Mn
- How is Mn removed in passive systems
- Mn removal in installed full scale systems
- Our experimental setup
- Our experimental results
- Where this technology is applicable

Mn removal in existing full scale passive systems



Greene, permitted system 154 gpm (580 lpm)		
Parameter	In	Out
pH	3.4	7.2
Al	4.0	0.1
Fe	5.6	0.2
Mn	40.0	0.1



Glasgow, permitted system 52 gpm (197 lpm)			
Parameter	VFP In	Mn Bed In	Mn Bed Out
pH	4.1	6.7	7.6
Al	40.1	0.1	<0.1
Fe	64.4	<0.1	<0.1
Mn	67.8	19.5	<0.1

Mn removal mechanisms

- Biotic
  - Fungi produce superoxide which catalyzes dissolved Mn oxidation and precipitation as MnO_2
  - Bacteria oxidize Mn for energy
- Abiotic
  - Dissolved Mn precipitate to form a MnO_2 crust on aggregate
  - Mn oxides adsorb and oxidize dissolved Mn and grow

Passive Mn removal interpreted as a mix of biotic and abiotic processes

Mn removal at installed full scale systems – Pennsylvania

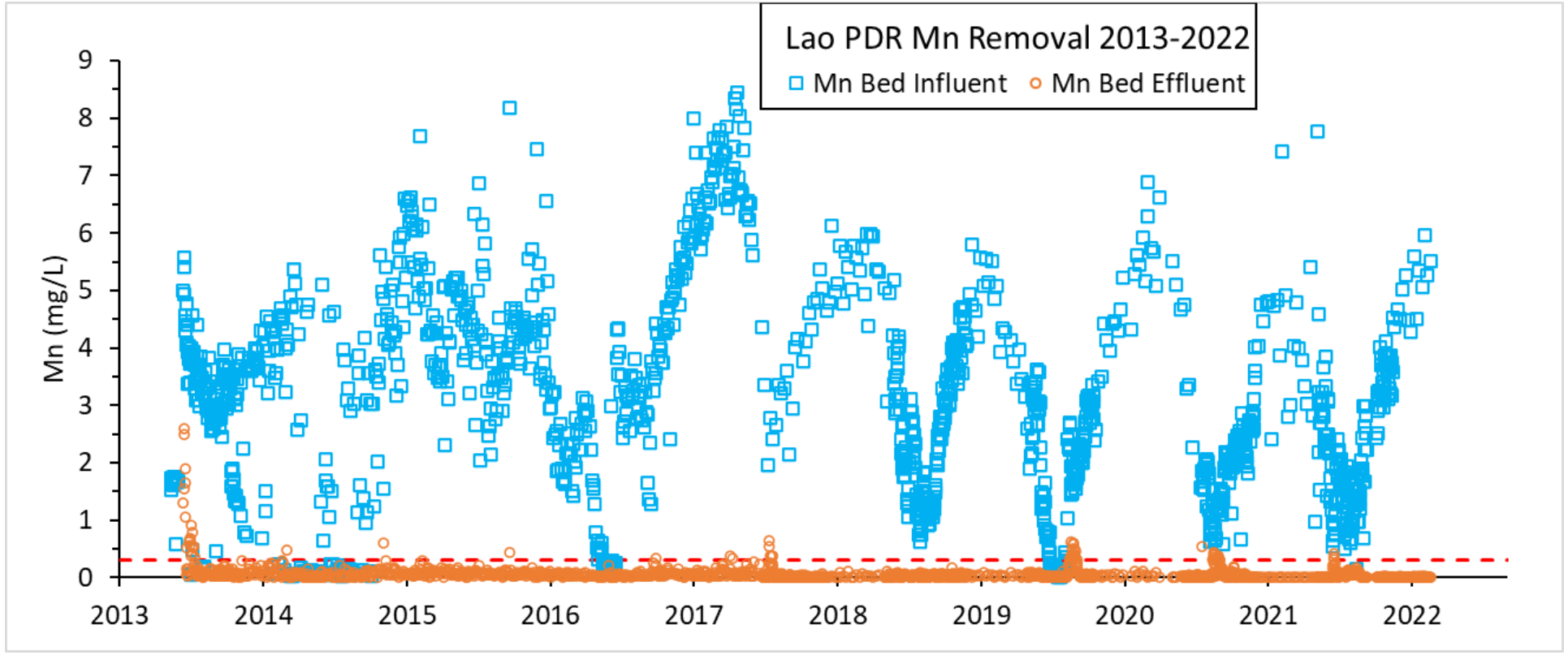
Site	Mn^{in}	Mn^{eff}
	mg/L	mg/L
K&J	27.8	0.4
Swisstock 1	16.4	4.4
Swisstock 2	8.5	5.6
PBS	28.1	1.1
Laurel Run	116	0.1
Stroud	8	1.2
Glenwhite	5.7	0.4
MB 1	20	6.7
MB 2	20	6.0
Ace	34.7	8.6
Glady Fork	9.4	1.7
De Sale 3	55.5	30.9
De Sale 2	31.2	17.1
Fairview	150	70
Derry Ridge	19.4	1.3
PBS	18.4	0.3
West Box	11.9	2.8
Scootac	23.5	1.6
Greene	30.8	1.1
Median	20	1.7

New types of passive systems needed to remove Mn to <0.3 mg/L.

Data from Rose et al, 2023, Luan et al 2012, and Hedin et al 2022

It can be done! Hedin Environmental International Work

- Mn removal systems installed in Laos (Lao PDR), Vietnam, Brazil, and Madagascar.
- In: 840 gpm (3,175 lpm), 2 – 10 mg/L Mn in
- Out: <0.3 mg/L Mn in 97% of measurements over 9 years



Experimental Locations

- Hollywood active treatment system
  - Aeration, hydrated lime, polymer, clarifier
  - Untreated = 3.3 pH, 36 mg/L Fe, 19 mg/L Al, 1.3 mg/L Mn
  - Treated = 7.3 pH, 1.4 mg/L Fe, **0.6 mg/L Mn**
- Brandy Camp active treatment system
  - Hydrogen peroxide, lime, polymer, settling ponds, wetlands
  - Untreated = 4.6 pH, 6.3 mg/L Fe, 8 mg/L Al, 10 mg/L Mn
  - Treated = 7.1 pH, 1.7 mg/L Fe, **5.8 mg/L Mn**

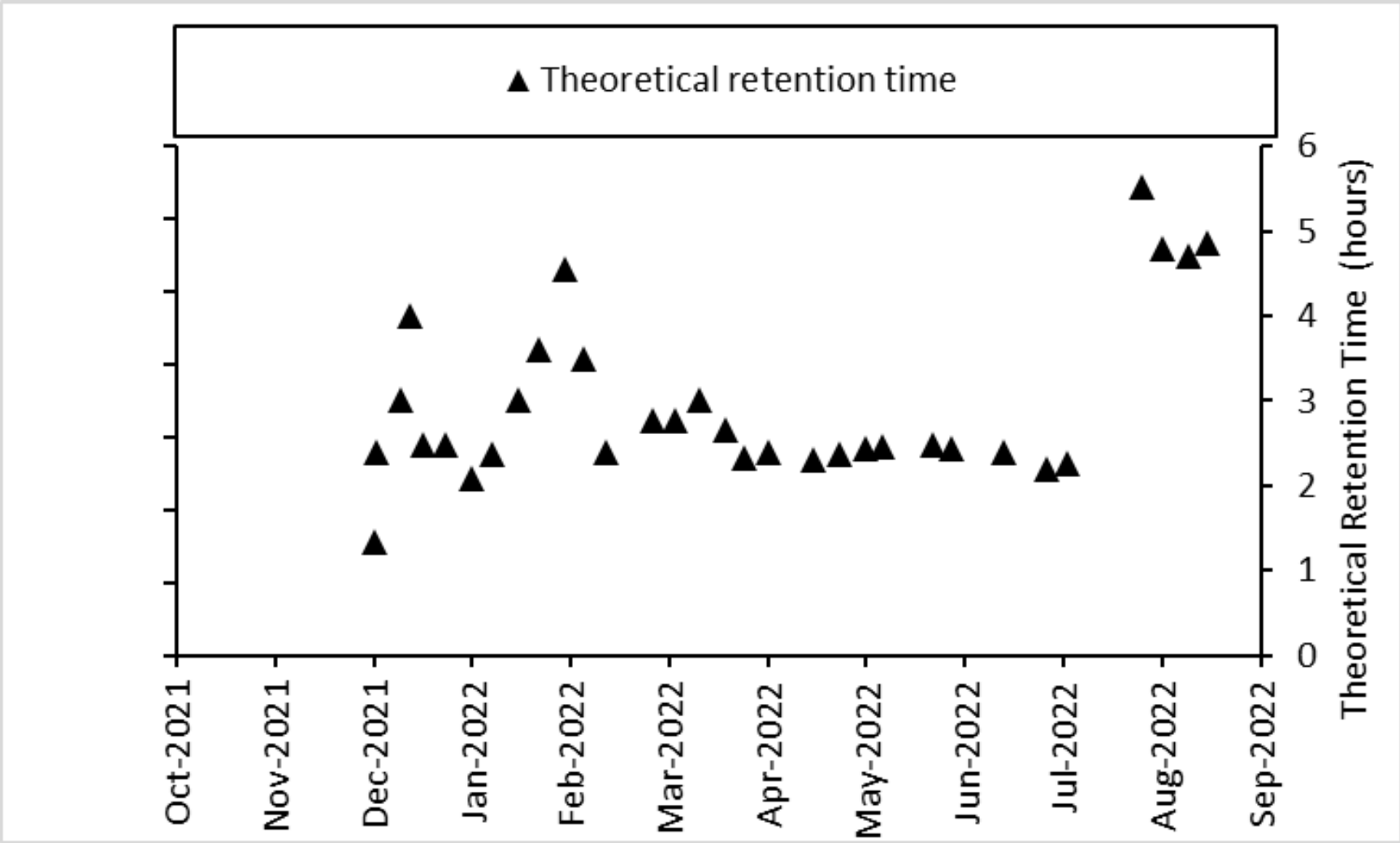
Hollywood experimental unit

- 30 yd^3 steel roll off container
- 36 tons of AASHTO #3
  - 3.8 cm diameter
- “Ripened” stone from Mn removal bed
- Water from clarifier

Brandy Camp experimental unit

- 10 yd^3 steel roll off container
- 12 tons of AASHTO #8
  - 0.7 cm diameter
- “Fresh” stone from quarry
- Water from wetland

Hollywood unit (ripened AASHTO 3)



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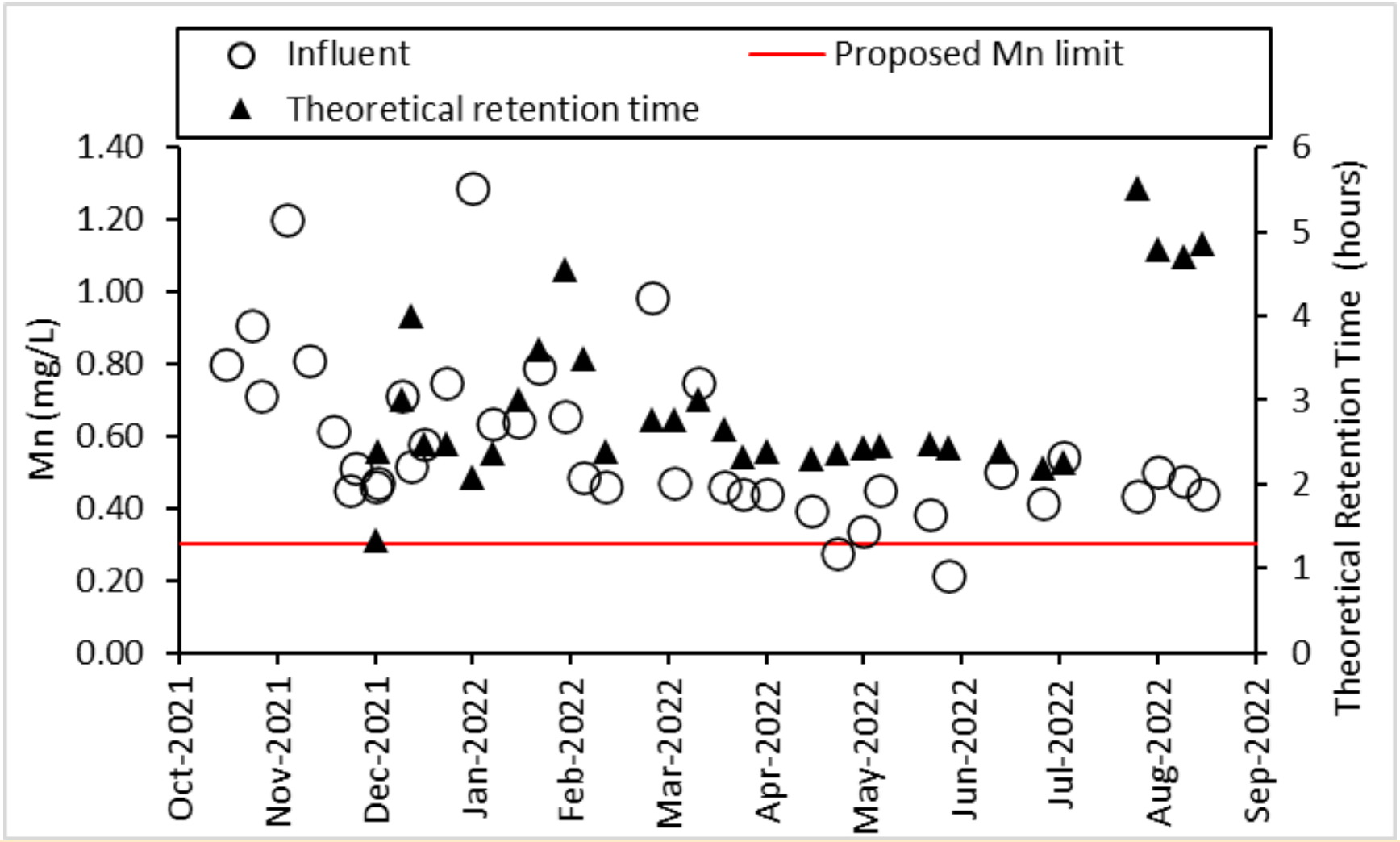

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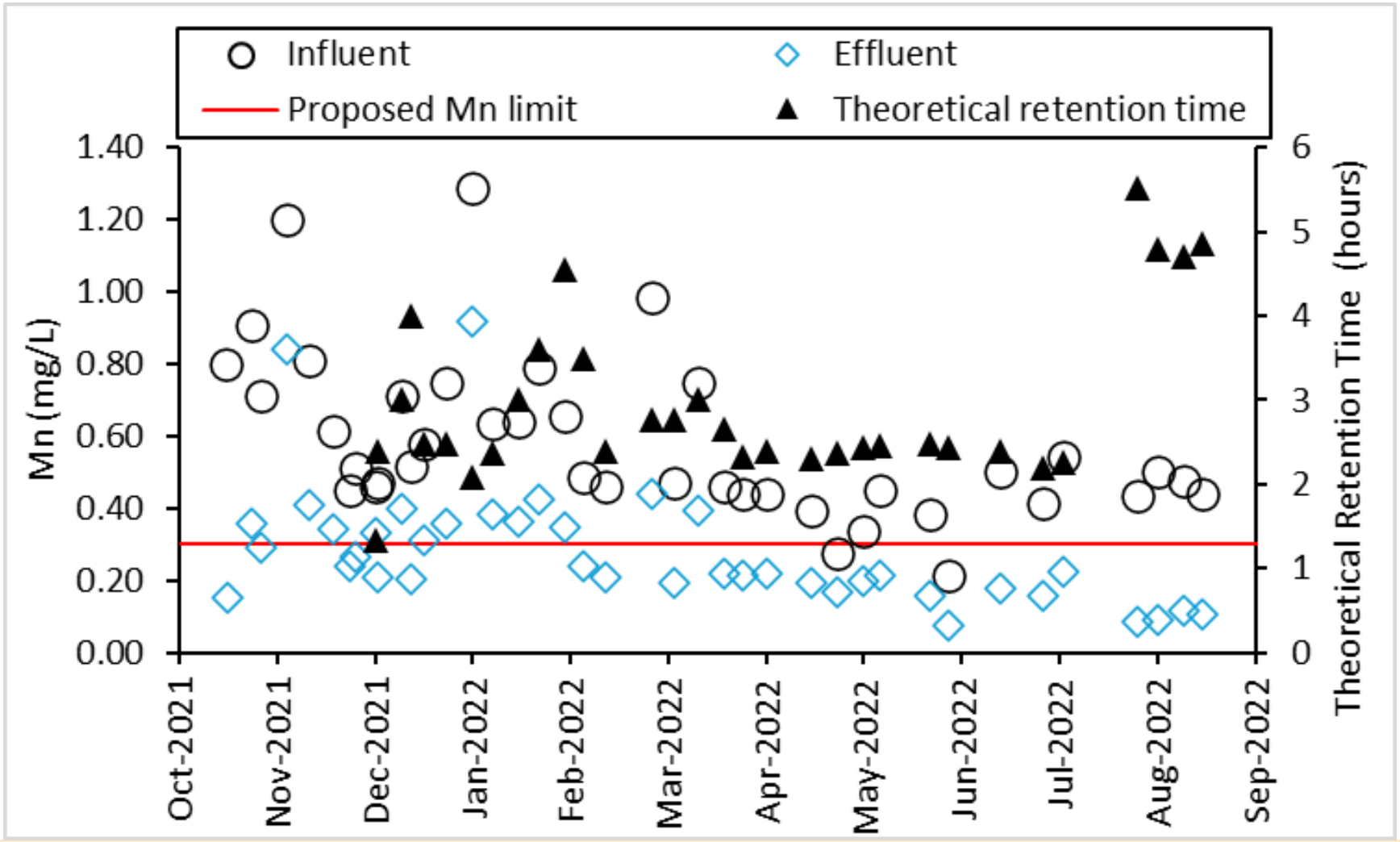
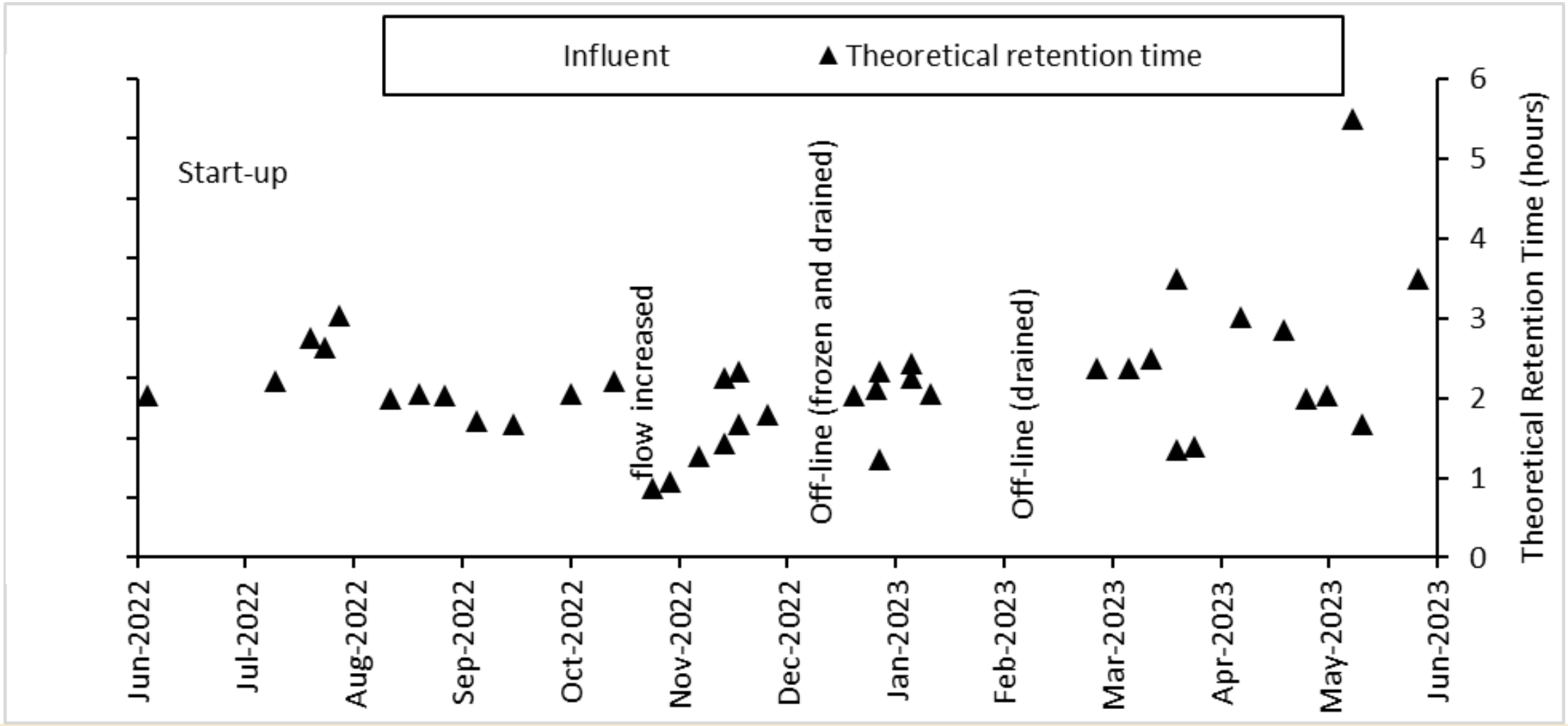


Brandy Camp unit (fresh AASHTO 8)



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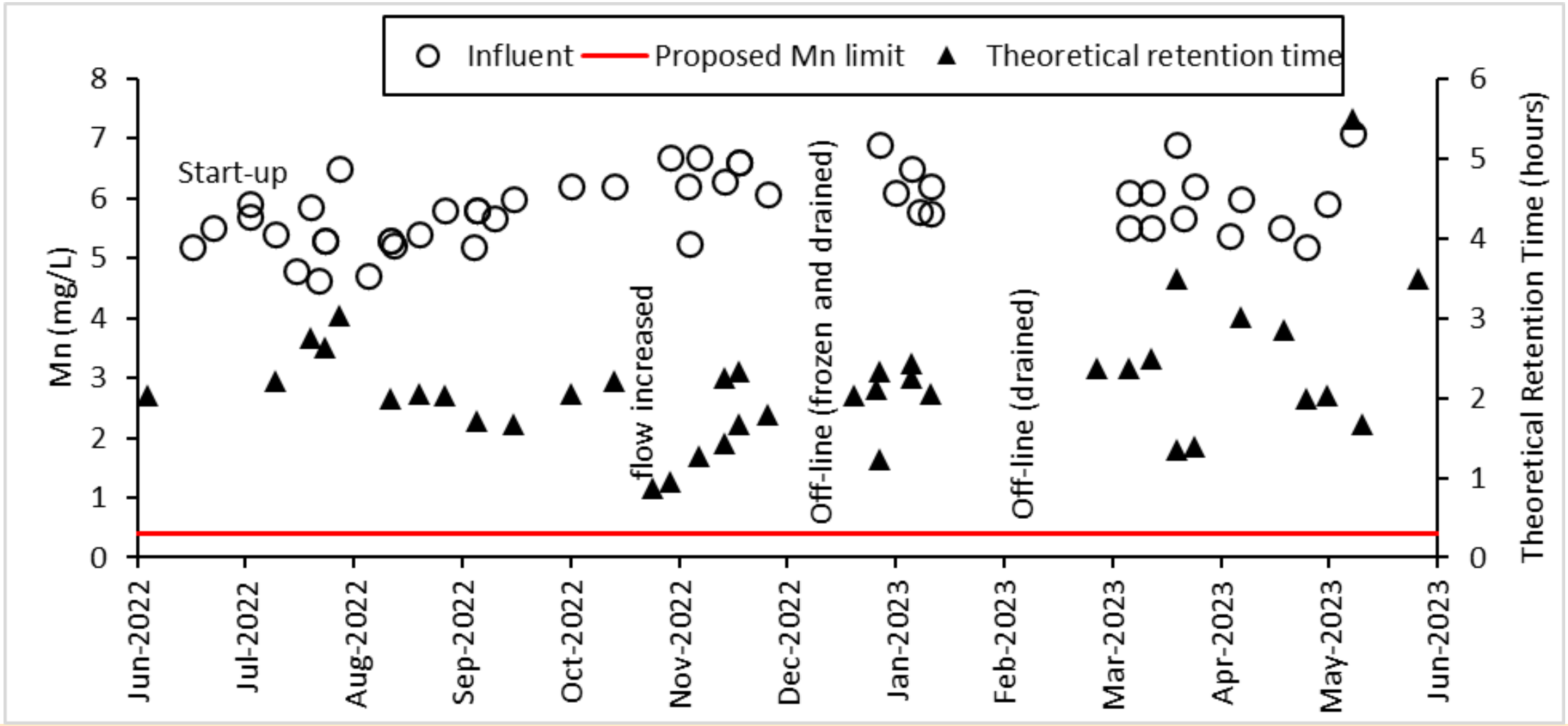
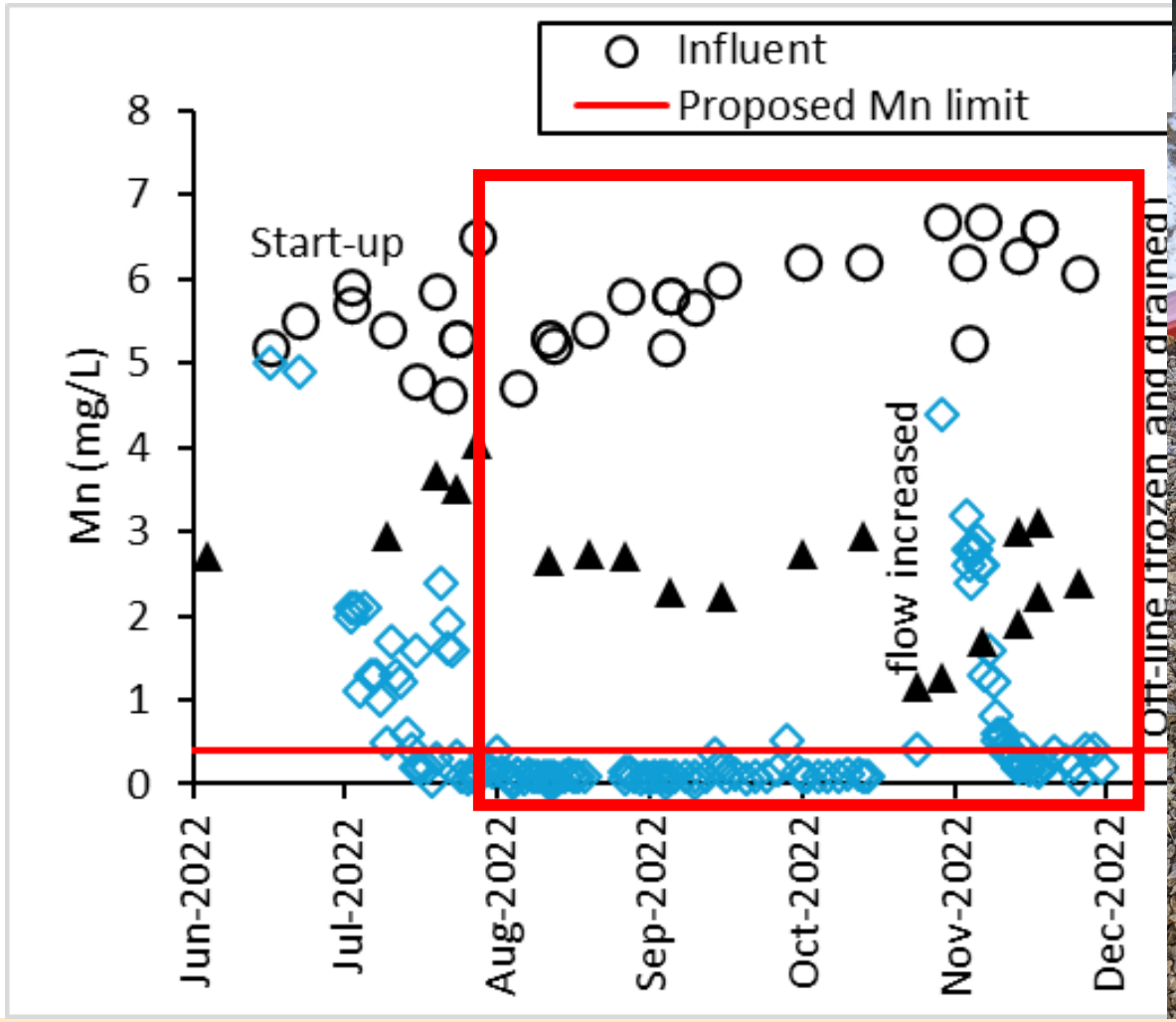


Brandy Camp unit (fresh



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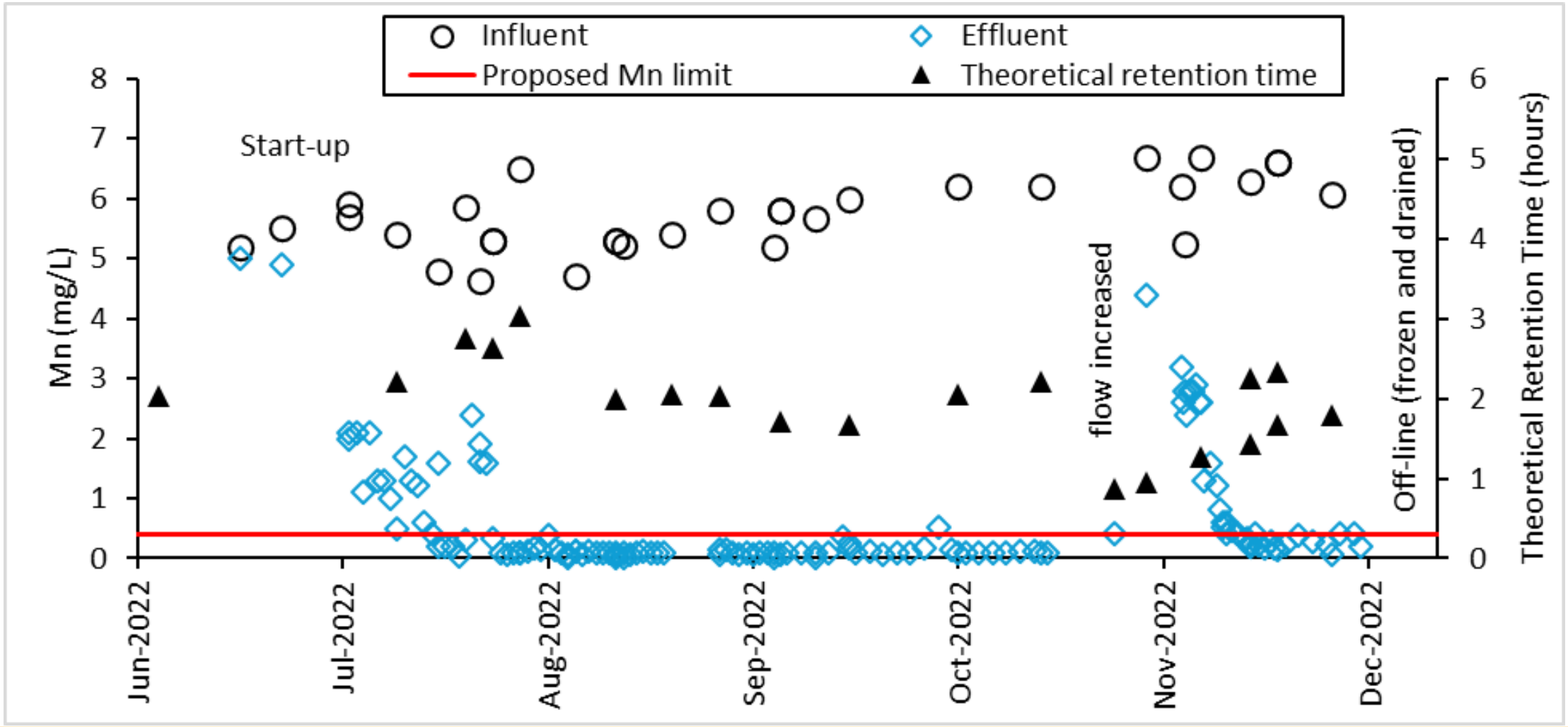

Results

Parameter	**units**	**PTSs**
Retention Time	hour	37
Mn^{in}	mg/L	20.0
Mn^{eff}	mg/L	1.7
$Mn^{eff} < 0.3$ mg/L	%	na

Results

Ripened AASHTO 3

Parameter	**units**	**PTSs**	**Hollywood**
Retention Time	hour	37	3.0 (30)
Mn^{in}	mg/L	20.0	0.6 (40)
Mn^{eff}	mg/L	1.7	0.3 (40)
$Mn^{eff} < 0.3$ mg/L	%	na	63%

Results

Ripened AASHTO 3

Fresh AASHTO 8

Parameter	**units**	**PTSs**	**Hollywood**	**Brandy Camp (all)**
Retention Time	hour	37	3.0 (30)	2.2 (40)
Mn^{in}	mg/L	20.0	0.6 (40)	5.8 (56)
Mn^{eff}	mg/L	1.7	0.3 (40)	0.5 (233)
$Mn^{eff} < 0.3$ mg/L	%	na	63%	68%

Results

Ripened AASHTO 3

Fresh AASHTO 8

Fresh AASHTO 8

Parameter	units	PTSs	Hollywood	Brandy Camp (all)	Brandy Camp (Aug-Oct)
Retention Time	hour	37	3.0 (30)	2.2 (40)	2.1 (8)
Mn^{in}	mg/L	20.0	0.6 (40)	5.8 (56)	5.7 (14)
Mn^{eff}	mg/L	1.7	0.3 (40)	0.5 (233)	0.1 (65)
$Mn^{eff} < 0.3$ mg/L	%	na	63%	68%	94%

Suspect different Mn removal processes in Hollywood vs Brandy Camp
Come talk to us during the conference to nerd out (exhibitor table)

Brandy Camp Performance

- Mn removal in Brandy Camp pilot system was faster and more complete than in full scale passive systems and the Hollywood pilot system
- Kinetics
  - Faster Mn removal kinetics with more surface area (aka smaller stone)
  - Documented by Stumm and Morgan (1981)
- Nutrients?
  - Wetland before Mn bed (aka pyrolusite bed) is beneficial
  - Vail and Riley

Passive Mn removal as an “add on”

- Aggregate beds as a final polishing step to remove Mn
- Not a new idea, but an optimized idea
- Brandy Camp example
  - 6 mg/L to 0.25 mg/L
  - 900 gpm

Site		k1	hr	Material
		hr^{-1}		tons
Traditional (kinetics)	AASHTO 3 or 5	-0.035	90	81,096
Traditional (retention time)	AASHTO 3 or 5		48	43,200

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Brandy Camp (kinetics)	AASHTO 8	-0.756	4	3,783
Brandy Camp (retention time)			3	2,700

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Brandy Camp (kinetics)	AASHTO 8	-0.756	4	3,783
Brandy Camp (retention time)			3	2,700
Rapid sand filter	Sand	-17.187	0.2	166

Operation and Maintenance (O&M)

- Traditional Mn bed O&M = stone cleaning ~ every five years

- Optimized Mn bed O&M = stone stirring ~ every 3 months?
  - Brandy camp box required minor O&M to break up Fe on top of stone but no stirring or cleaning of stone over 12 months

- Rapid sand filter = backflushing ~ weekly
  - When hydraulic conductivity falls below critical threshold

Summary

- Lower Mn effluent regulations are
- Conventional passive treatment sy
  to <0.3 mg/L
- Our pilot scale units show that pas
  fast Mn removal (<<< 48 hours) to

Future

- Optimized passive Mn removal should be considered a tool in the toolbox of Mn compliance
- We can bring our pilot scale system to you for testing

Acknowledgements

- Western Pennsylvania Conservancy funded this work (PA Growing Greener Grant)
- PADEP BAMR for technical input
- USDOI OSMRE for technical input
- USGS for technical input

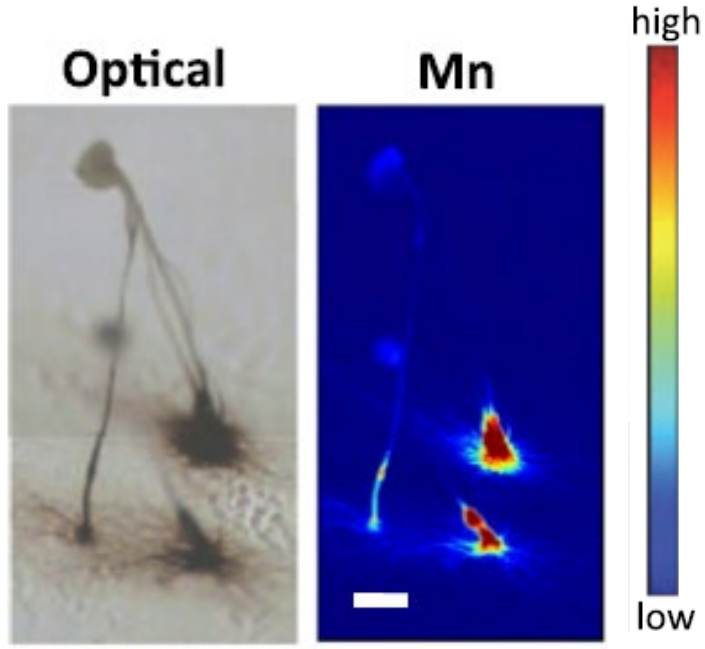
Contact

HedinEnvironmental

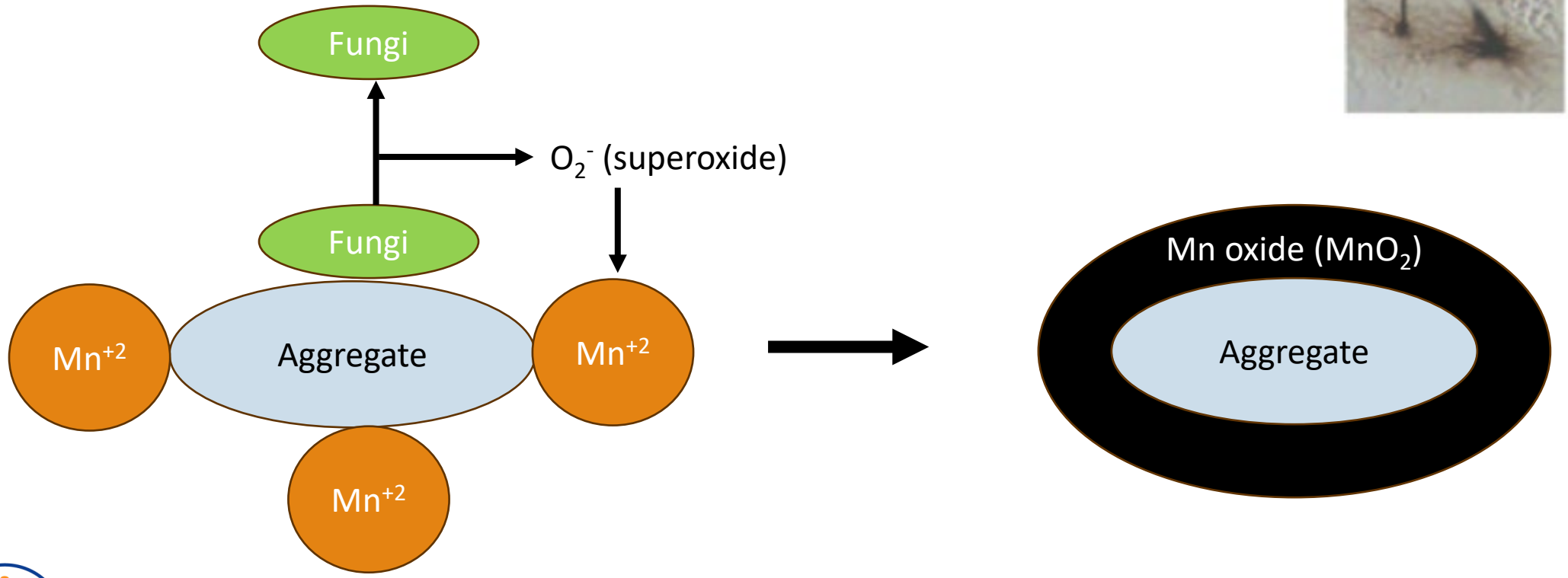
- Ben.hedin@hedinenv.com
- Exhibitor booth

Questions?

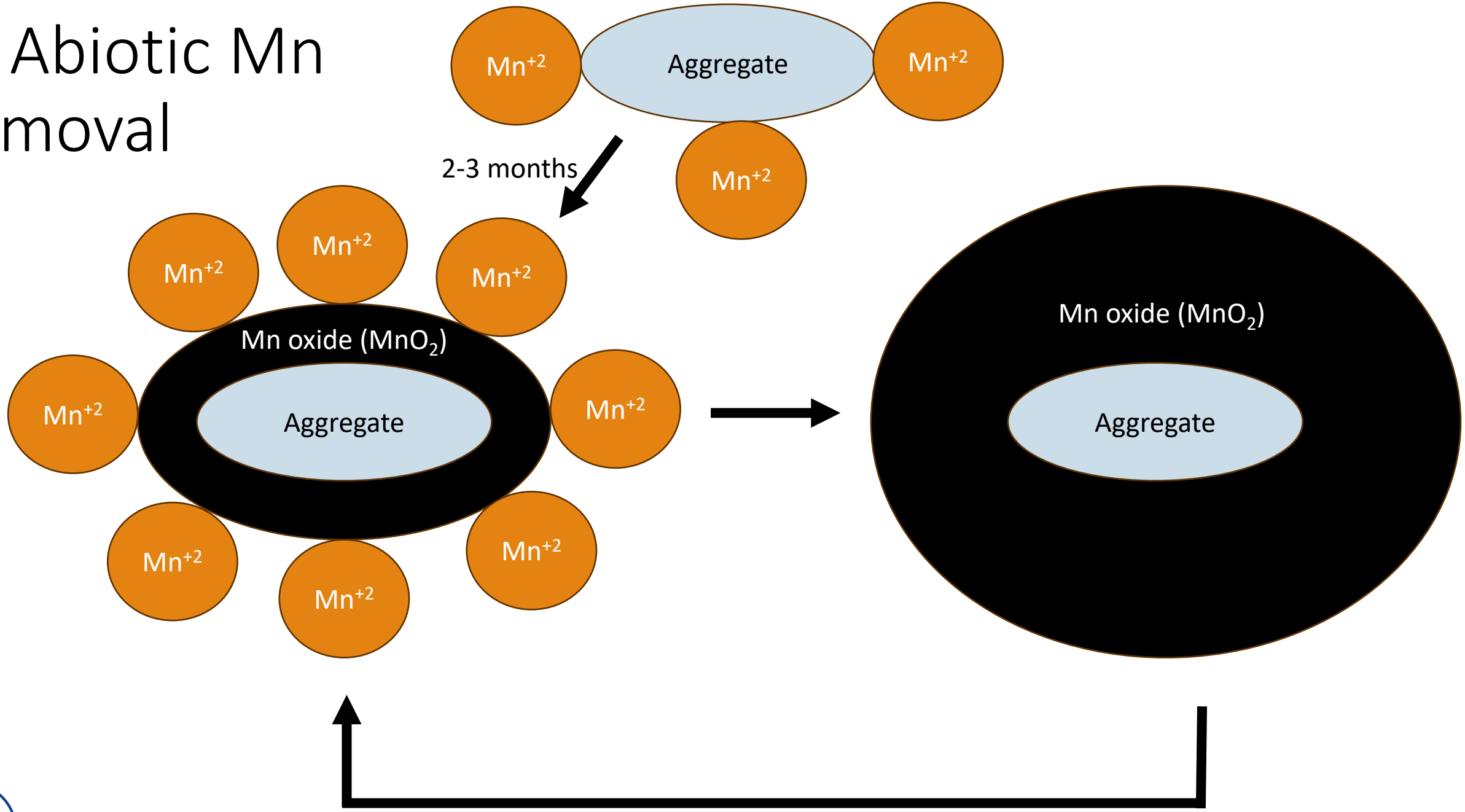
1. Biotic Mn removal

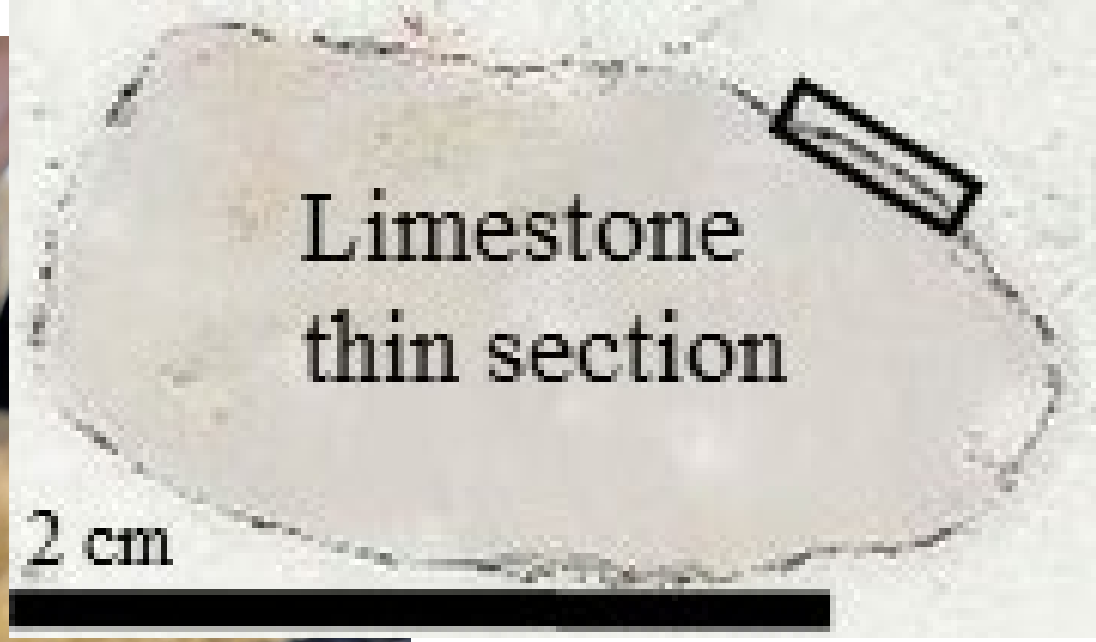


Hansel et al. 2012



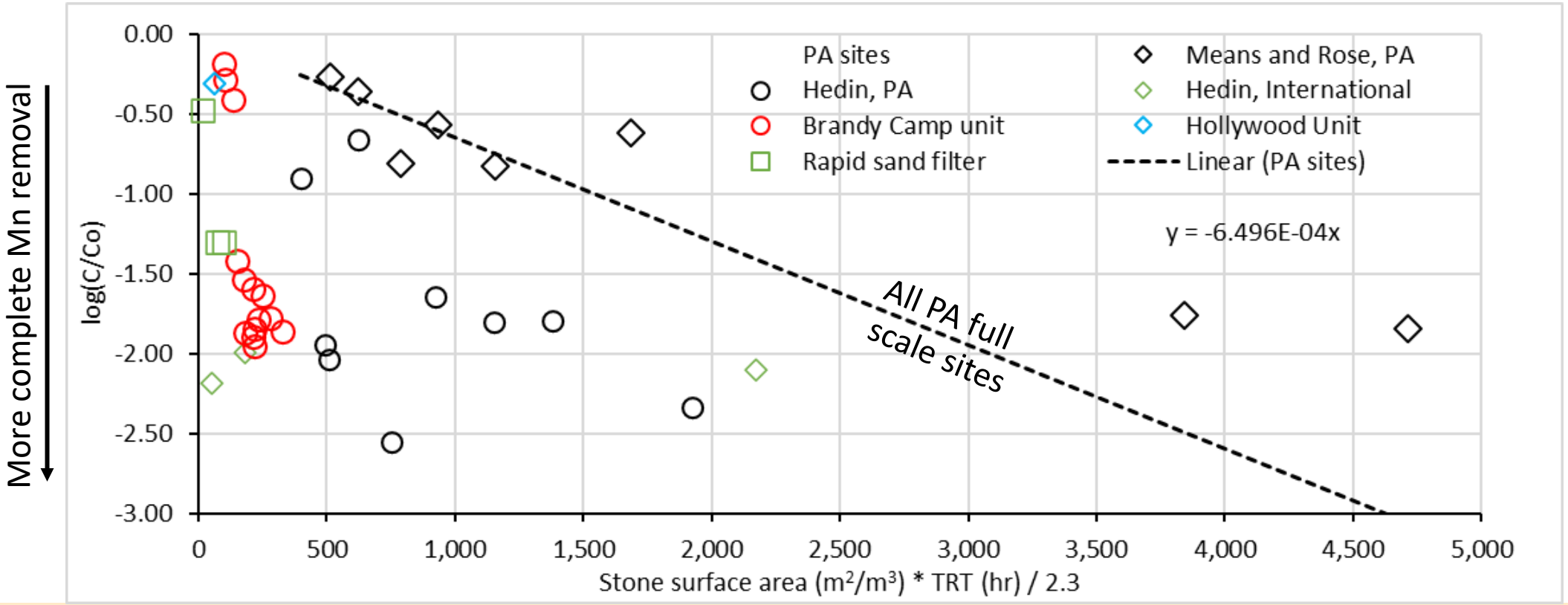
2. Abiotic Mn removal




Limestone
thin section
2 cm

Kinetics

- Faster Mn removal kinetics with more surface area (aka smaller stone)
  - Documented by Stumm and Morgan (1981)
- Wetland before Mn bed (aka pyrolusite bed) is beneficial
  - Vail and Riley



Outline

- Mn is common constituent of polluted mine drainage
- Mn removal methods
  - Active and passive
- Why are we talking about Mn?
  - PADEP's proposed Mn instream limits
  - International Mn limits
  - Mining industry concerns on Mn removal. Cost effective removal is challenging. Passive Mn removal not considered realistic for large flows.
- Passive Mn removal
  - Mn removal in DLBs
  - Mn removal in Mn beds
  - Mechanism of Mn removal. Important variables to Mn removal.
- Documented Mn removal in full scale passive systems
  - In and out chemistry
  - Kinetics of Mn removal
- Pilot scale systems setup
  - Hollywood setup
  - Brandy Camp setup
- Pilot scale systems results
  - Hollywood results. Removal mechanism. Kinetics.
  - Brandy Camp results. Removal mechanism. Kinetics.
- Conclusions
  - Passive Mn removal can be optimized
  - Passive Mn removal can be added onto existing systems