Metal Mass Retention in Passive Treatment Systems at the Tar Creek Superfund Site

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CREW Director

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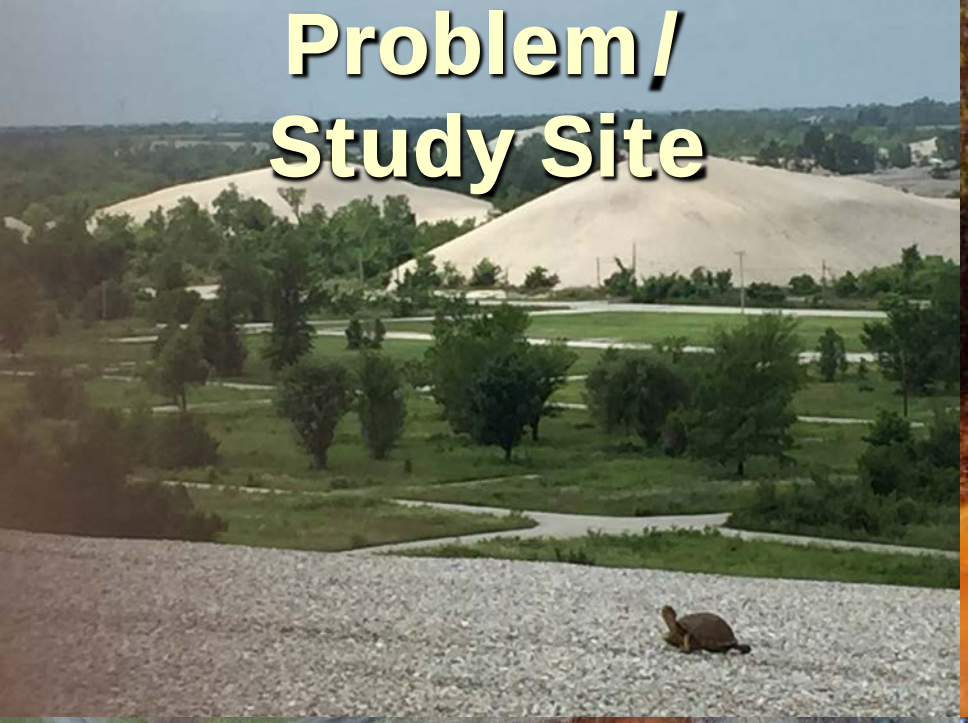
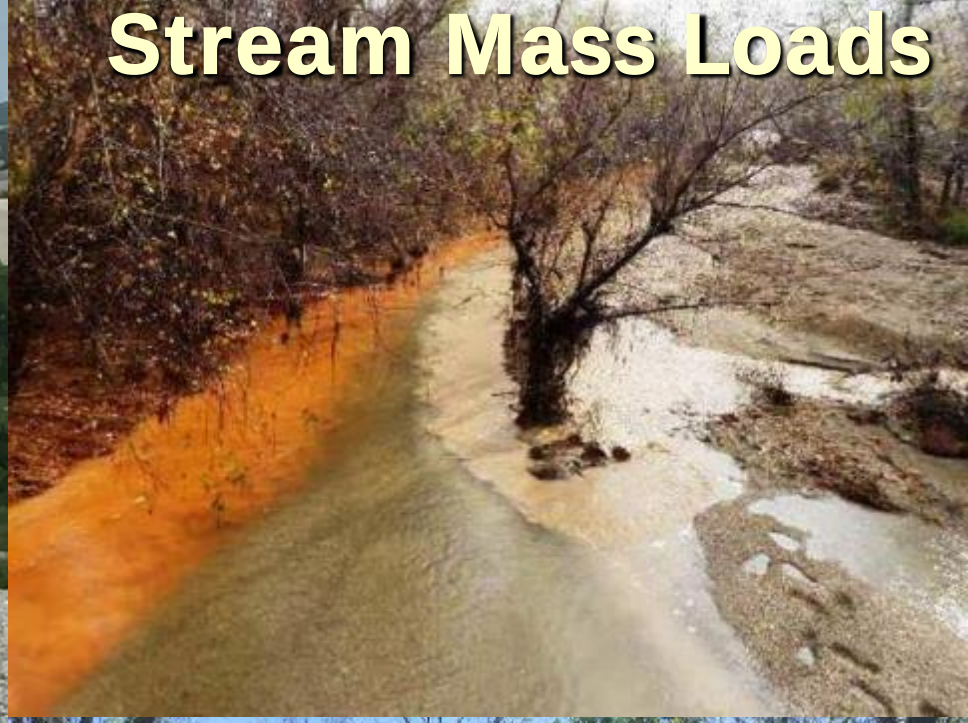
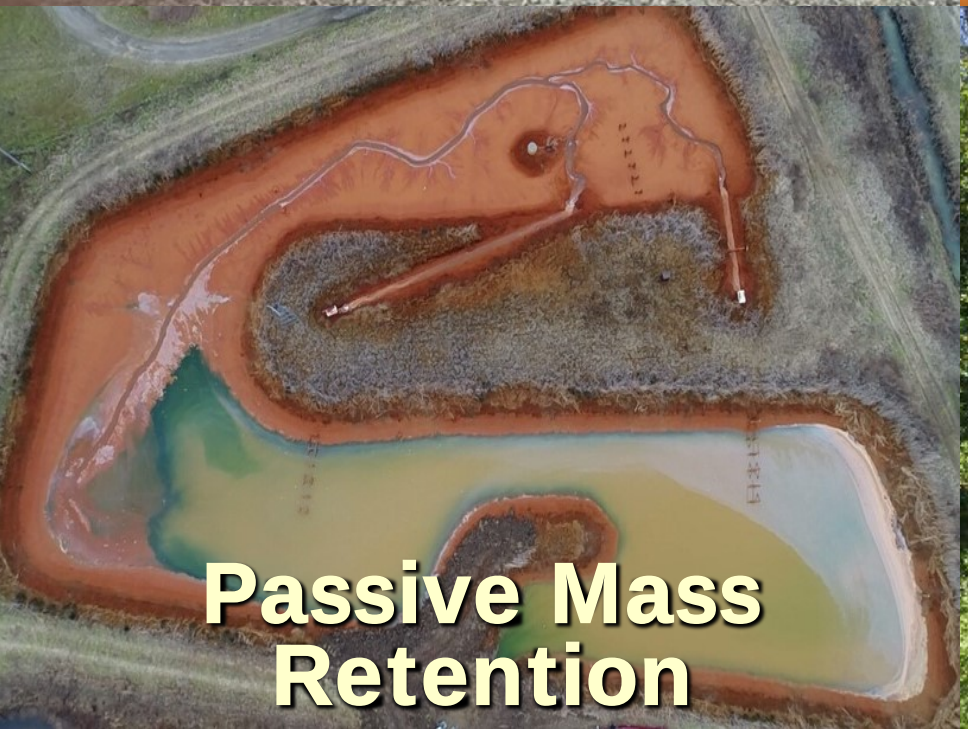
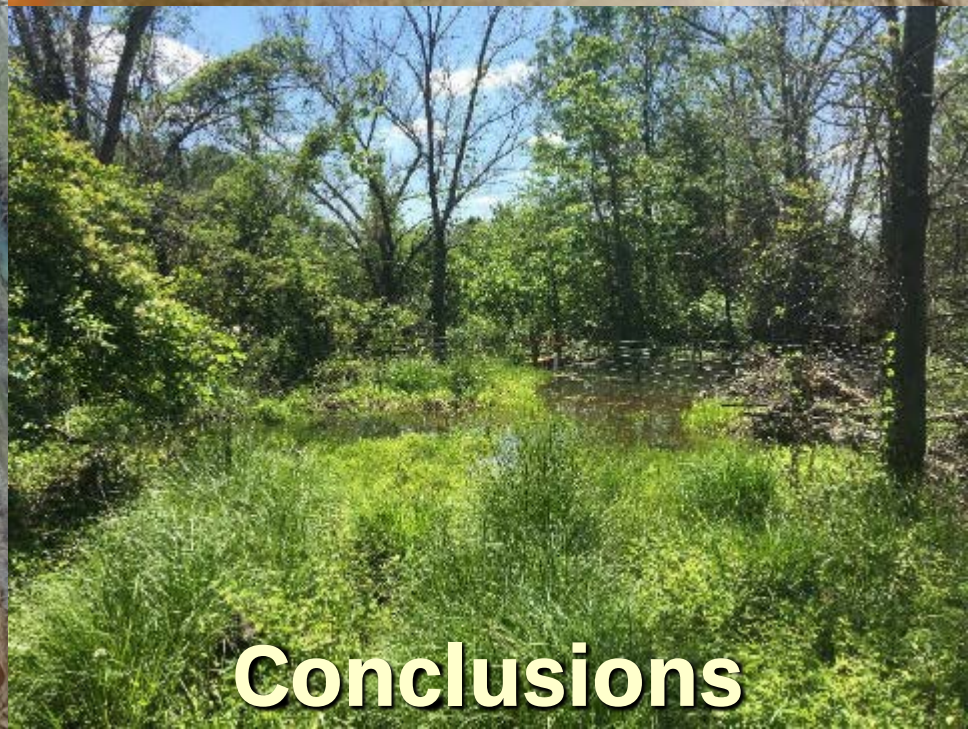
Gallogly College of Engineering
School of Civil Engineering and Environmental Science

CREW
Center for Restoration of Ecosystems and Watersheds
University of Oklahoma

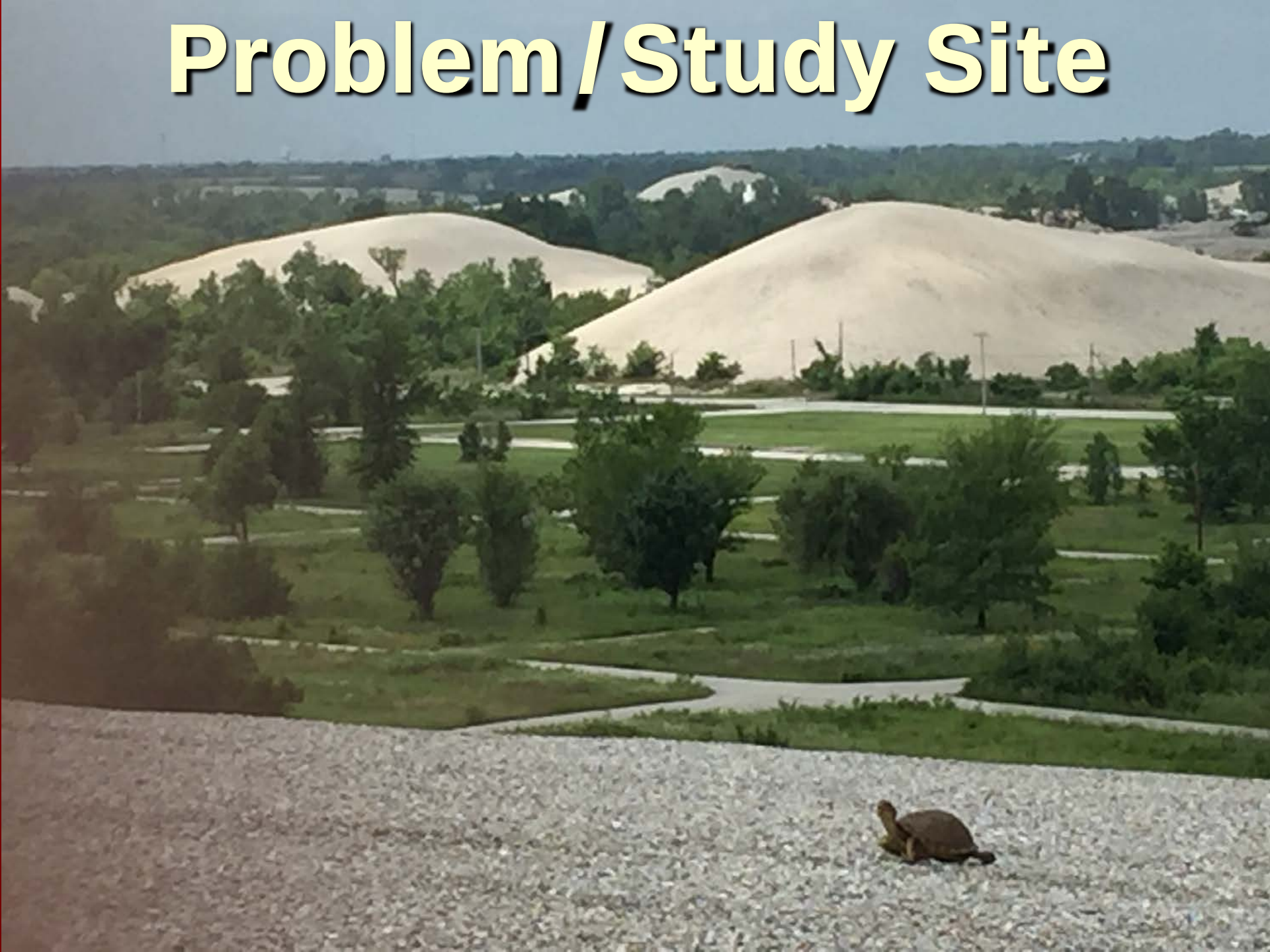

Problem /
Study Site


Stream Mass Loads


Passive Mass
Retention

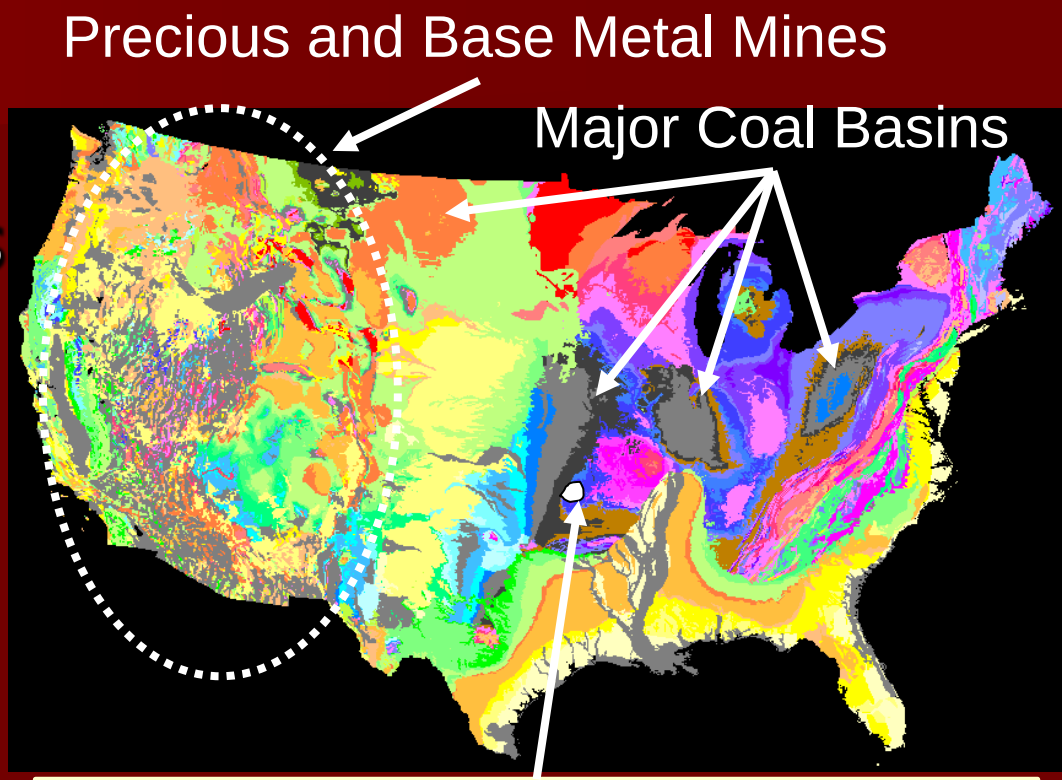

Conclusions

Problem/Study Site



Tri-State Lead-Zinc Mining District

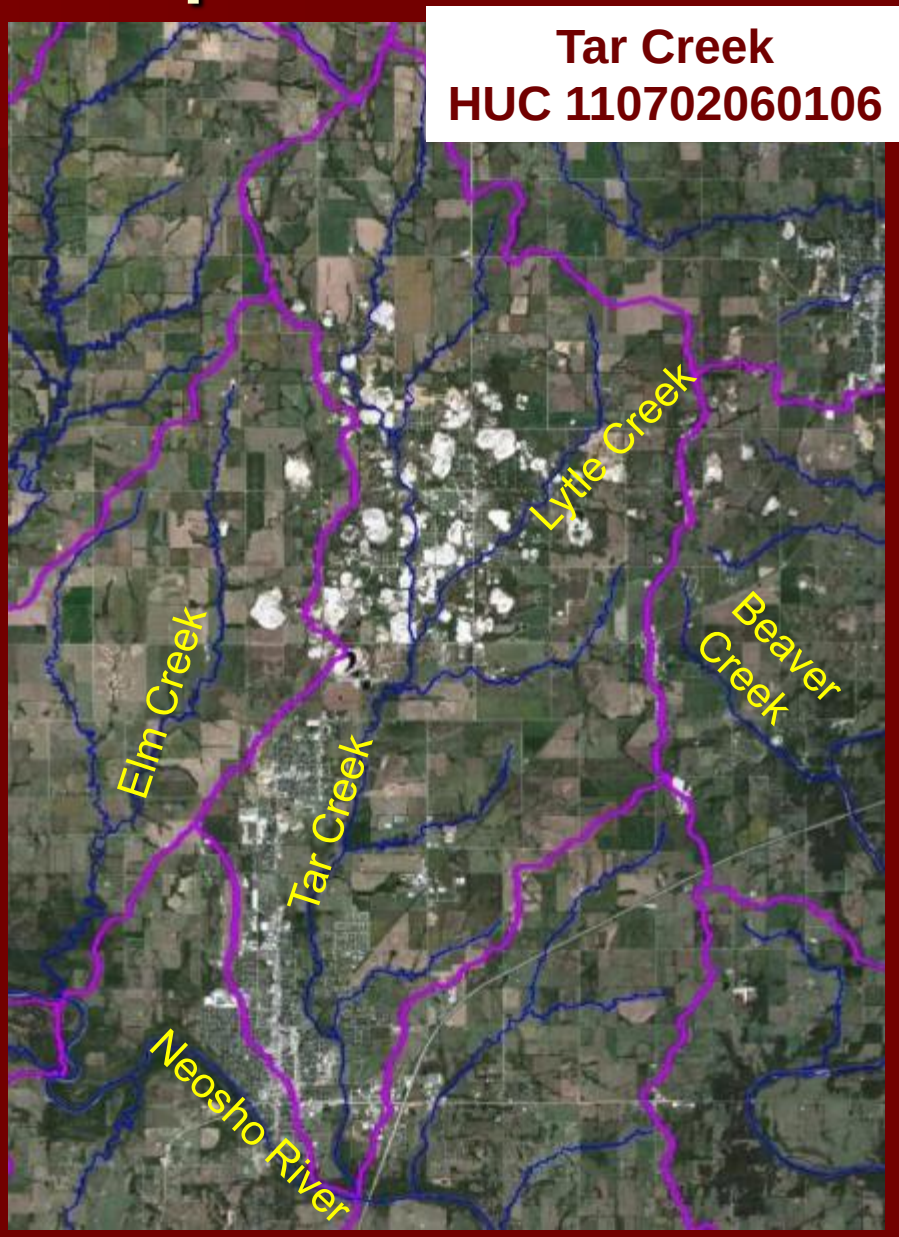
- >3000 km^2 mined ~1838-1971
- Mississippian sulfides
  - Galena (PbS)
  - Sphalerite (ZnS)
- Extensive underground workings
- Massive surface processing operations



Tri-State Lead-Zinc Mining District
- Joplin Field, Missouri
- Galena Field, Kansas
- Picher Field, Oklahoma

Tar Creek (OK) Superfund Site

- National Priorities List (1983)
- 137 km^2 watershed
- Elevated Fe, Zn, Cd, Pb, As in water, soils, wastes, and biota
- Ten Native American Tribes
- Mining “mega-site”



$95x10^6$ m^3 polluted mine pool
Several dozen artesian upwellings


24x10⁶ m³ “chat” waste material
Pervasive runoff/leachate pollution


Stream Mass Loads

The CREW Dataset

- 10 small watersheds from 2004-2018 (some since 1997)
- 75 surface water, groundwater, mine pool, artesian discharge, leachate and passive treatment locations
  - Full suite of physical parameters
  - Total and dissolved metals
  - Major anions
  - Volumetric discharge rate via ADV, USGS pygmy meter, weirs with pressure transducers, bucket and stopwatch
- Sampled monthly or quarterly for ~ 15 years

Mass Loading/ Mass Retention

- Median values presented

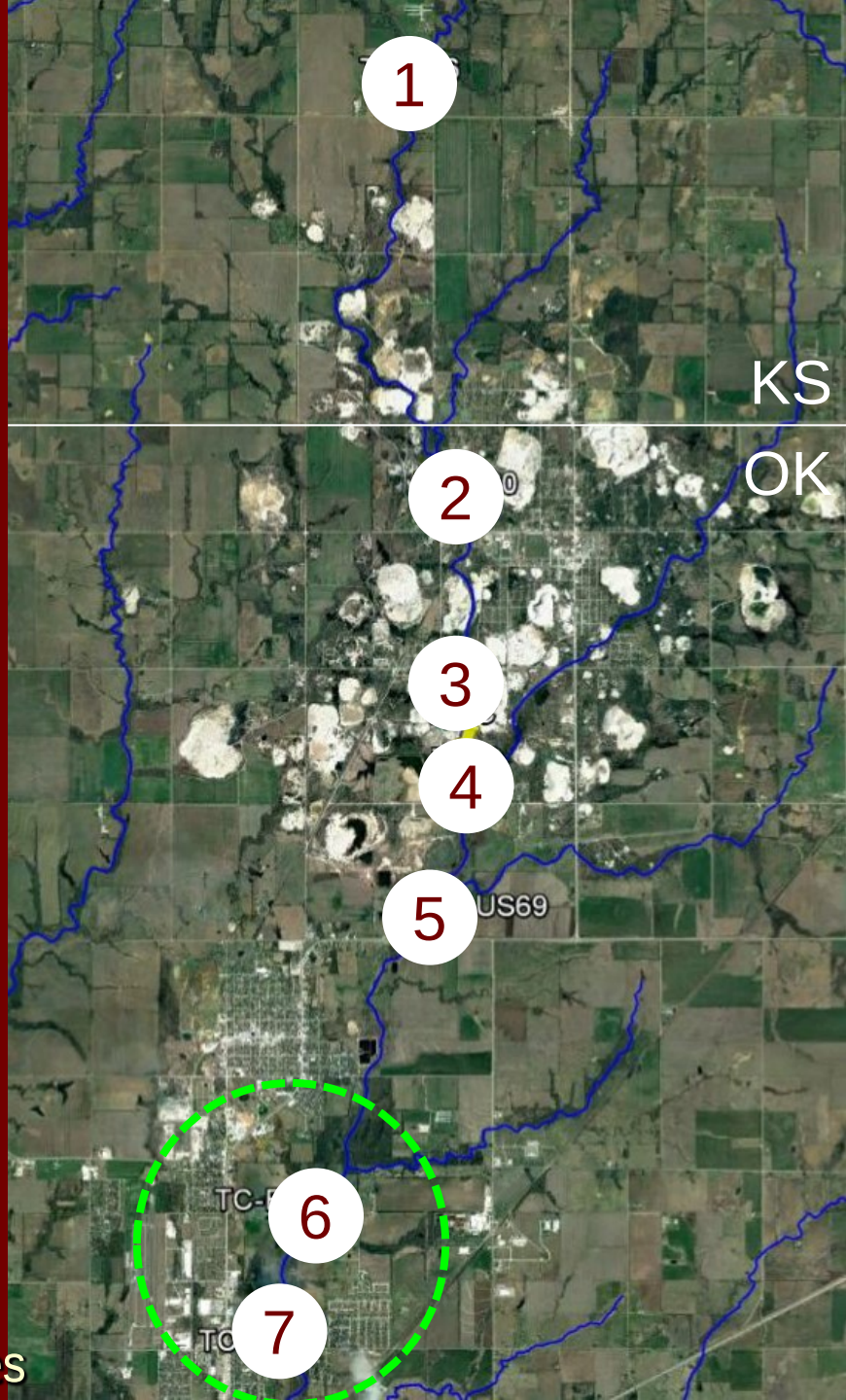
ML_{Zn} (kg/day) =

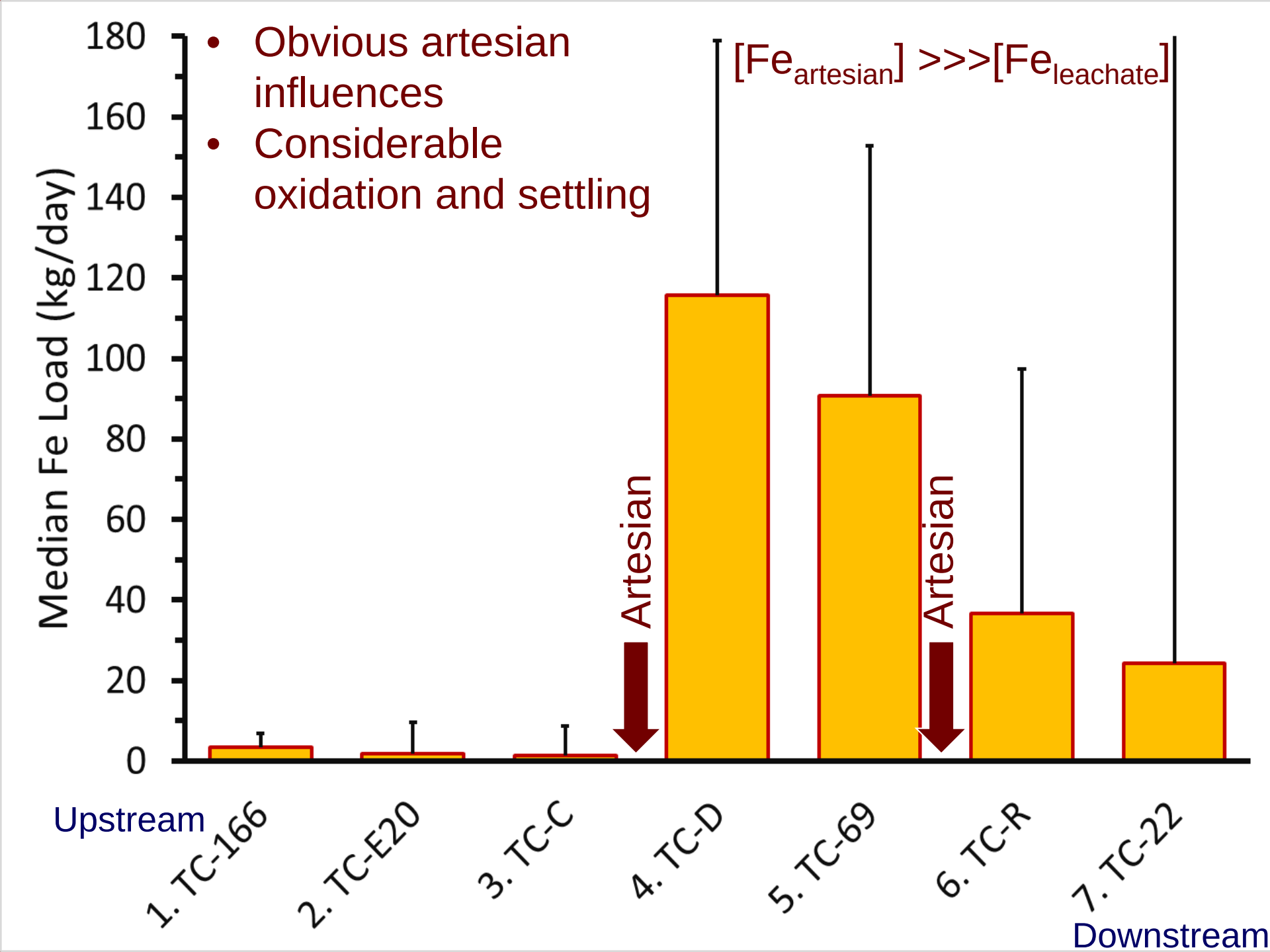
Q (L/min) x [Zn] (mg/L)
x unit conversions

- $Retention_{PTS} = ML_{in} - ML_{out}$

Tar Creek (main stem) locations

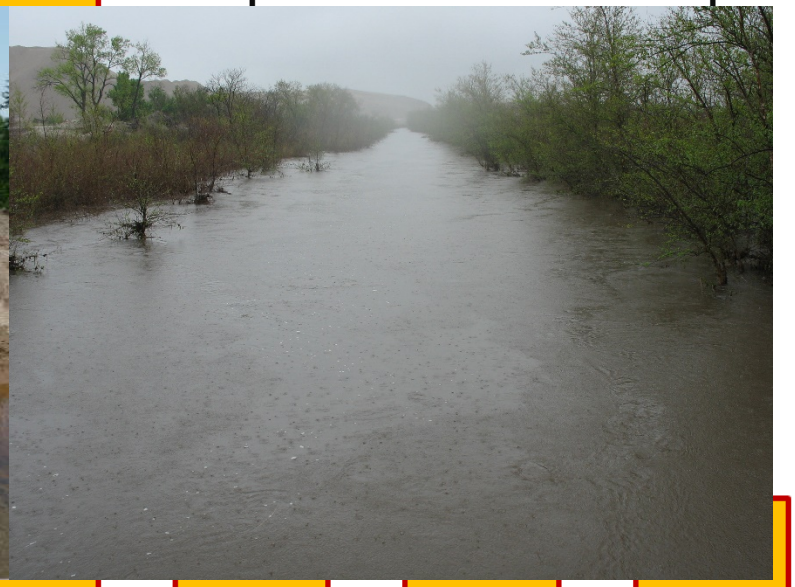
1. TC-166
   - Upstream of mining influence
2. TC-E20
   - Chat influence
3. TC-C
   - Major chat influence
4. TC-D
   - Major chat influence
   - Substantial artesian upwellings
5. TC-69
   - Downstream major impacts
6. TC-R
   - Substantial artesian upwellings
   - Minor chat influence
7. TC-22
   - Downstream of all mining influences




Obvious artesian influences
Considerable oxidation and settling
[Fe artesian] >>>[Fe leachate]
Median Fe Load (kg/day)
180
160
140
120
100
80
60
40
20
0
Artesian
Artesian
Upstream
1. TC-166
2. TC-E20
3. TC-C
4. TC-D
5. TC-69
6. TC-R
7. TC-22
Downstream

- Obvious artesian influences
- Considerable oxidation and settling

- Obvious artesian influences
- Considerable oxidation and settling
- Substantial dilution effects



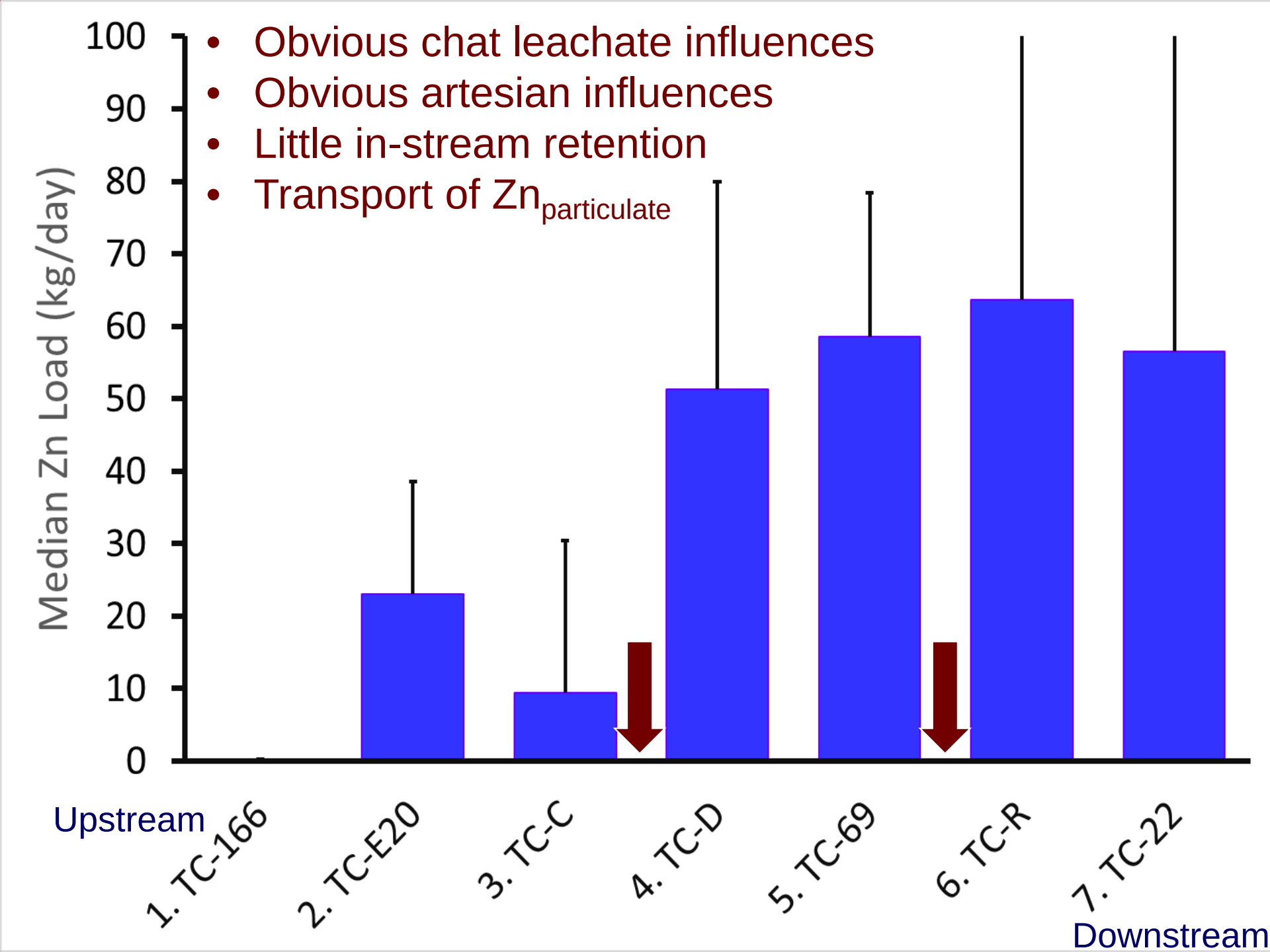
Median Fe Load (kg/day)

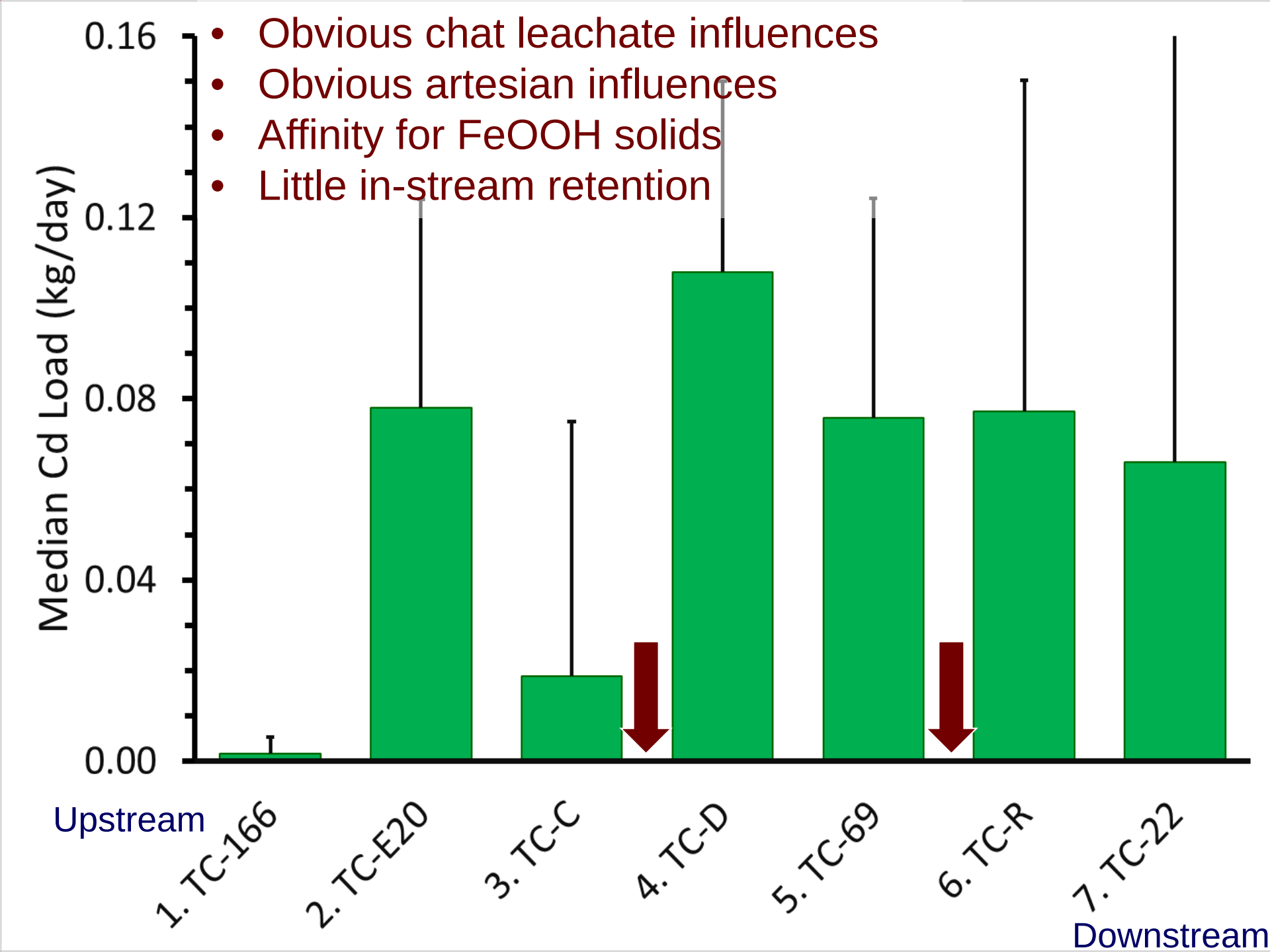
180
160
140
120
100
80
60
40
20
0

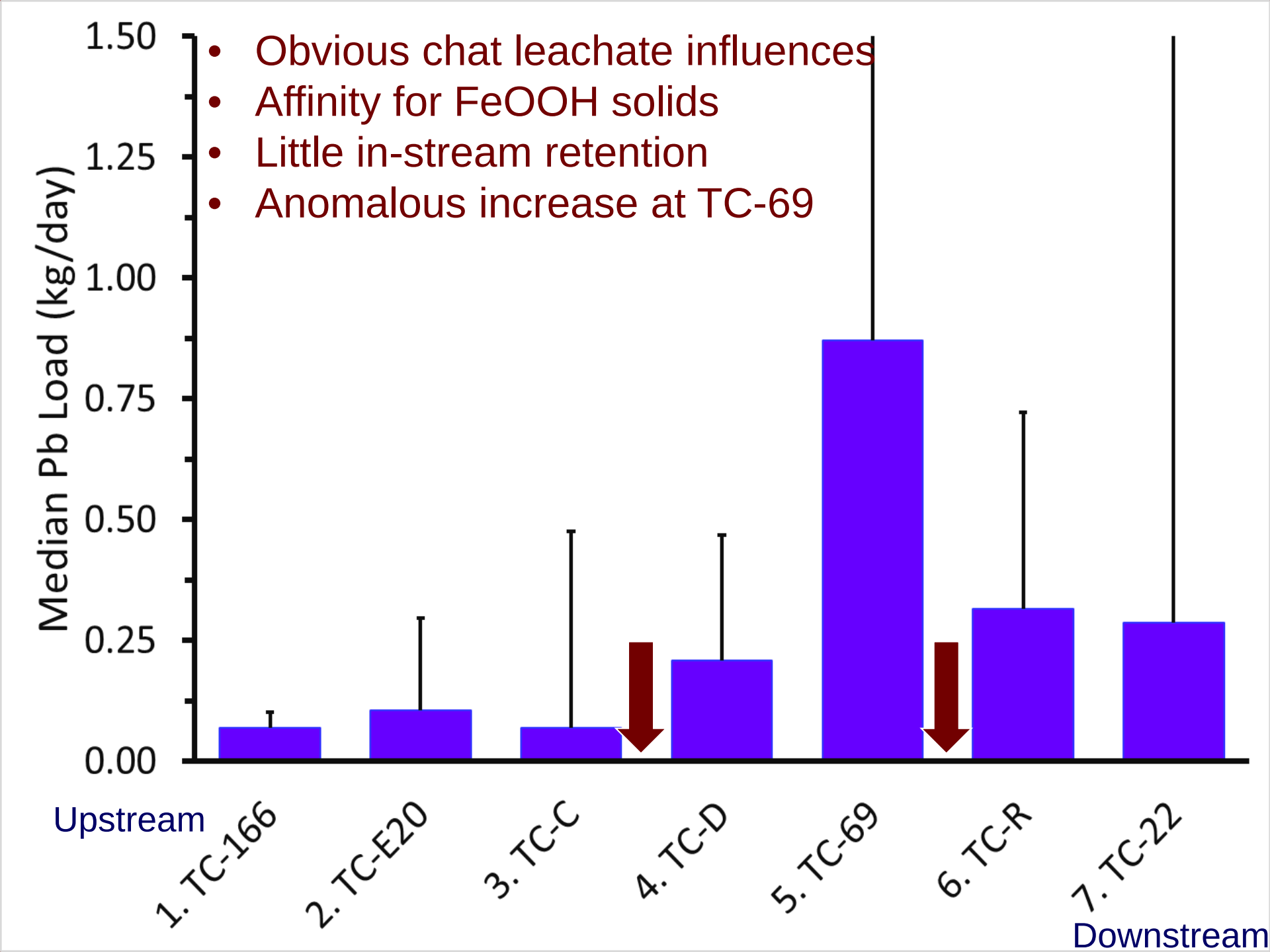
Upstream

1. TC-166
2. TC-E20
3. TC-C
4. TC-D
5. TC-69
6. TC-R
7. TC-22

Downstream


Obvious chat leachate influences
Obvious artesian influences
Little in-stream retention
Transport of Zn particulate
Median Zn Load (kg/day)
100
90
80
70
60
50
40
30
20
10
0
Upstream
1. TC-166
2. TC-E20
3. TC-C
4. TC-D
5. TC-69
6. TC-R
7. TC-22
Downstream

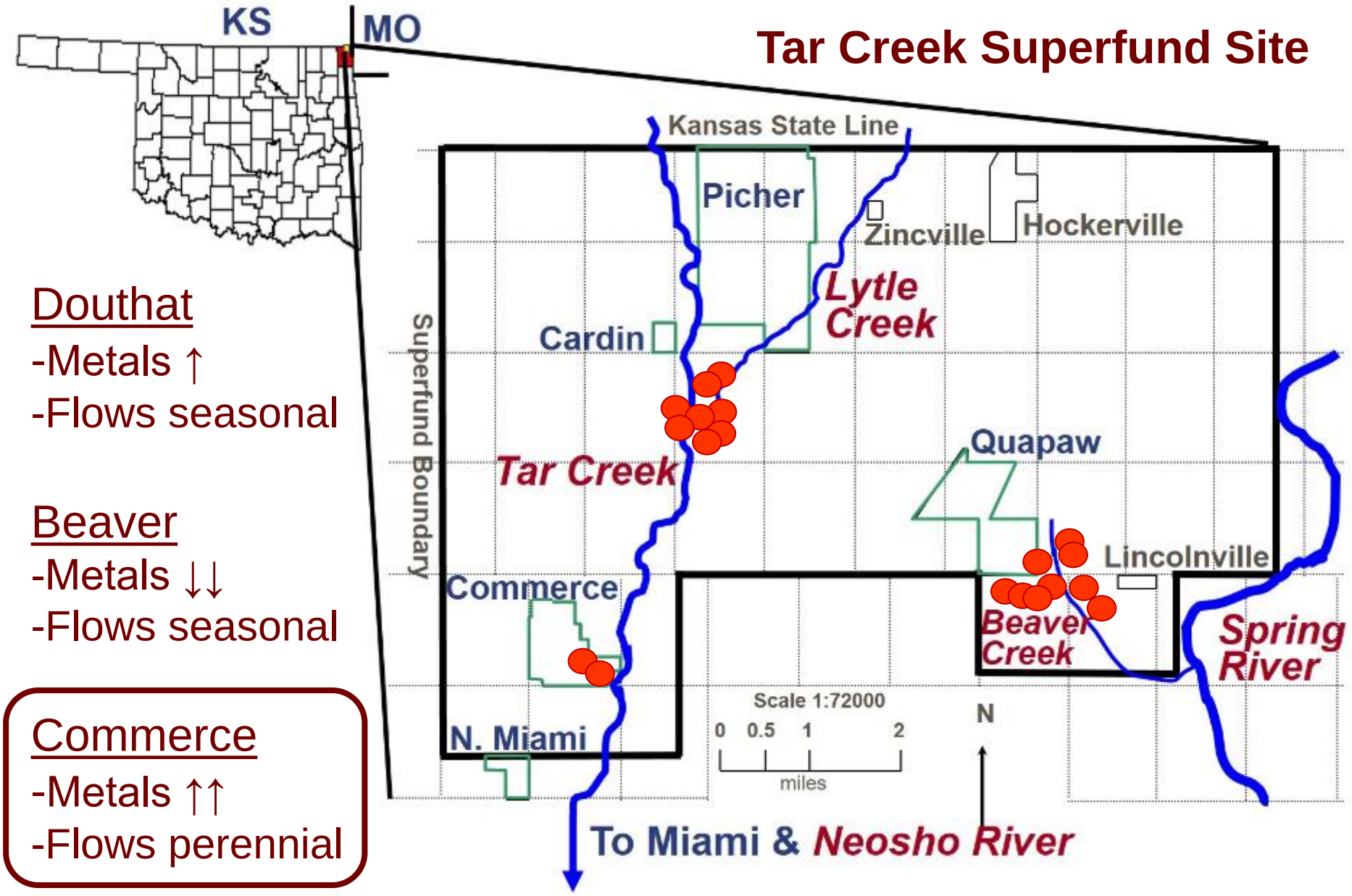

Obvious chat leachate influences
Obvious artesian influences
Affinity for FeOOH solids
Little in-stream retention
Median Cd Load (kg/day)
0.16
0.12
0.08
0.04
0.00
Upstream
1. TC-166
2. TC-E20
3. TC-C
4. TC-D
5. TC-69
6. TC-R
7. TC-22
Downstream


Obvious chat leachate influences
Affinity for FeOOH solids
Little in-stream retention
Anomalous increase at TC-69
Median Pb Load (kg/day)
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Upstream
1. TC-166
2. TC-E20
3. TC-C
4. TC-D
5. TC-69
6. TC-R
7. TC-22
Downstream


Galena Field
Picher Field
Joplin Field
Far-reaching, downstream contamination
Tar Creek
Neosho River
Spring River
Grand Lake o' the Cherokees
6 mi

Passive Mass Retention

Artesian Mine Water Discharges

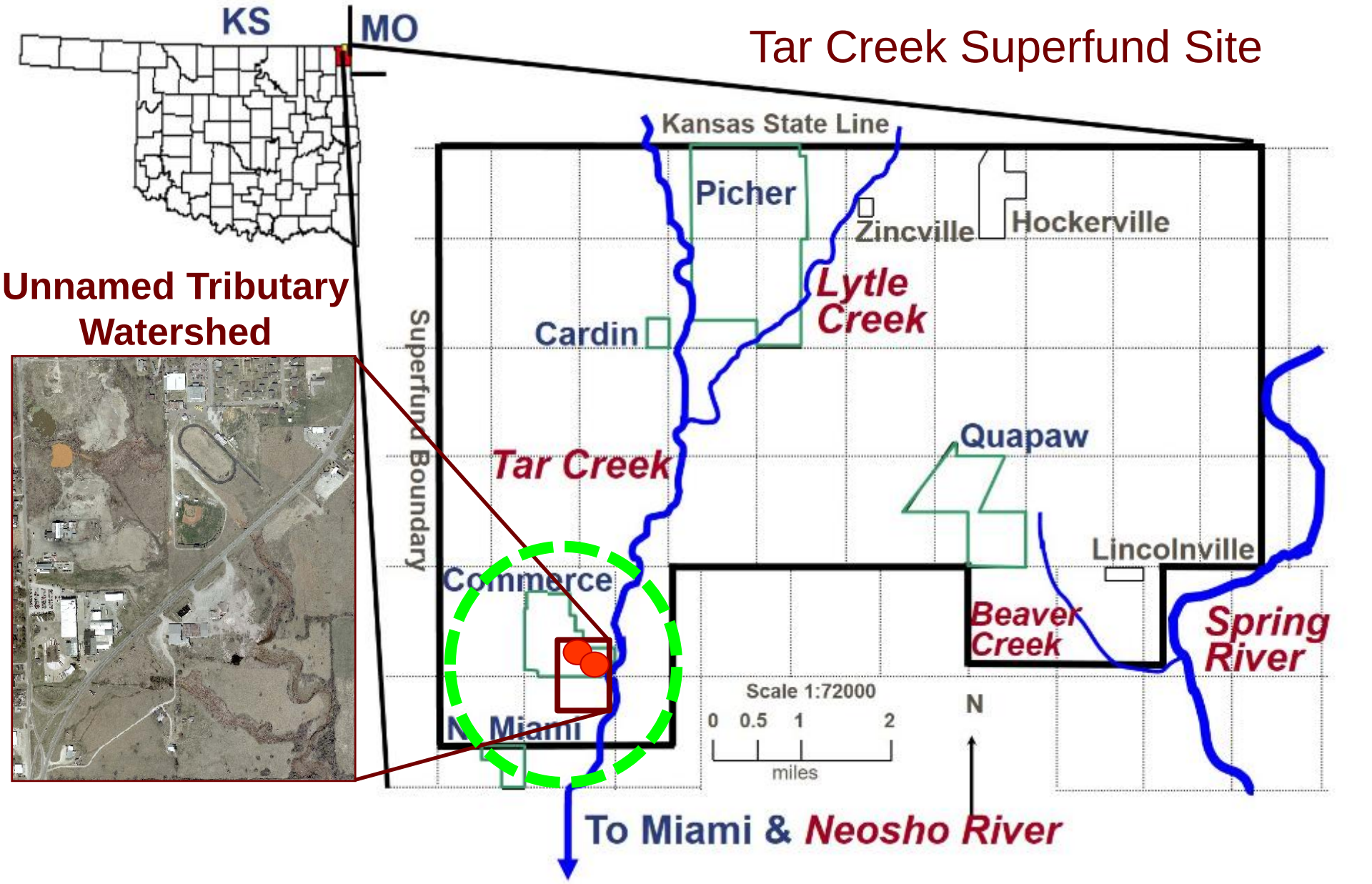


Douthat
-Metals ↑
-Flows seasonal

Beaver
-Metals ↓↓
-Flows seasonal

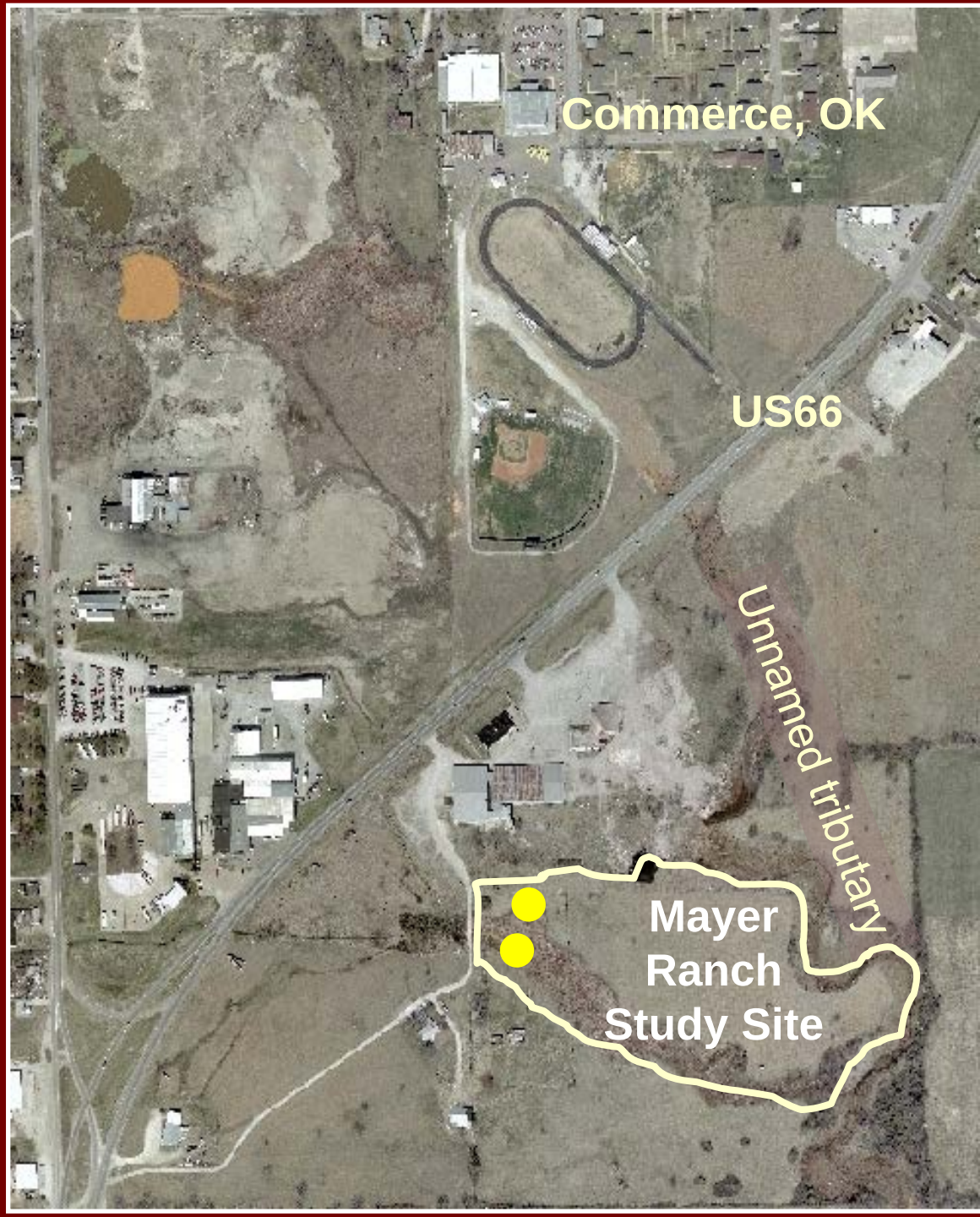
Commerce
-Metals ↑↑
-Flows perennial

Artesian Mine Water Discharges



Mayer Ranch

- Artesian discharges
  - Abandoned boreholes
- 110 – 250 gpm
- Elevated Fe, Zn, Pb, Cd, As
- Represent ~20% contaminant mass load in watershed

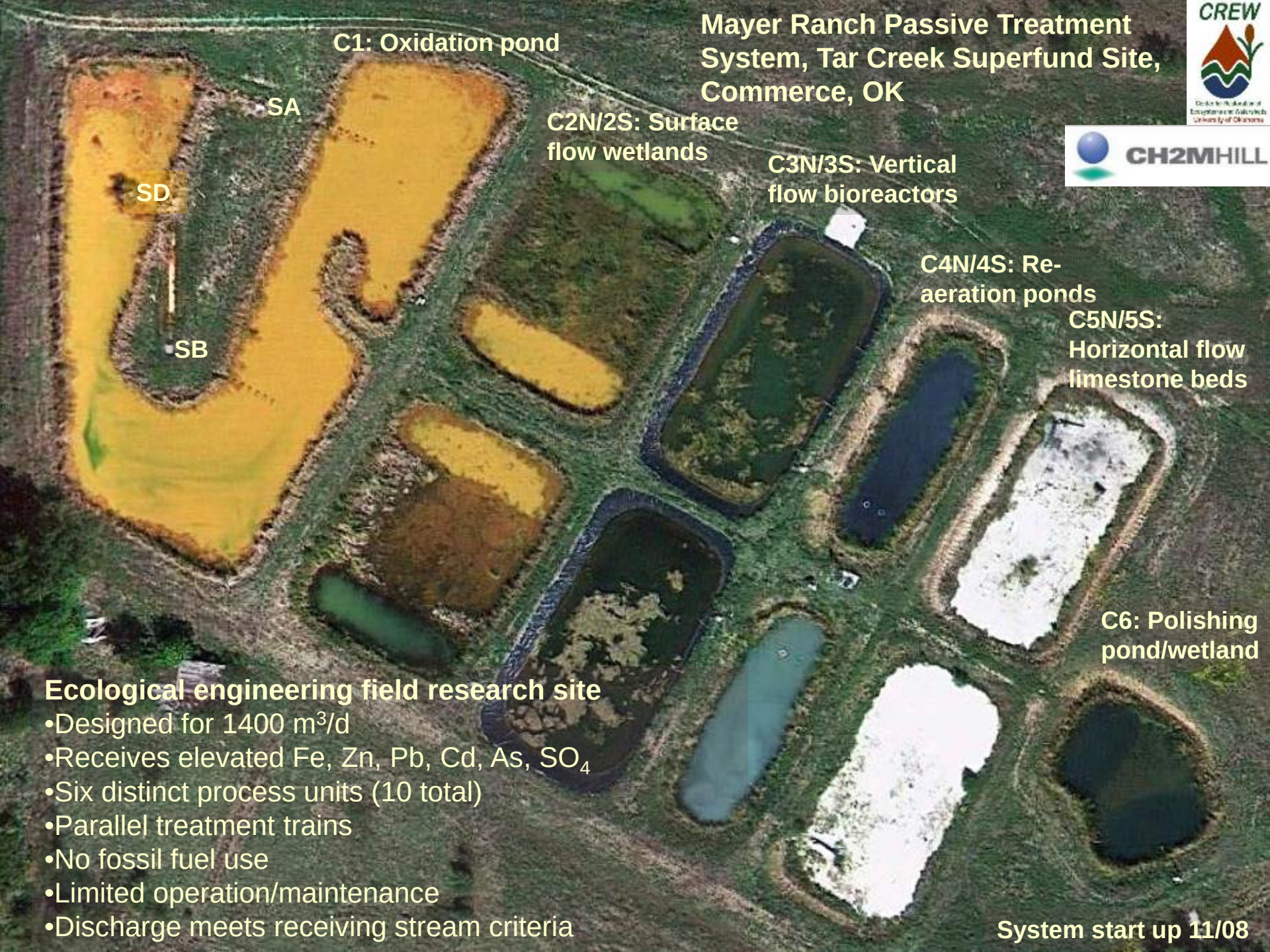


Mayer Ranch Water Quality

pH	5.95 ± 0.06
Alk. (net)	393 ±18 (29) mg/L
Fe	192 ± 3 mg/L
Zn	11 ± 0.07 mg/L
Ni	0.97 ± 0.02 mg/L
Cd	17 ± 4 μg/L
Pb	60 ± 13 μg/L
As	64 ± 2 μg/L
SO_4^{-2}	2239 ± 26 mg/L

Mayer Ranch Passive Treatment System

- USEPA funding 2004-10
- 10 process units
  - 8 in parallel trains
  - Coupled oxidative-reductive mechanisms
  - Solar- and wind-powered re-aeration
- First PTS in entire Tri-State Mining District
- Continuous operation since 11/2008
- Long-term CREW ecological engineering research site


Mayer Ranch Passive Treatment System, Tar Creek Superfund Site, Commerce, OK
CREW
CH2MHILL
C1: Oxidation pond
SA
SD
SB
C2N/2S: Surface flow wetlands
C3N/3S: Vertical flow bioreactors
C4N/4S: Re-aeration ponds
C5N/5S: Horizontal flow limestone beds
C6: Polishing pond/wetland
Ecological engineering field research site
•Designed for 1400 m3/d
•Receives elevated Fe, Zn, Pb, Cd, As, SO4
•Six distinct process units (10 total)
•Parallel treatment trains
•No fossil fuel use
•Limited operation/maintenance
•Discharge meets receiving stream criteria
System start up 11/08

SE Commerce

- Surface reclaimed
- Artesian discharges from collapse feature
- Captured in subsurface drain
- 100 gpm
- Represent ~10 % mass load

SE Commerce

- Surface reclaimed
- Artesian discharges from collapse feature
- Captured in subsurface drain
- 100 gpm
- Represent ~10 % mass load

Southeast Commerce Water Quality

pH	5.47 ± 0.05
Alk.	311 ± 5 mg/L
Fe	138 ± 0.8 mg/L
Zn	11 ± 0.04 mg/L
Ni	0.59 ± 0.01 mg/L
Cd	37 ± 1.5 μg/L
Pb	62 ± 1.8 μg/L
As	40 ± 1 μg/L
SO_4^{-2}	2040 ± 63 mg/L

Southeast Commerce Passive Treatment System

- Oklahoma DEQ funding 2015-present
- 4 process units
  - Three units share common water surface
  - Directional baffle curtains and z-piling
  - Innovative solar-powered air-lift aerators
  - Multiple effluent structure VFBR
  - Unique activated carbon sulfide-capture system
- Second PTS in Tri-State Mining District
- Continuous operation since 02/2017

Ecological engineering field research site

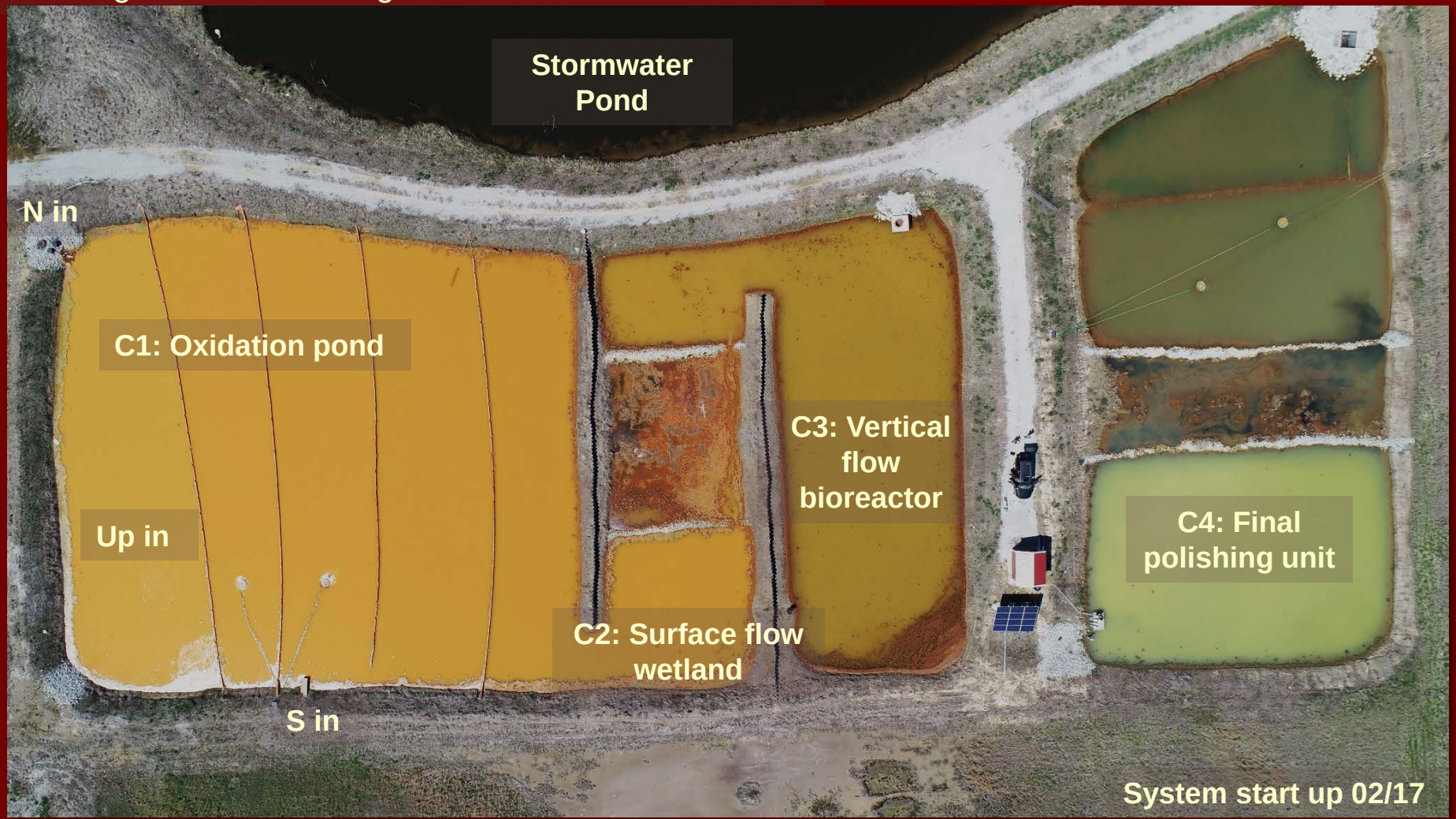
- Designed for 550 m^3/d
- Receives elevated Fe, Zn, Pb, Cd, As, SO_4
- Four total process units
- Shared water surfaces/baffles/z-piling
- Solar-powered aeration/reaeration
- Limited operation/maintenance
- Discharge meets receiving stream criteria

Southeast Commerce Passive Treatment System, Tar Creek Superfund Site, Commerce, OK

CREW

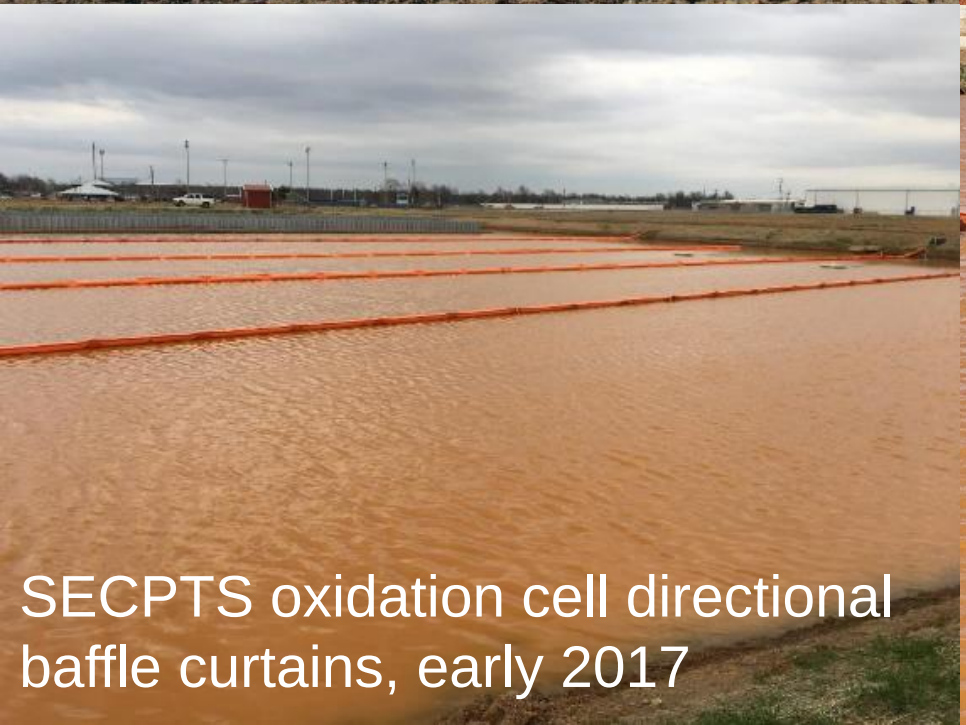
BioMost, Inc.
Mining & Reclamation Services

Riverman Engineering



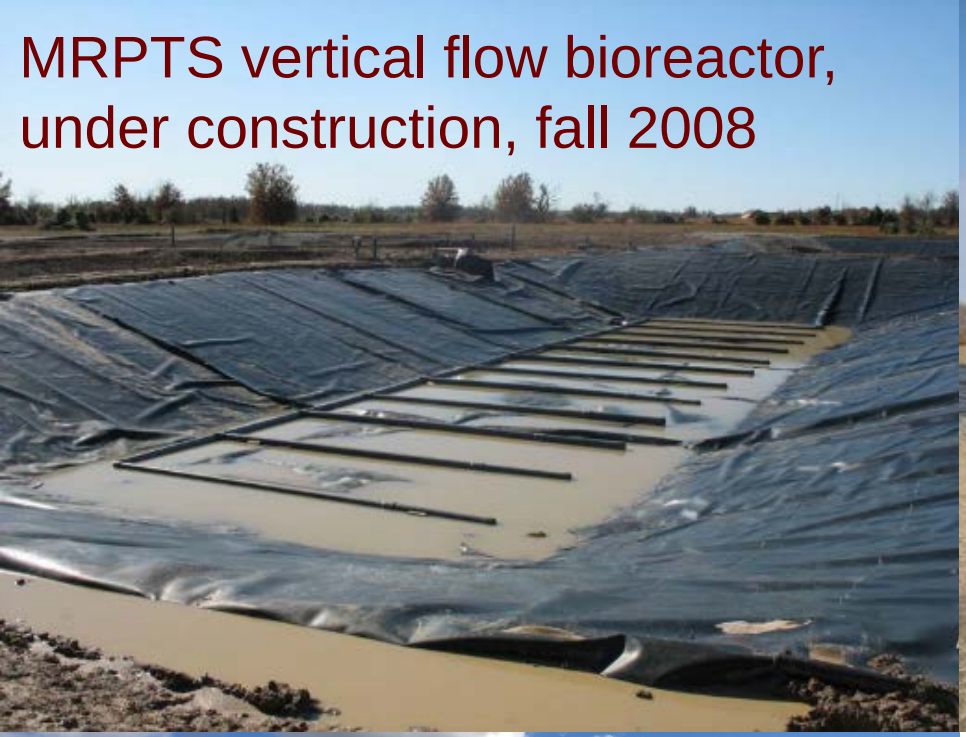
MRPTS oxidation cell under construction, fall 2008

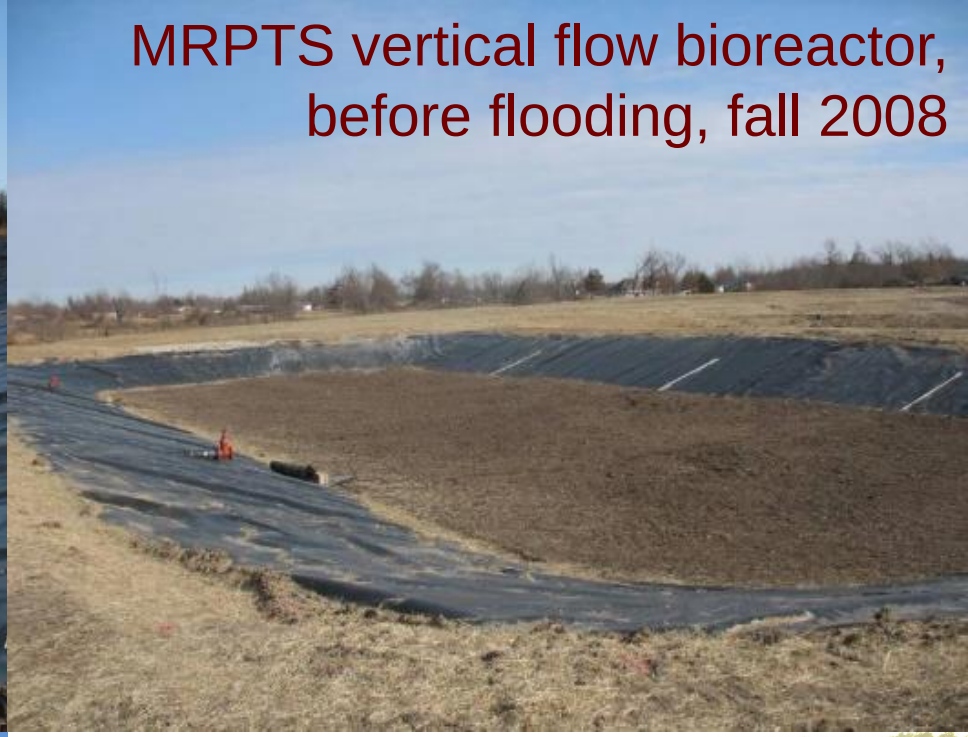
MRPTS oxidation cell during managed drawdown, winter 2017



SECPTS oxidation cell directional baffle curtains, early 2017

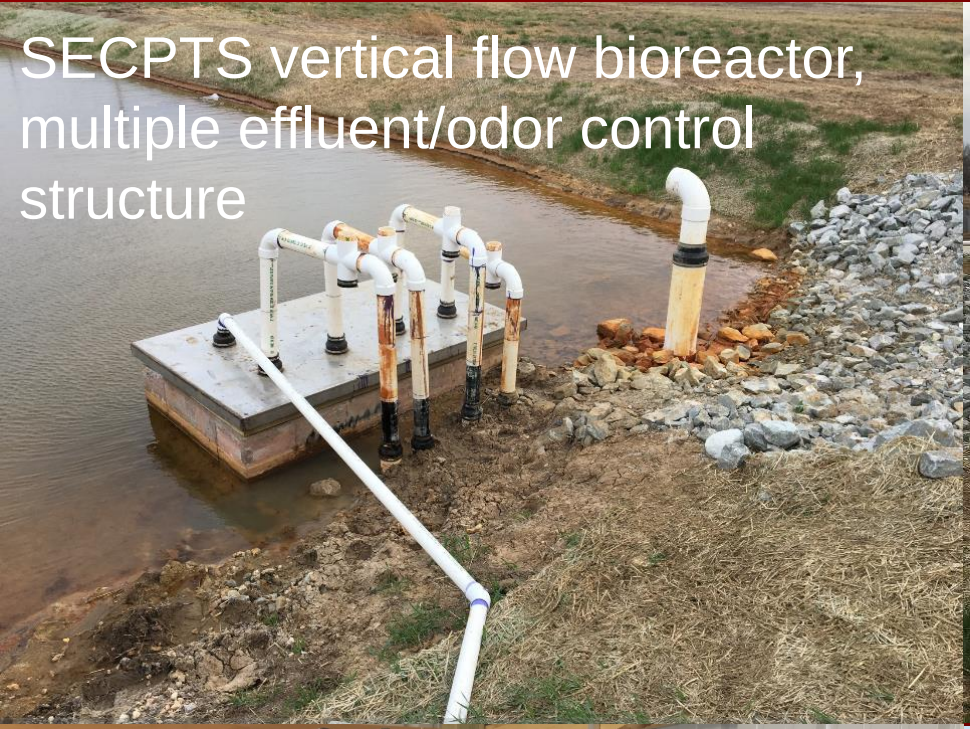
SECPTS oxidation cell solar-powered aerators, early 2017


MRPTS vertical flow bioreactor,
under construction, fall 2008


MRPTS vertical flow bioreactor,
before flooding, fall 2008


SECPTS vertical flow bioreactor,
under construction, fall 2016


SECPTS vertical flow bioreactor,
before flooding, early 2017



SECPTS vertical flow bioreactor, multiple effluent/odor control structure

SECPTS VFBR outflow, OCS, solar-panel, activated carbon filter

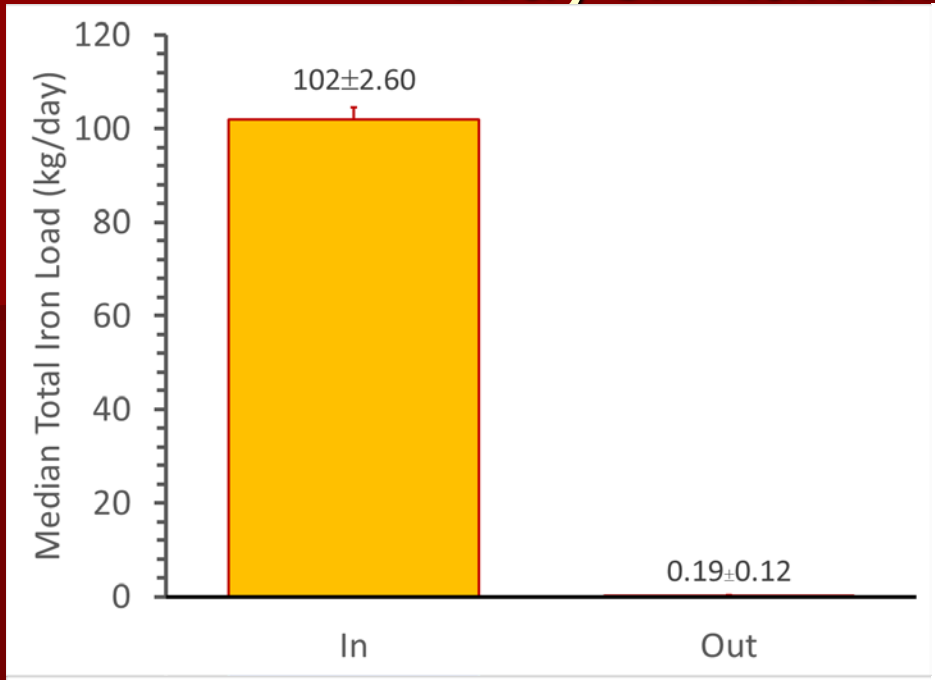
Measuring air flow and H_2S at SECPTS

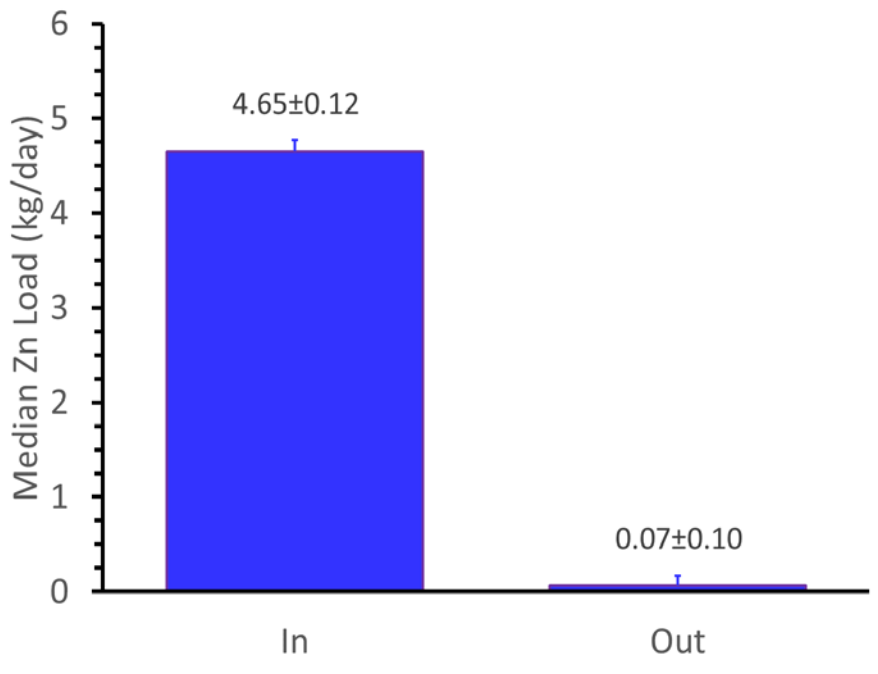
SECPTS solar-powered aeration in final polishing unit

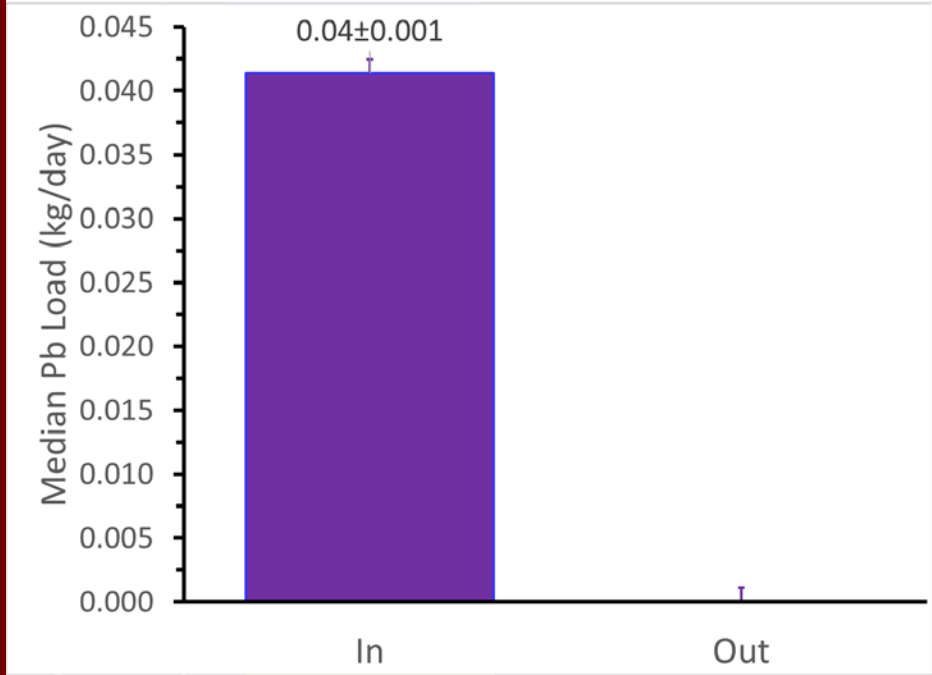
MRPTS Water Quality Changes

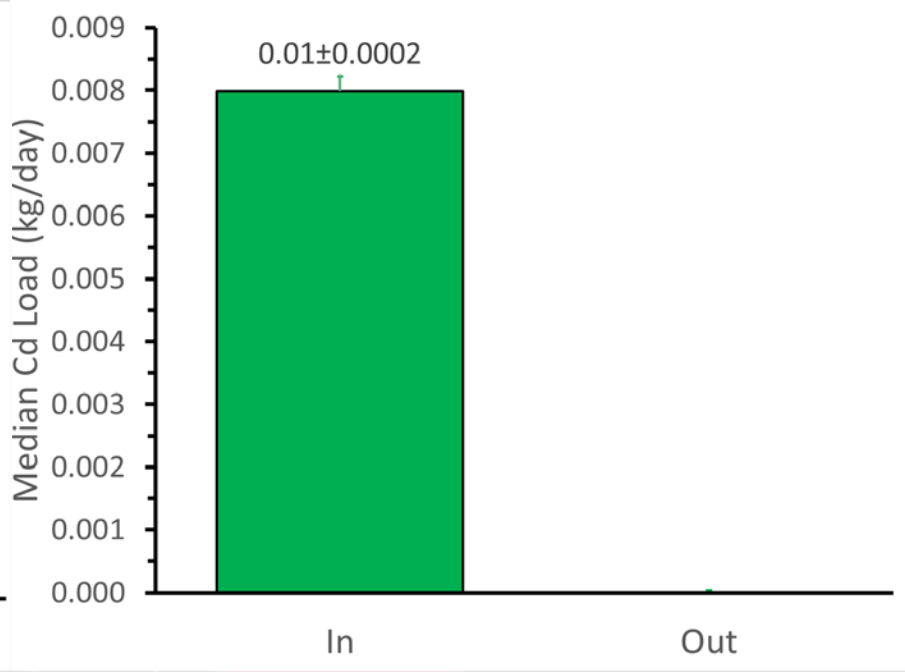
	In	Out
pH	5.95	7.02
Tot. Alk. (mg/L)	393	224
Net Alk. (mg/L)	29	224
Fe (mg/L)	192	0.13
Zn (mg/L)	11	0.25
Ni (mg/L)	0.97	0.15
Cd (μg/L)	17	<PQL
Pb (μg/L)	60	<PQL
As (μg/L)	64	<PQL
SO_4^{-2} (mg/L)	2239	2057

Mayer Ranch PTS - COCs

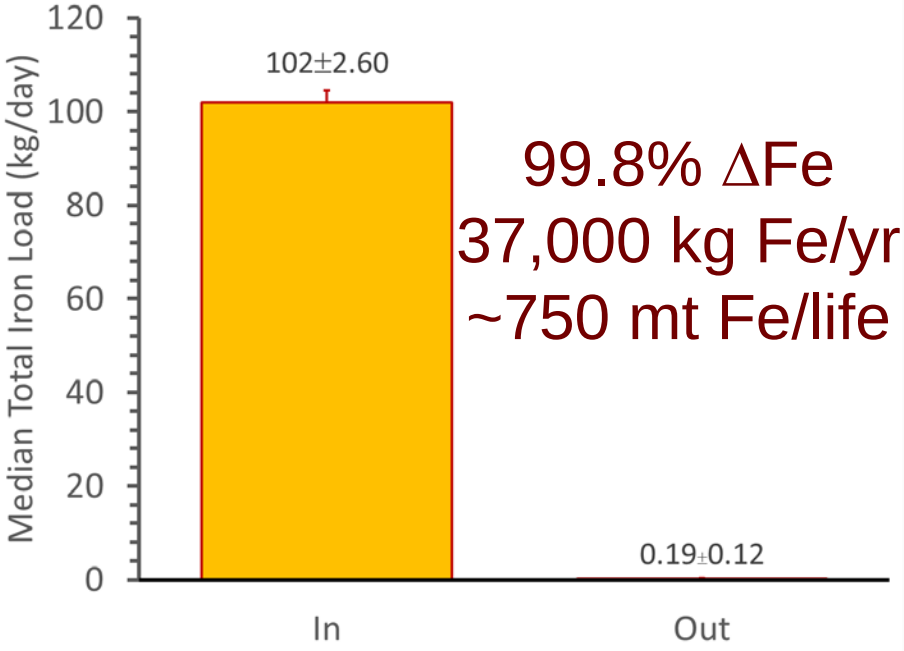




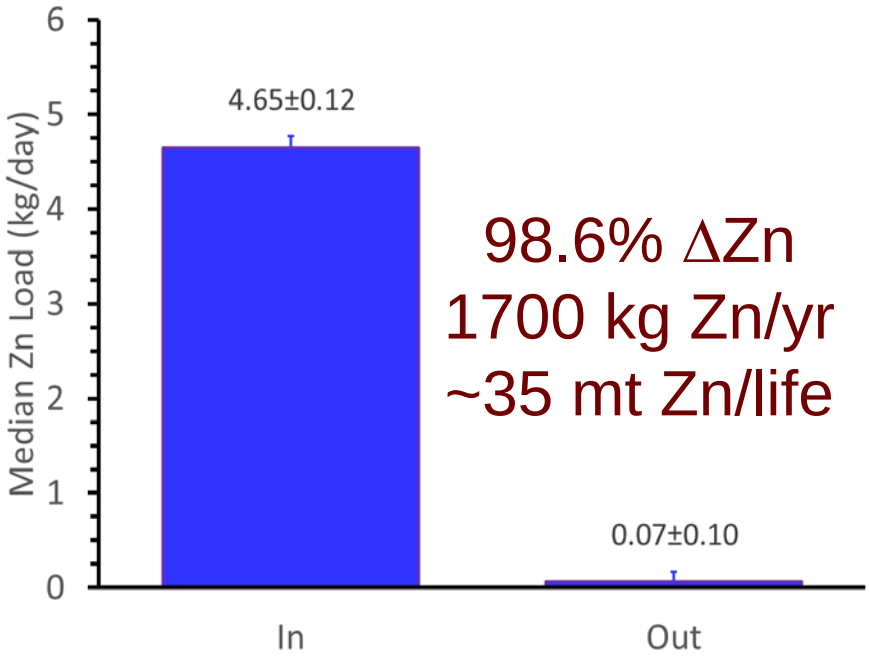




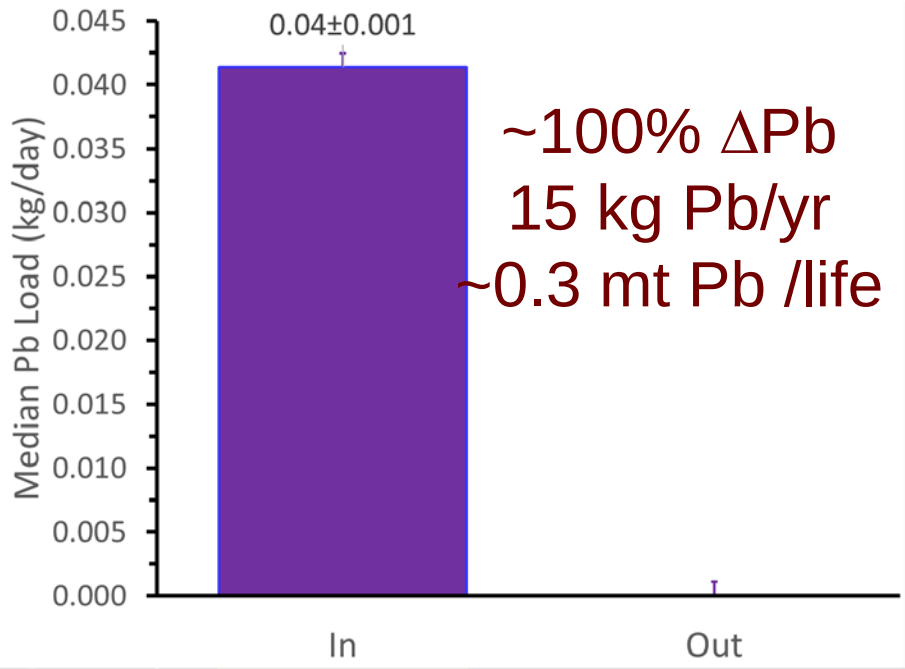
Mayer Ranch PTS - COCs



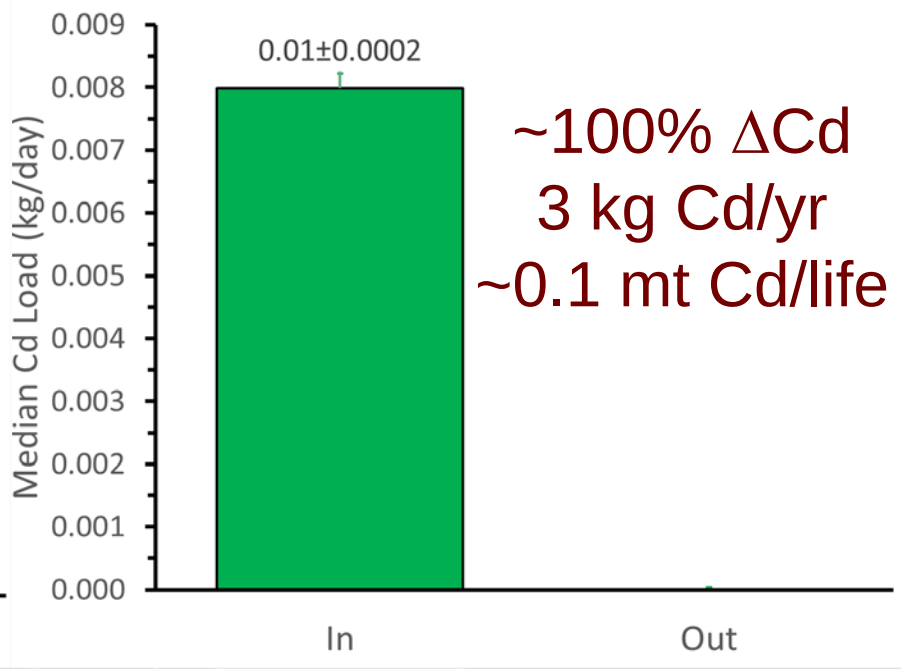
99.8% ΔFe
37,000 kg Fe/yr
~750 mt Fe/life



98.6% ΔZn
1700 kg Zn/yr
~35 mt Zn/life

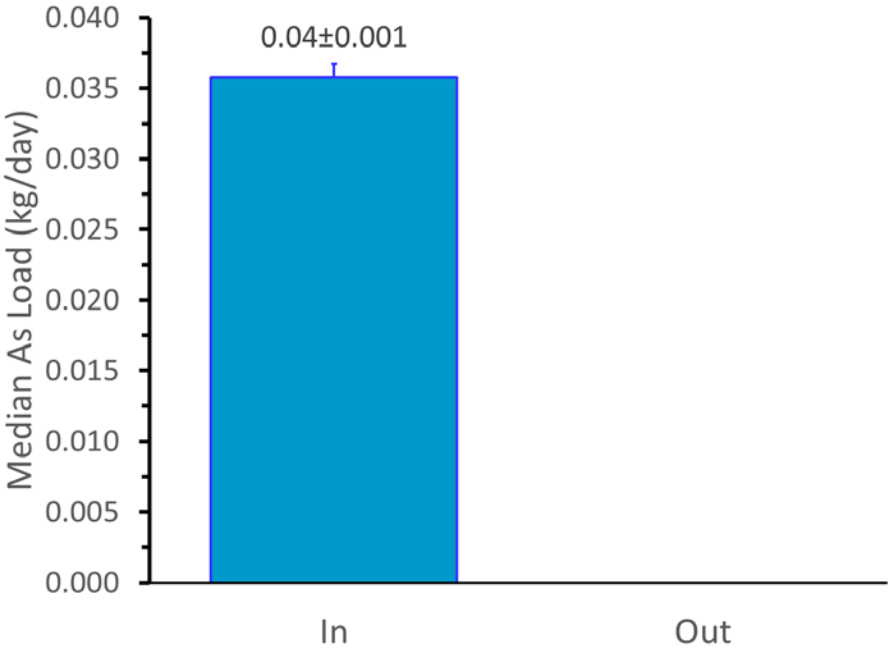


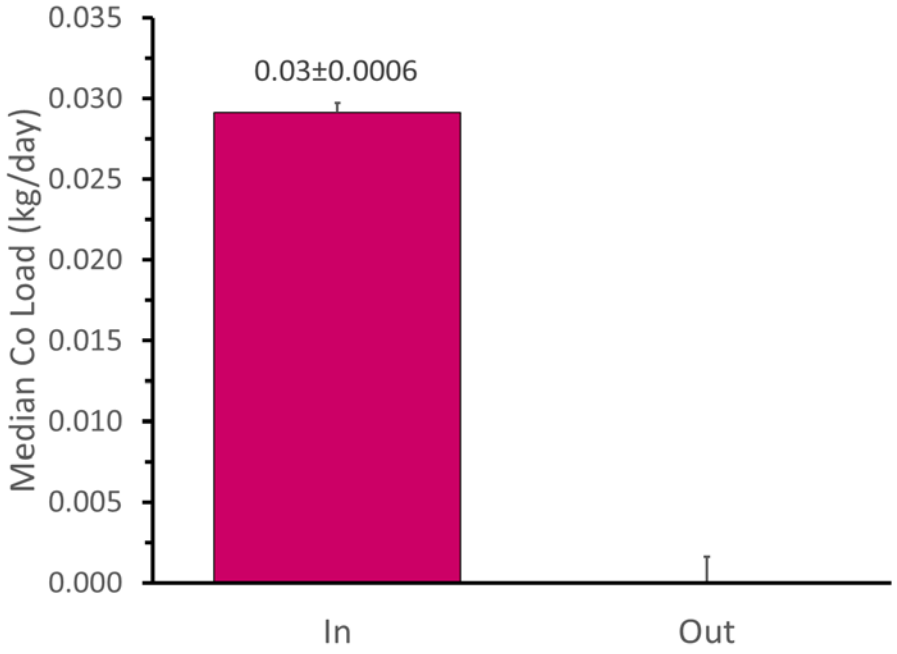
~100% ΔPb
15 kg Pb/yr
~0.3 mt Pb /life

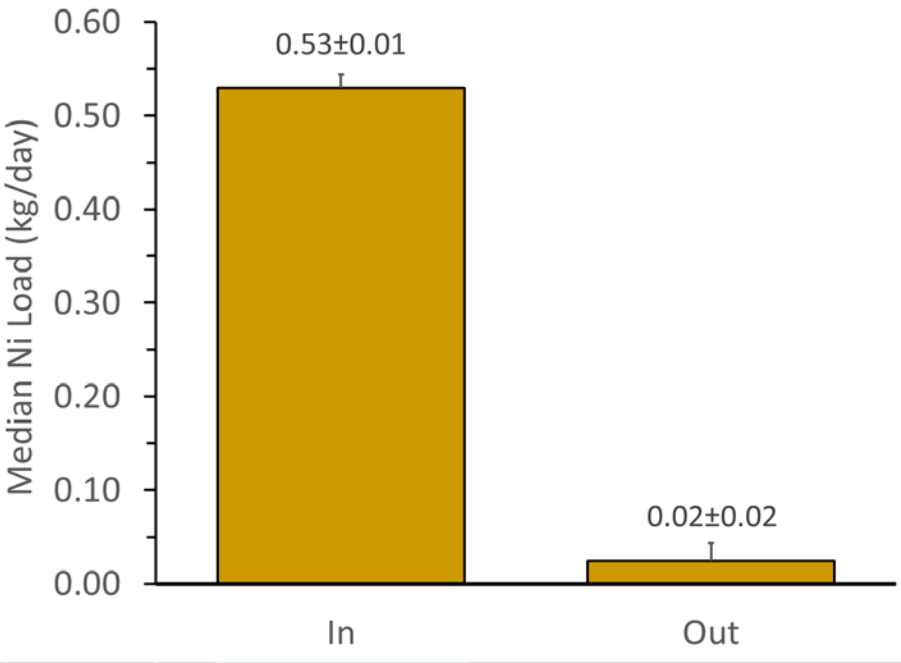


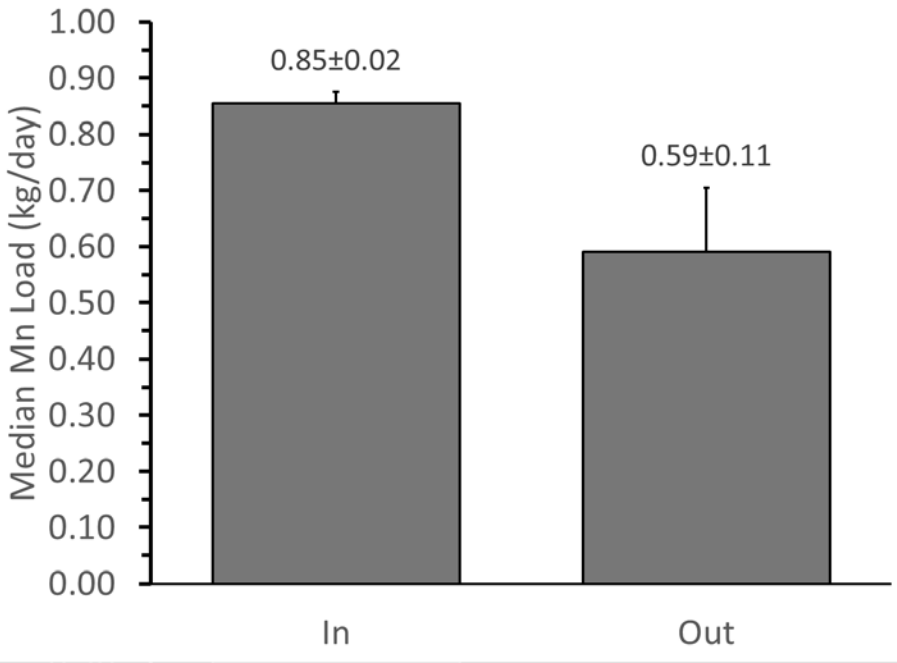
~100% ΔCd
3 kg Cd/yr
~0.1 mt Cd/life

Mayer Ranch PTS – Other Metals

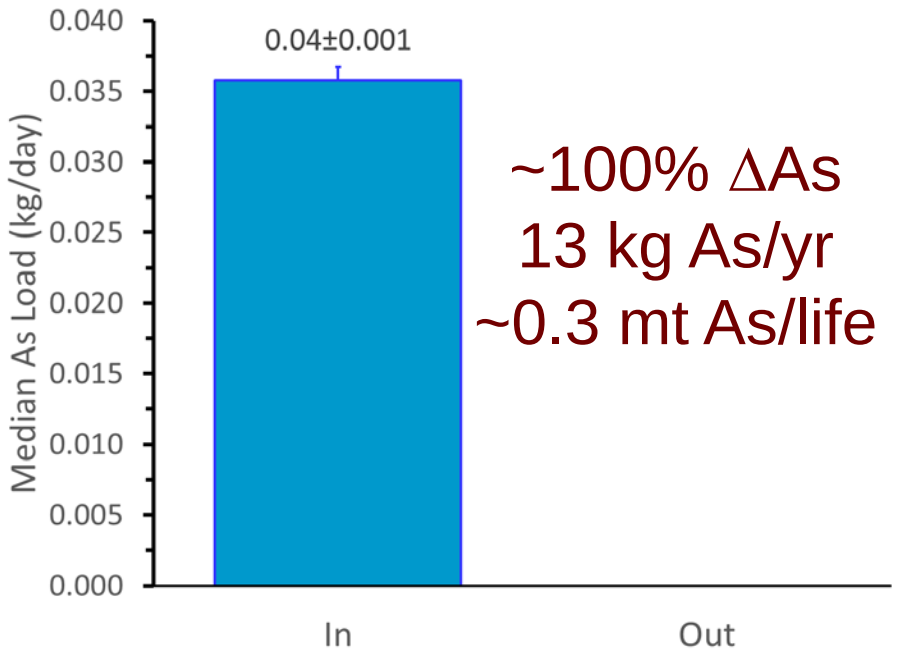




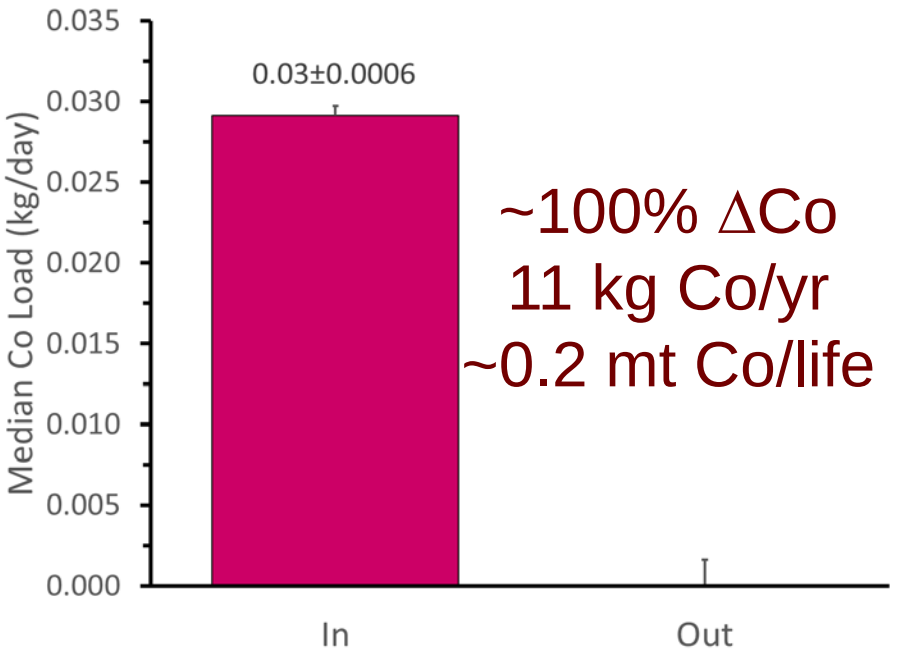




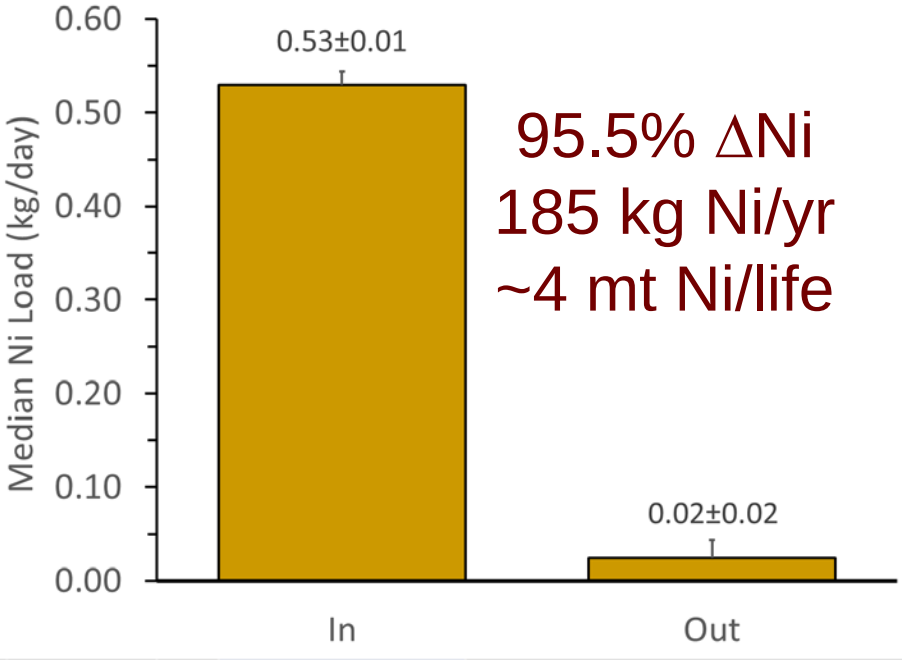
Mayer Ranch PTS – Other Metals



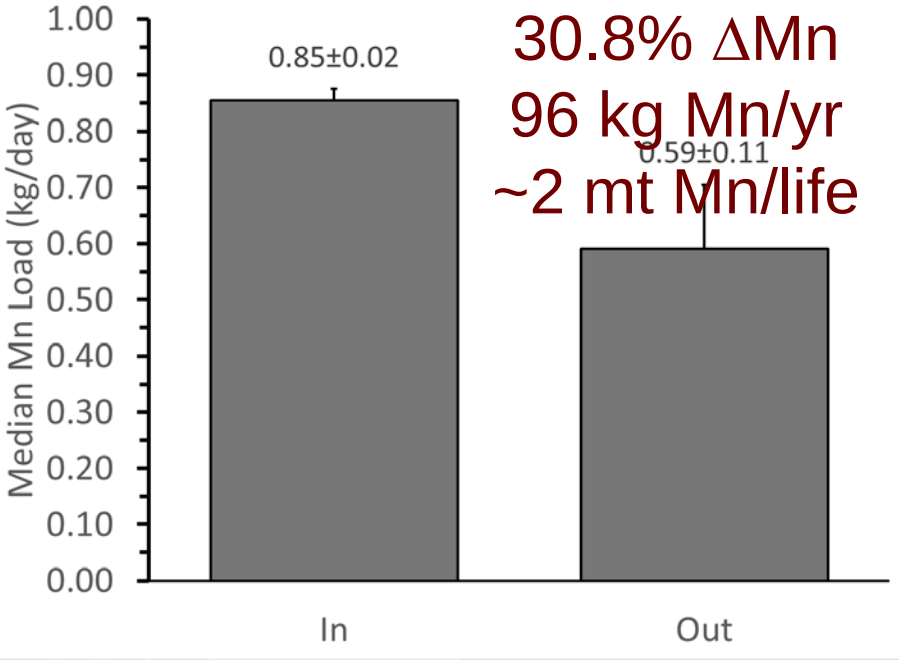
~100% ΔAs
13 kg As/yr
~0.3 mt As/life



~100% ΔCo
11 kg Co/yr
~0.2 mt Co/life

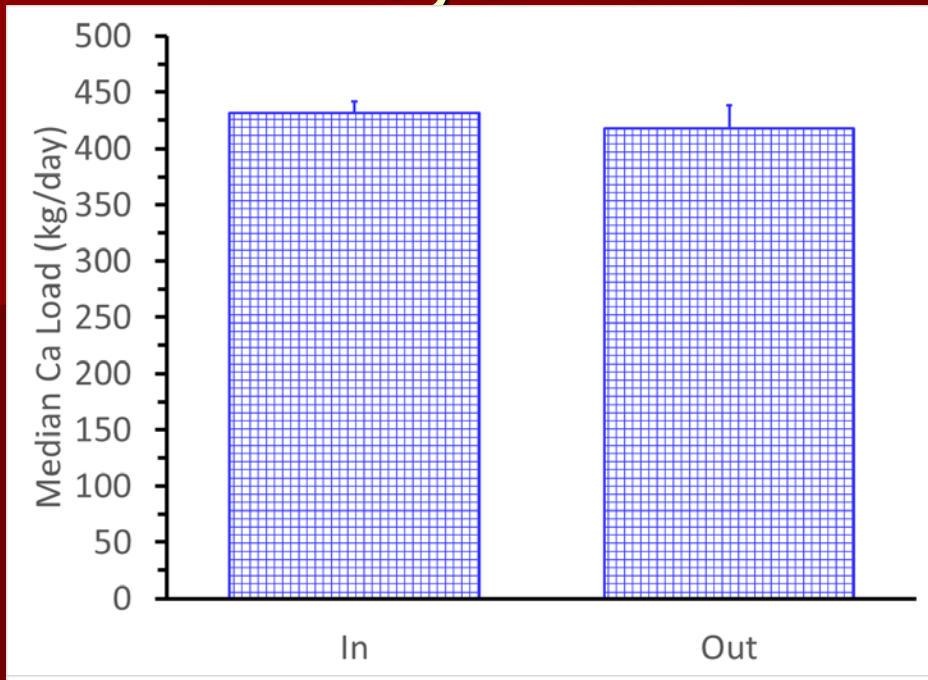


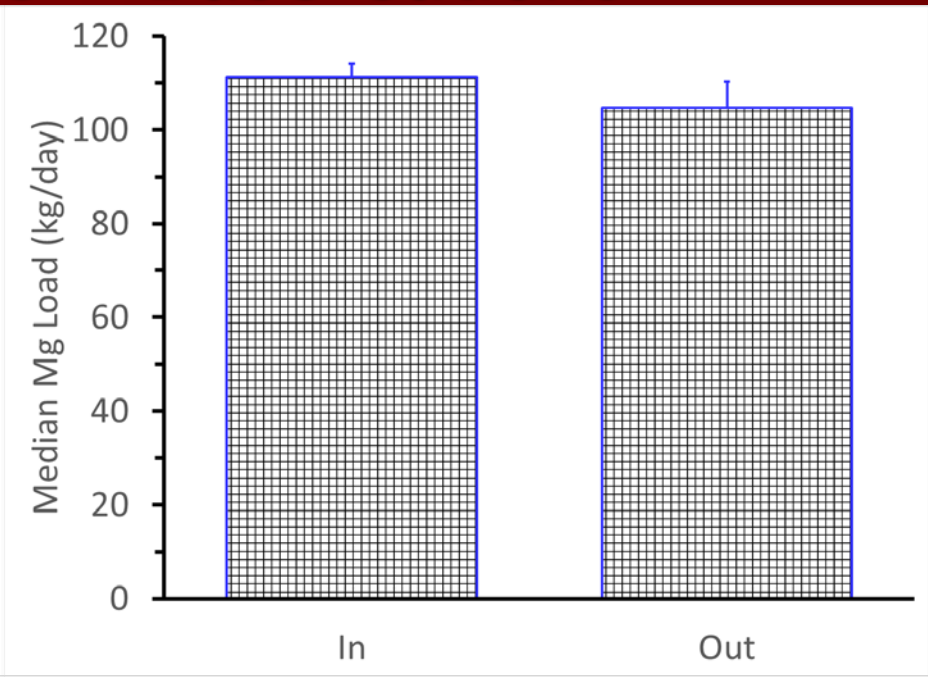
95.5% ΔNi
185 kg Ni/yr
~4 mt Ni/life

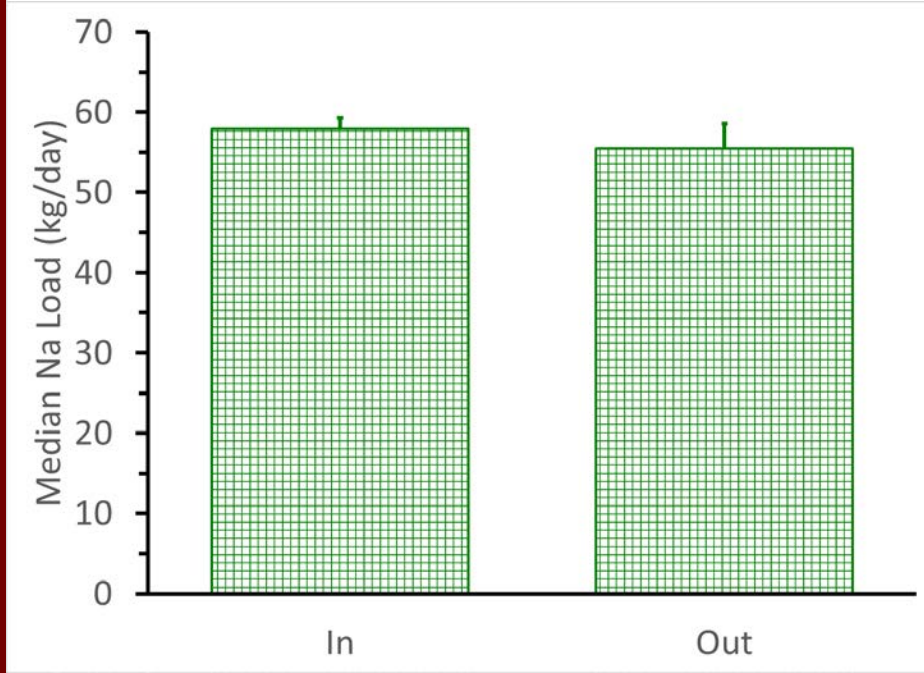


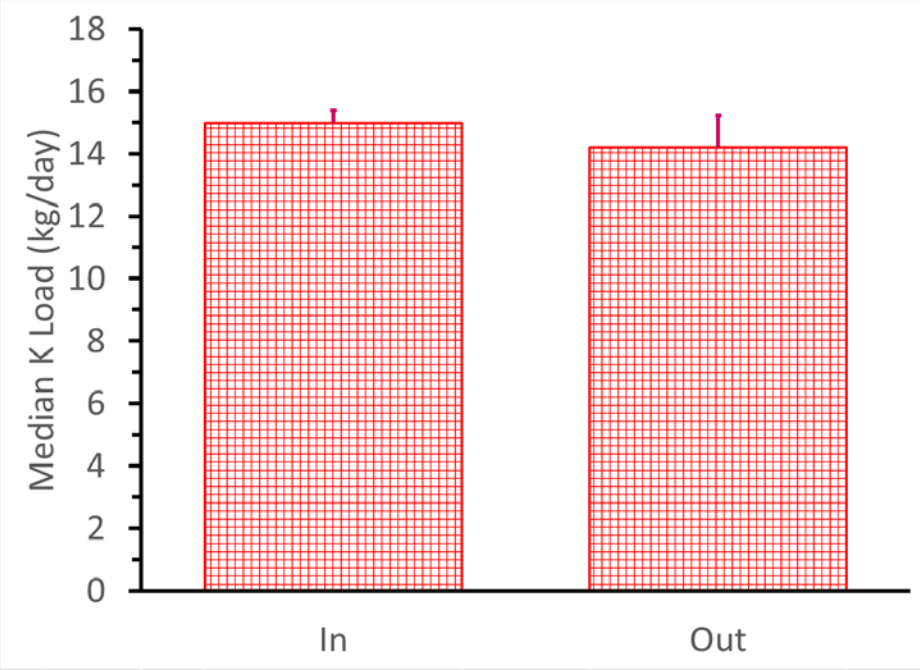
30.8% ΔMn
96 kg Mn/yr
~2 mt Mn/life

Mayer Ranch PTS – Base Cations

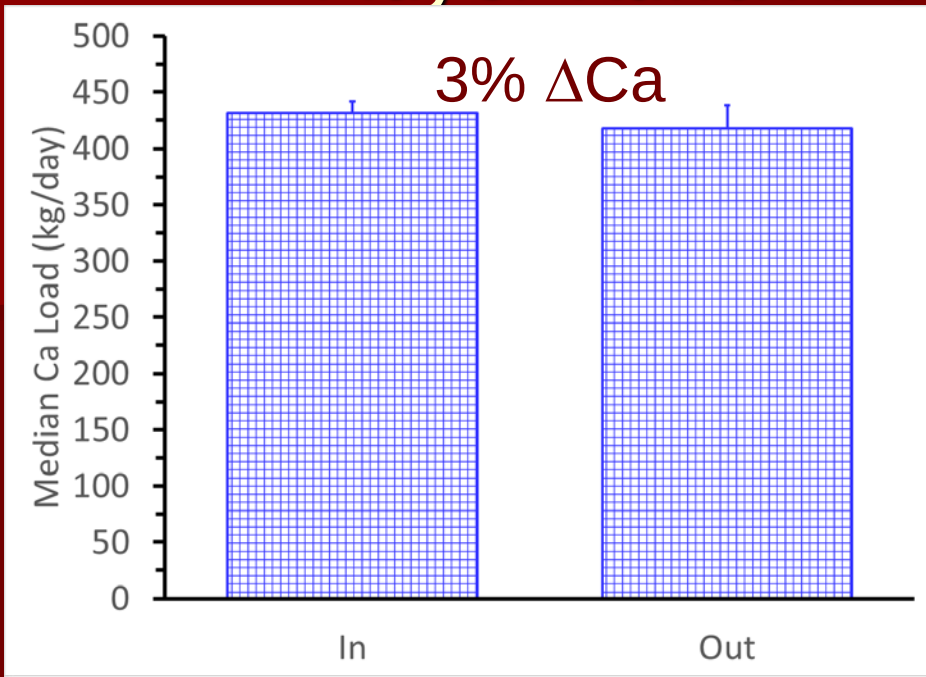


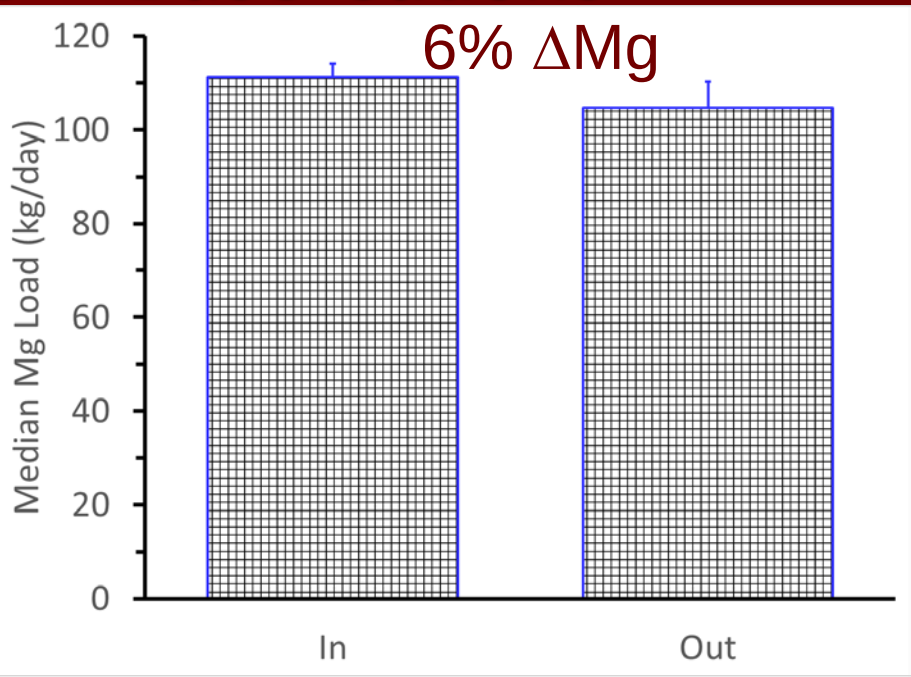


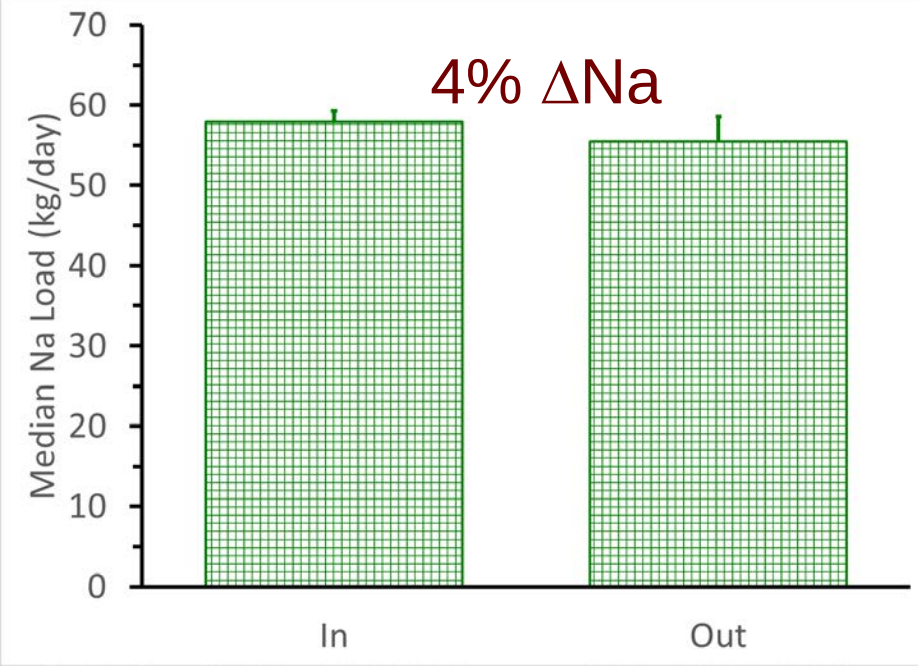


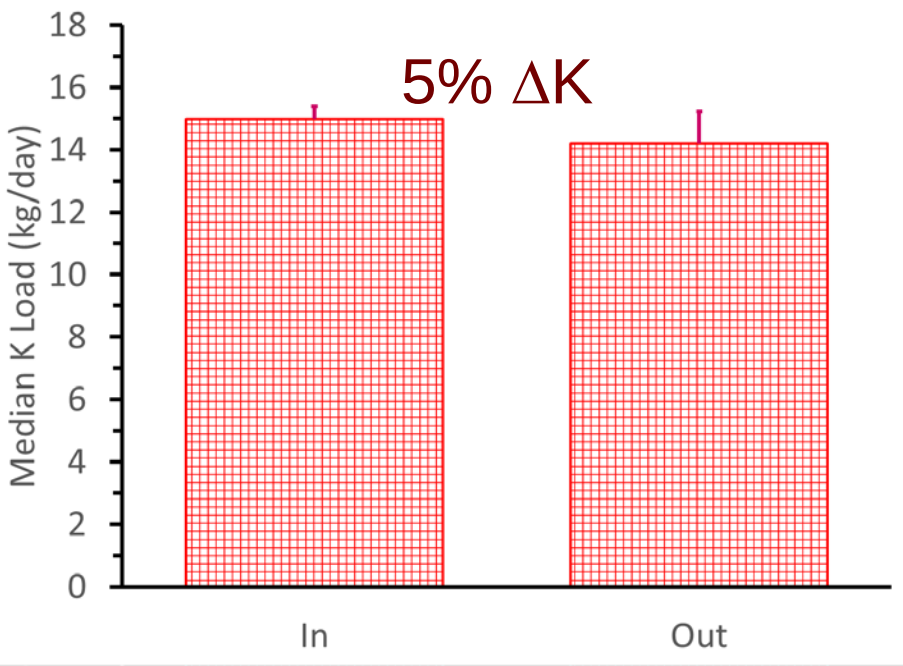


Mayer Ranch PTS – Base Cations





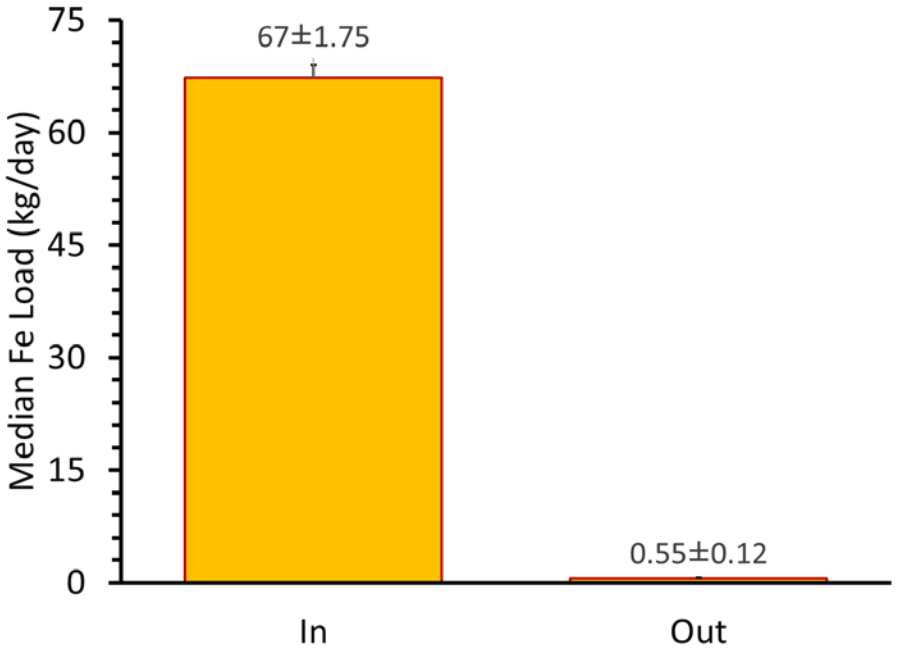


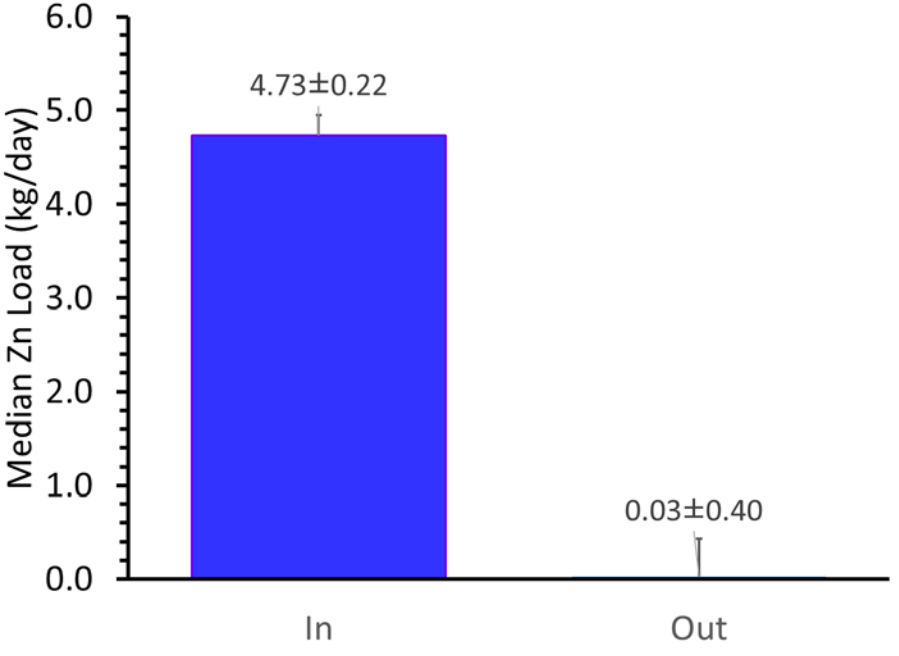


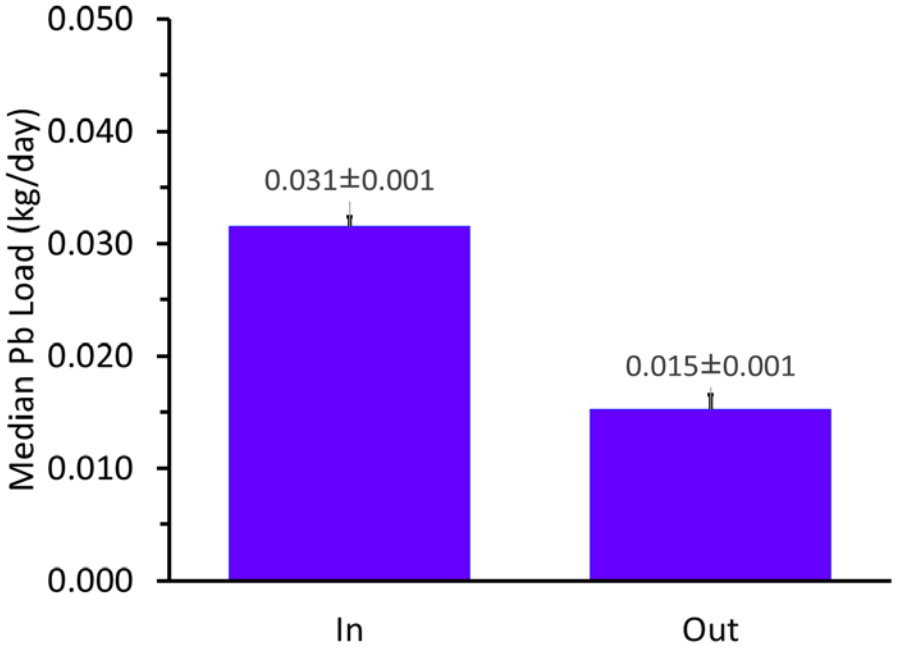
SECPTS Water Quality Changes

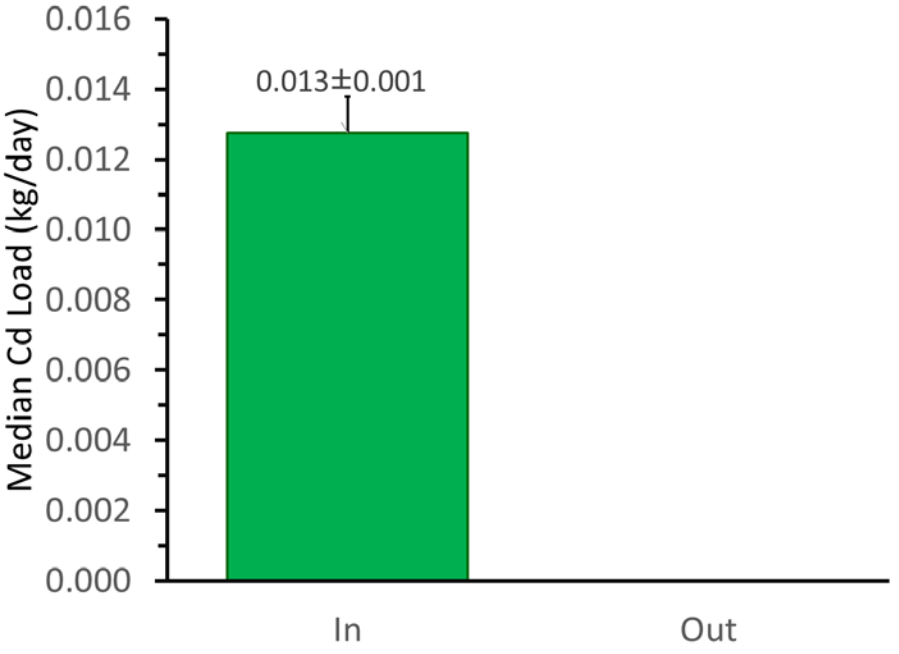
	In	Out
pH	6.06	7.02
Tot. Alk. (mg/L)	350	117
Fe (mg/L)	127	0.79
Zn (mg/L)	6.15	0.69
Ni (mg/L)	0.52	0.06
Cd (μg/L)	18	<PQL
Pb (μg/L)	80	26
As (μg/L)	38	<PQL
SO_4^{-2} (mg/L)	2102	1956

Southeast Commerce PTS - COCs

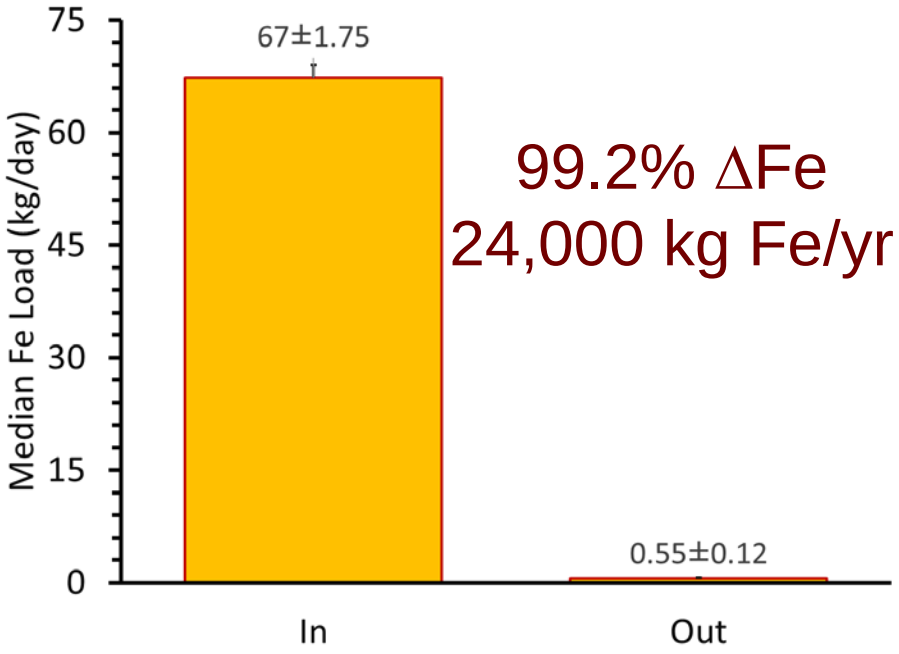




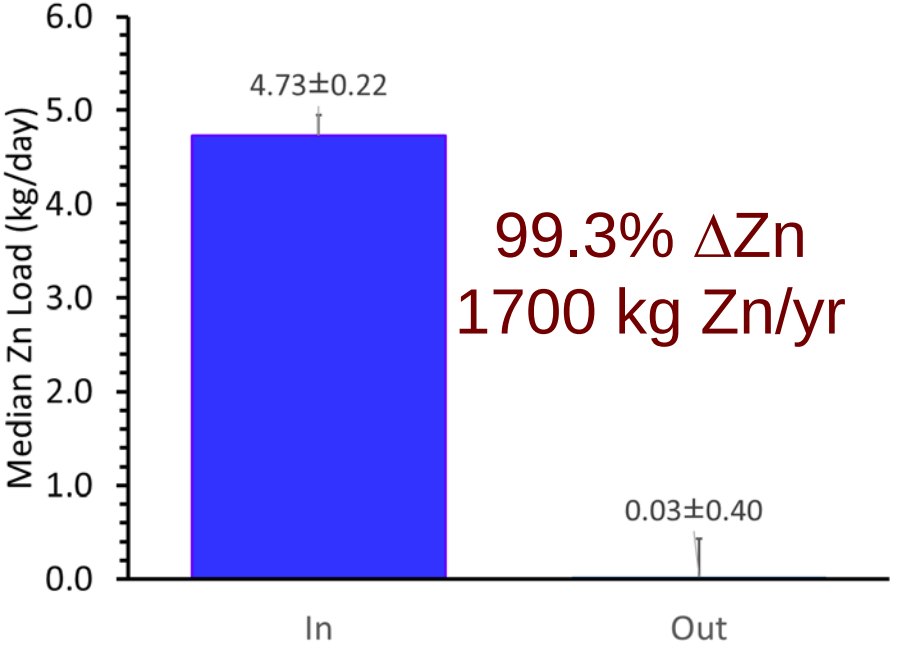




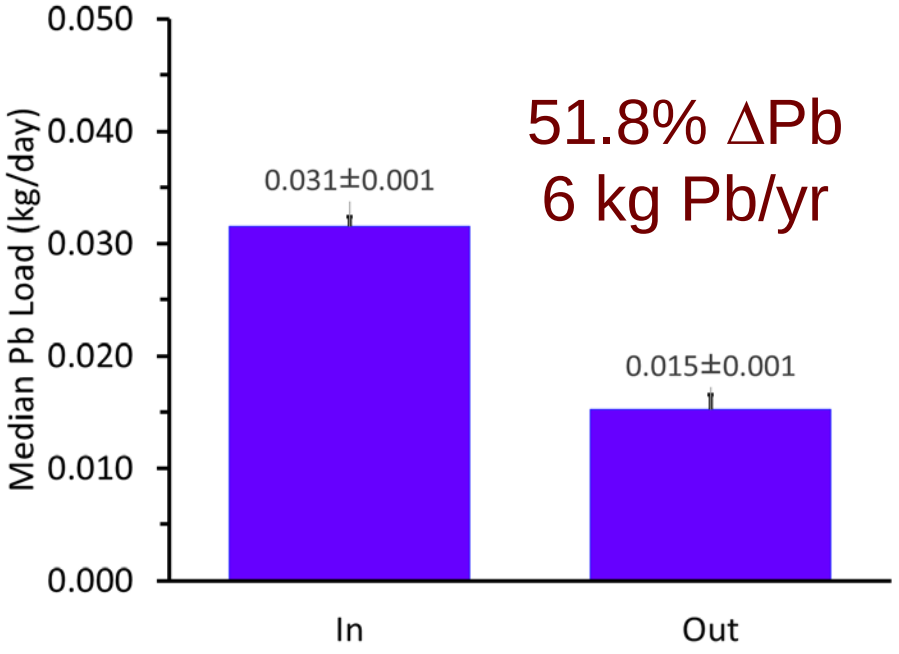
Southeast Commerce PTS - COCs



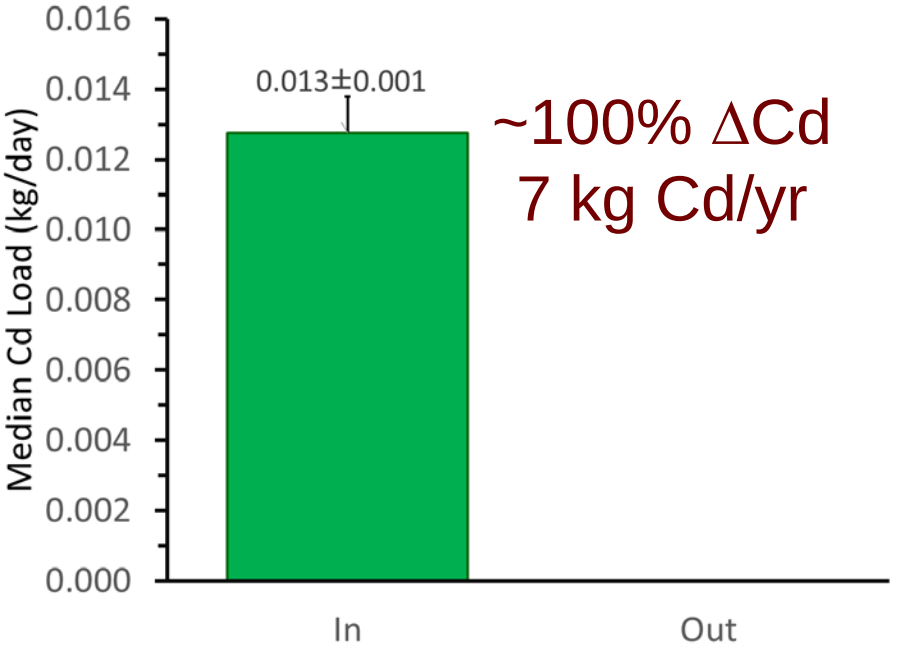
99.2% ΔFe
24,000 kg Fe/yr



99.3% ΔZn
1700 kg Zn/yr

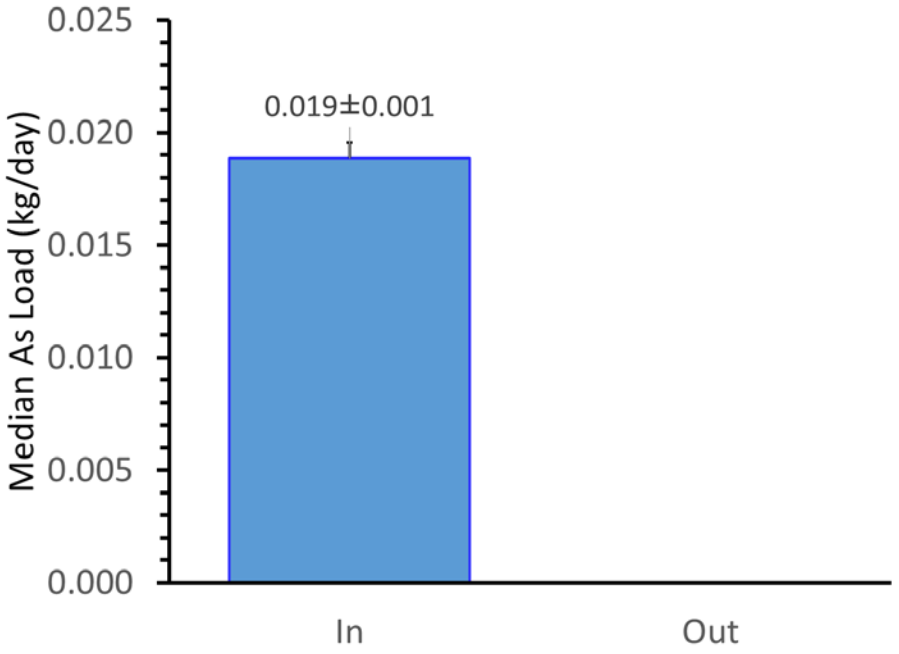


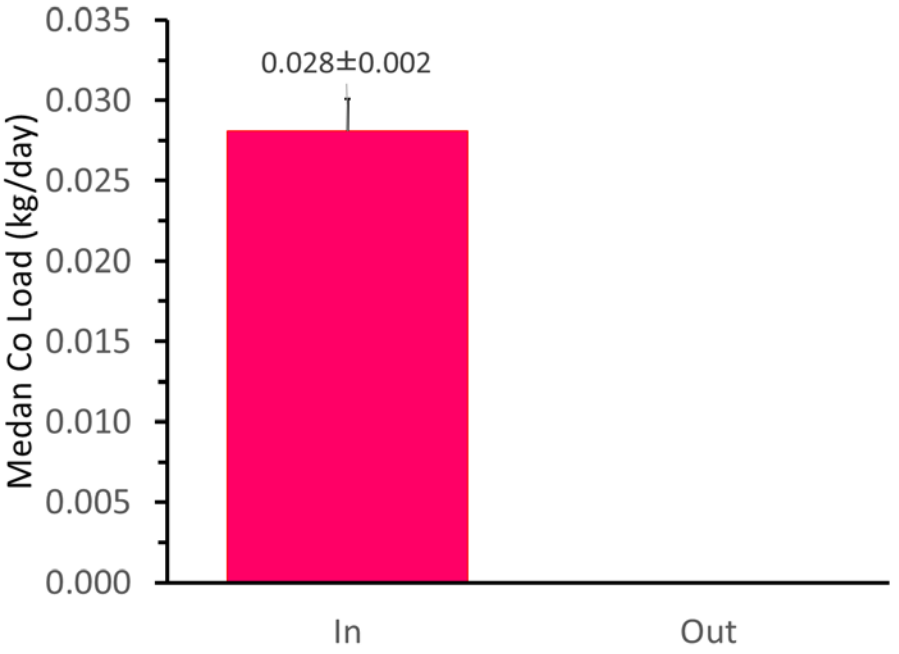
51.8% ΔPb
6 kg Pb/yr

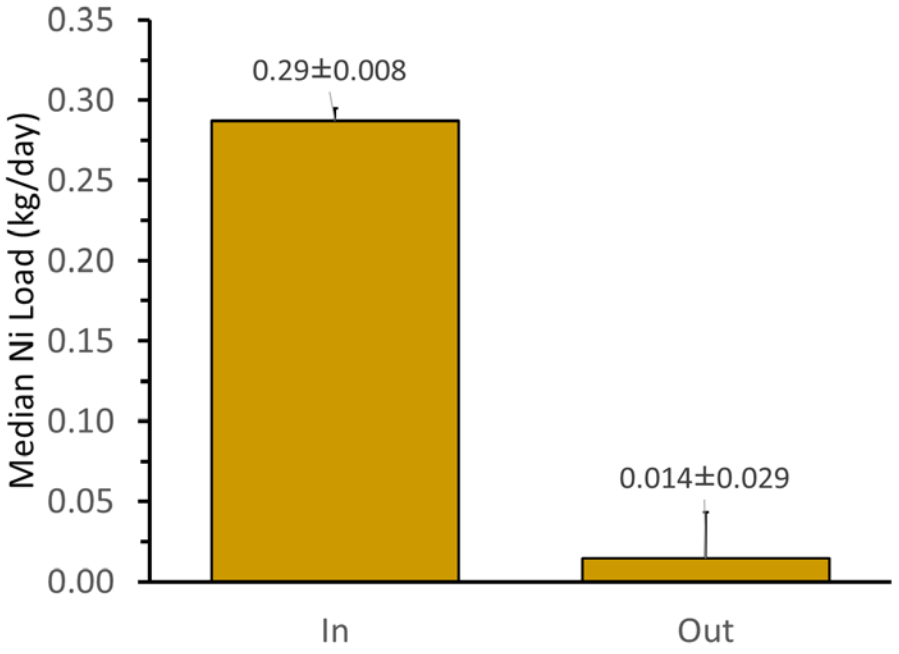


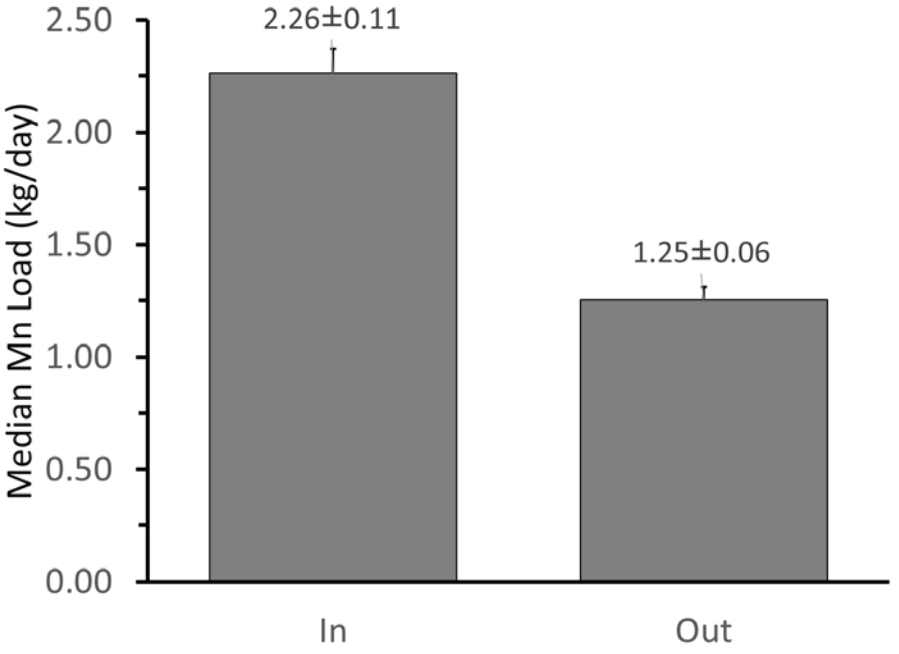
~100% ΔCd
7 kg Cd/yr

Southeast Commerce PTS – Other Metals

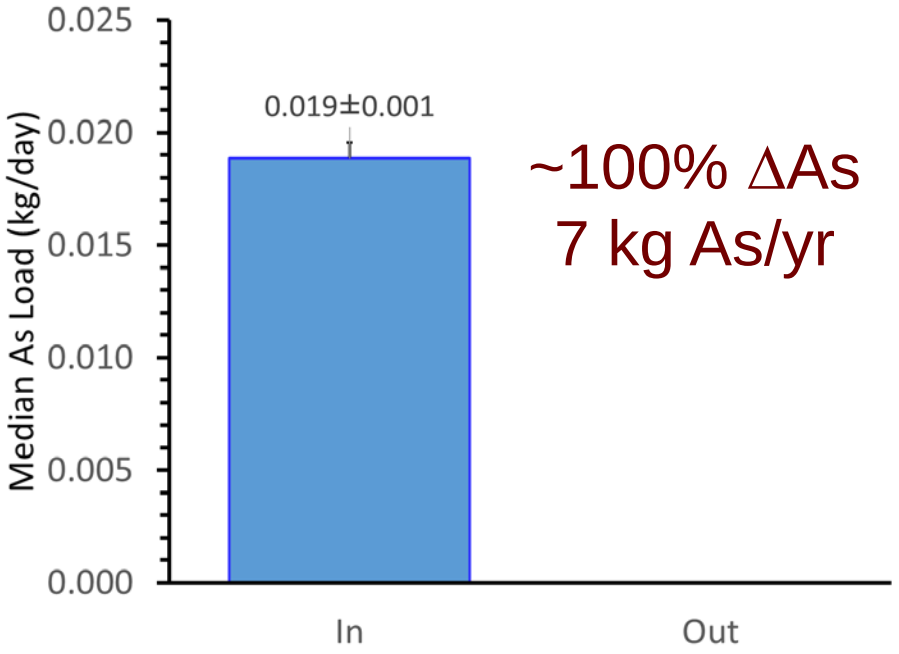




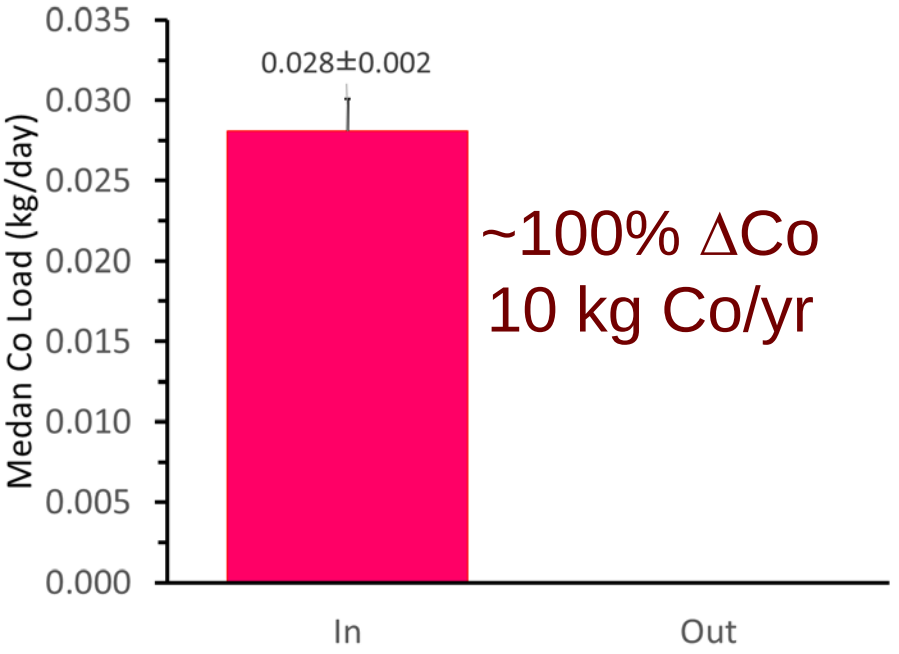




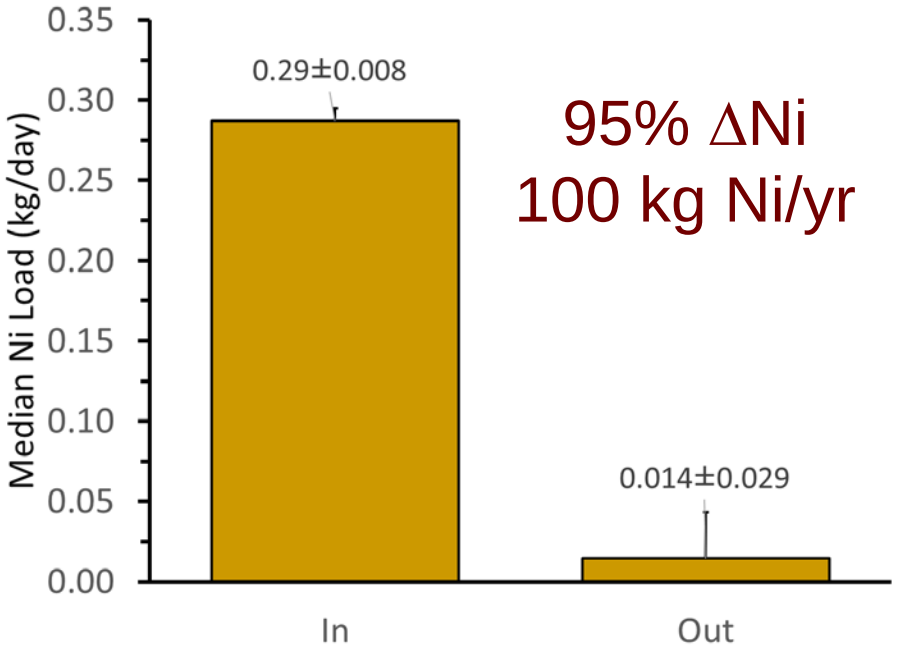
Southeast Commerce PTS – Other Metals



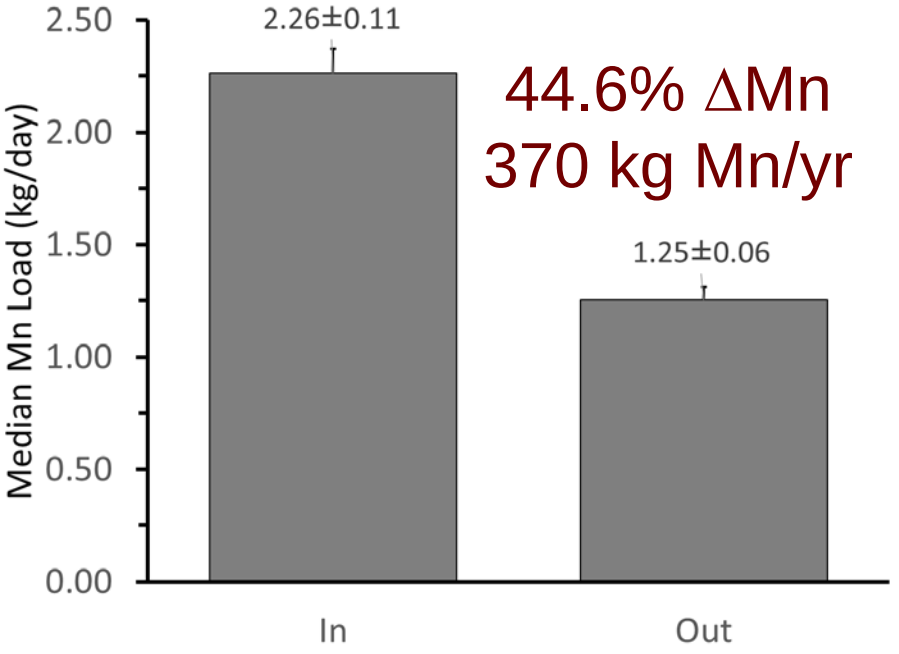
~100% ΔAs
7 kg As/yr



~100% ΔCo
10 kg Co/yr

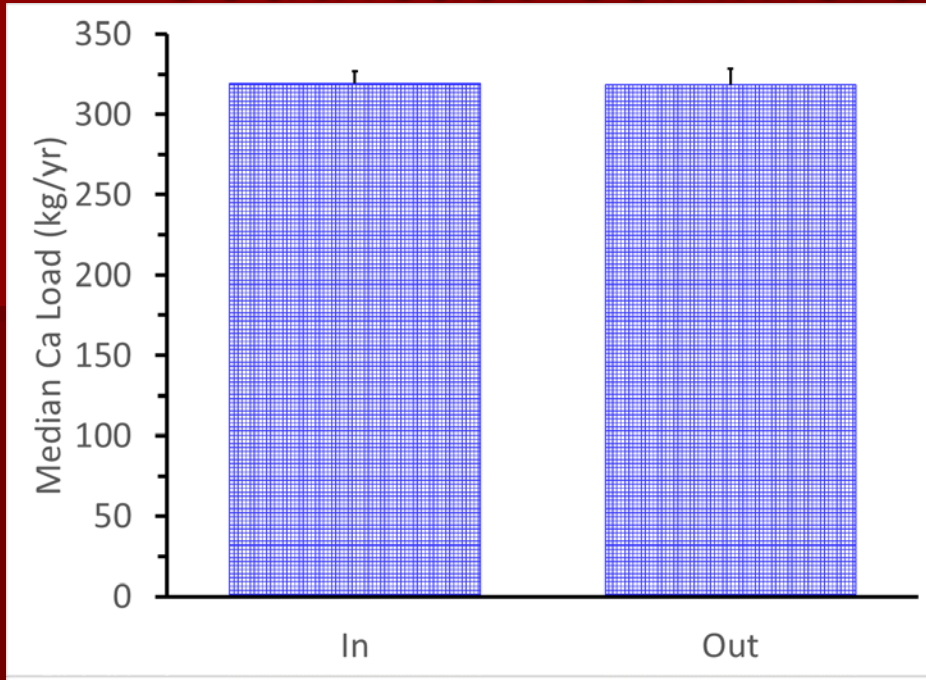


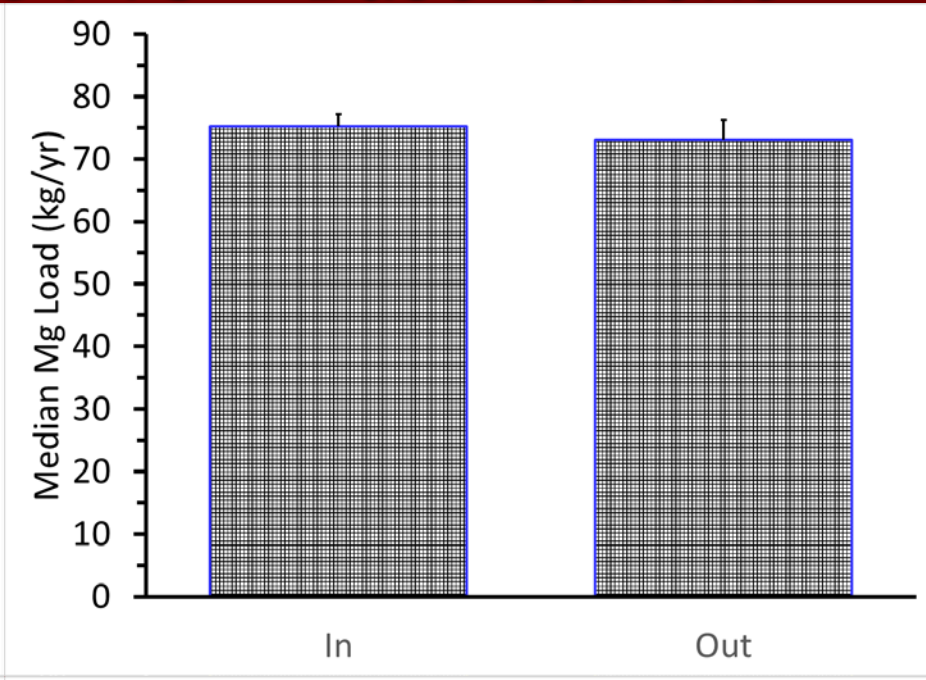
95% ΔNi
100 kg Ni/yr

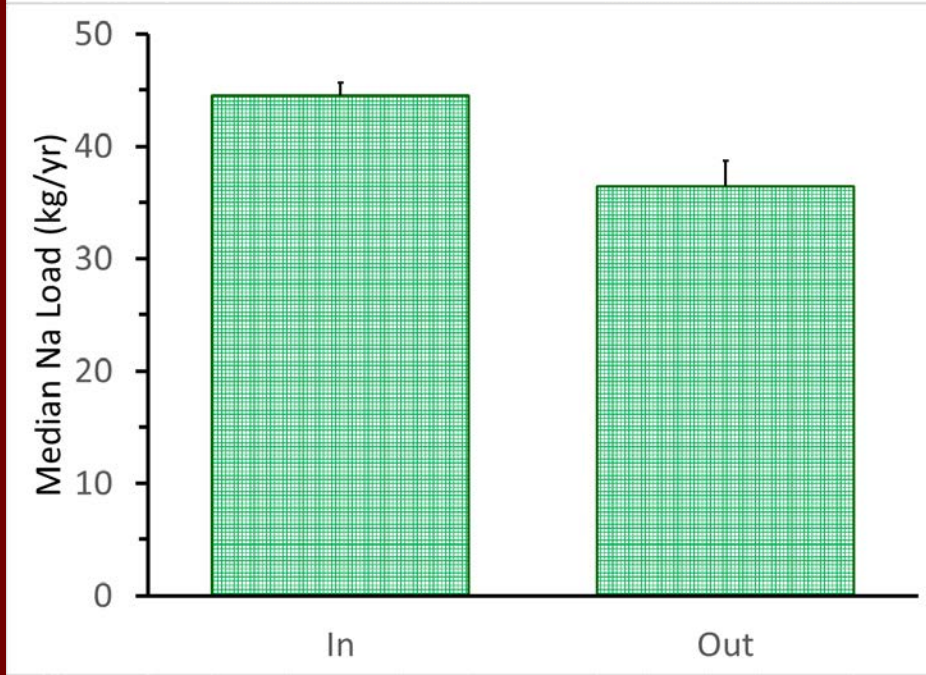


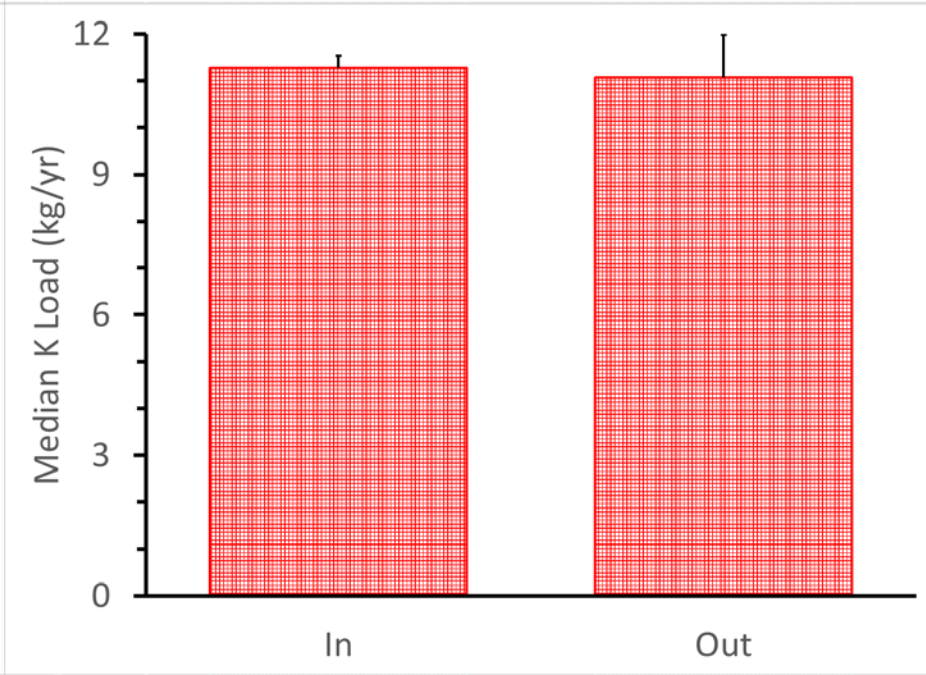
44.6% ΔMn
370 kg Mn/yr

Southeast Commerce PTS – Base Cations

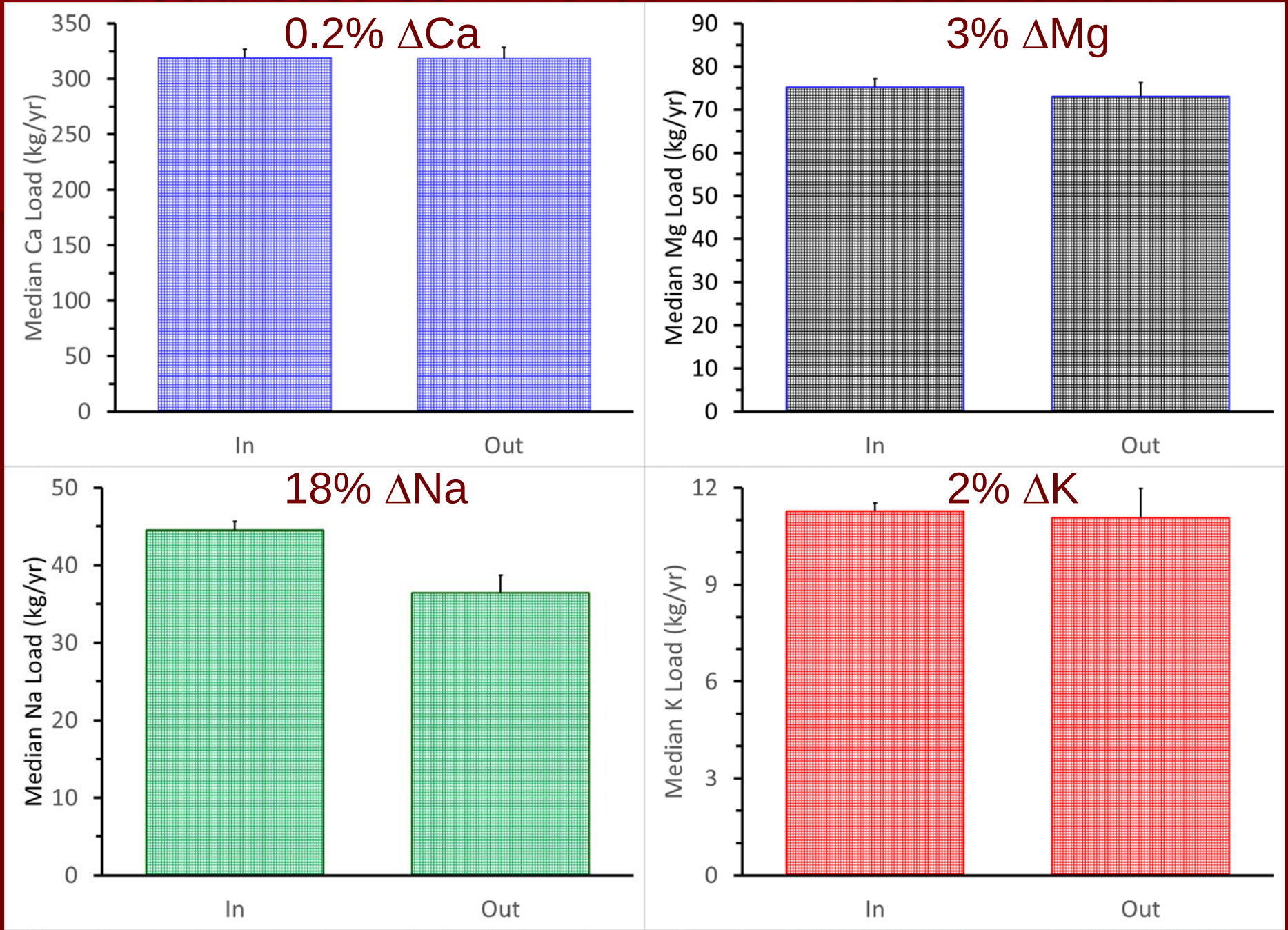






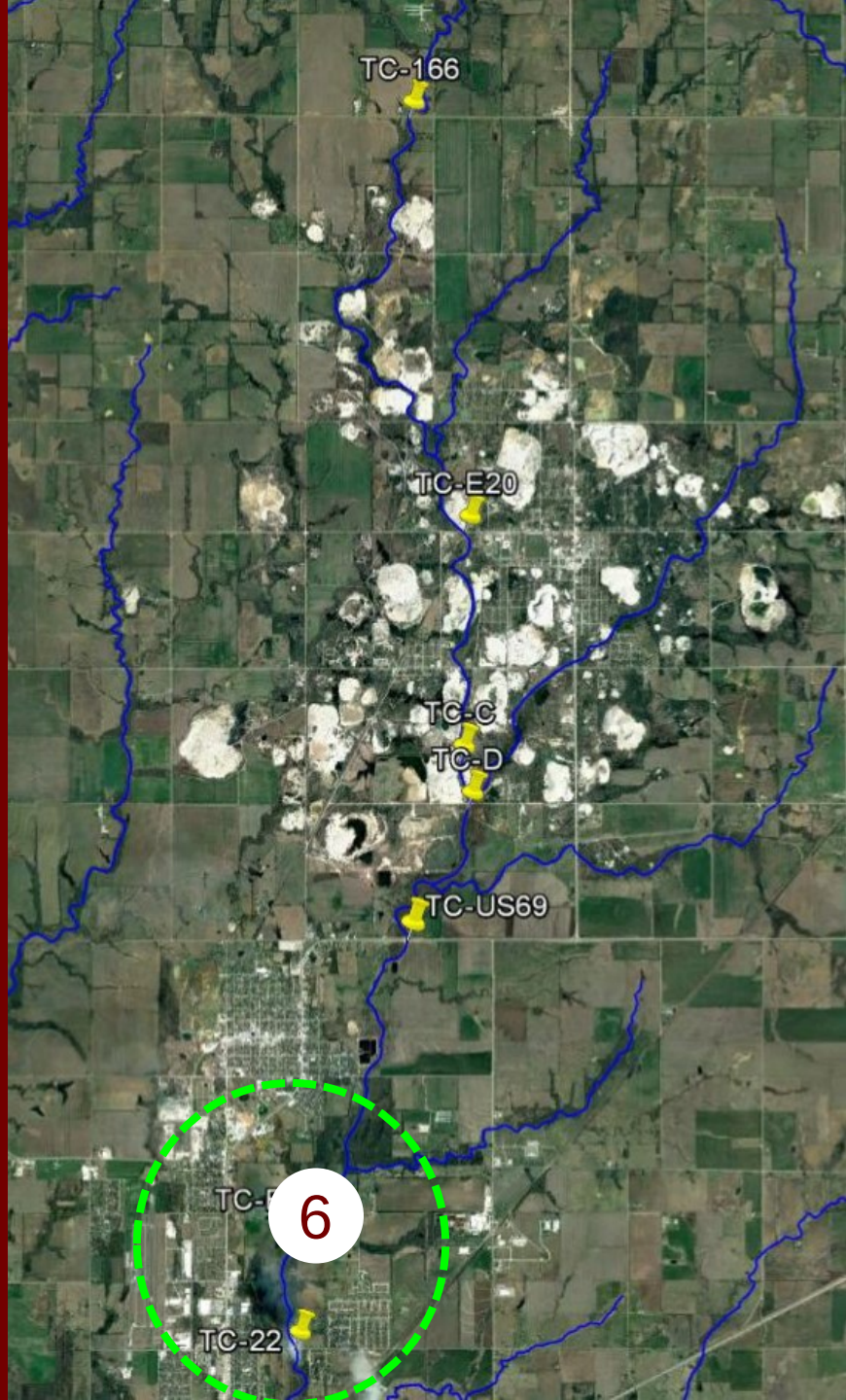


Southeast Commerce PTS – Base Cations



PTS Contaminant Mass Retention

	MR	SEC
Fe (kg/yr)	37000	24000
Zn (kg/yr)	1700	1700
Cd (kg/yr)	15	6
Pb (kg/yr)	3	7



PTS Contaminant Mass Retention

	MR	SEC
Fe (kg/yr)	37000	24000
Zn (kg/yr)	1700	1700
Cd (kg/yr)	15	6
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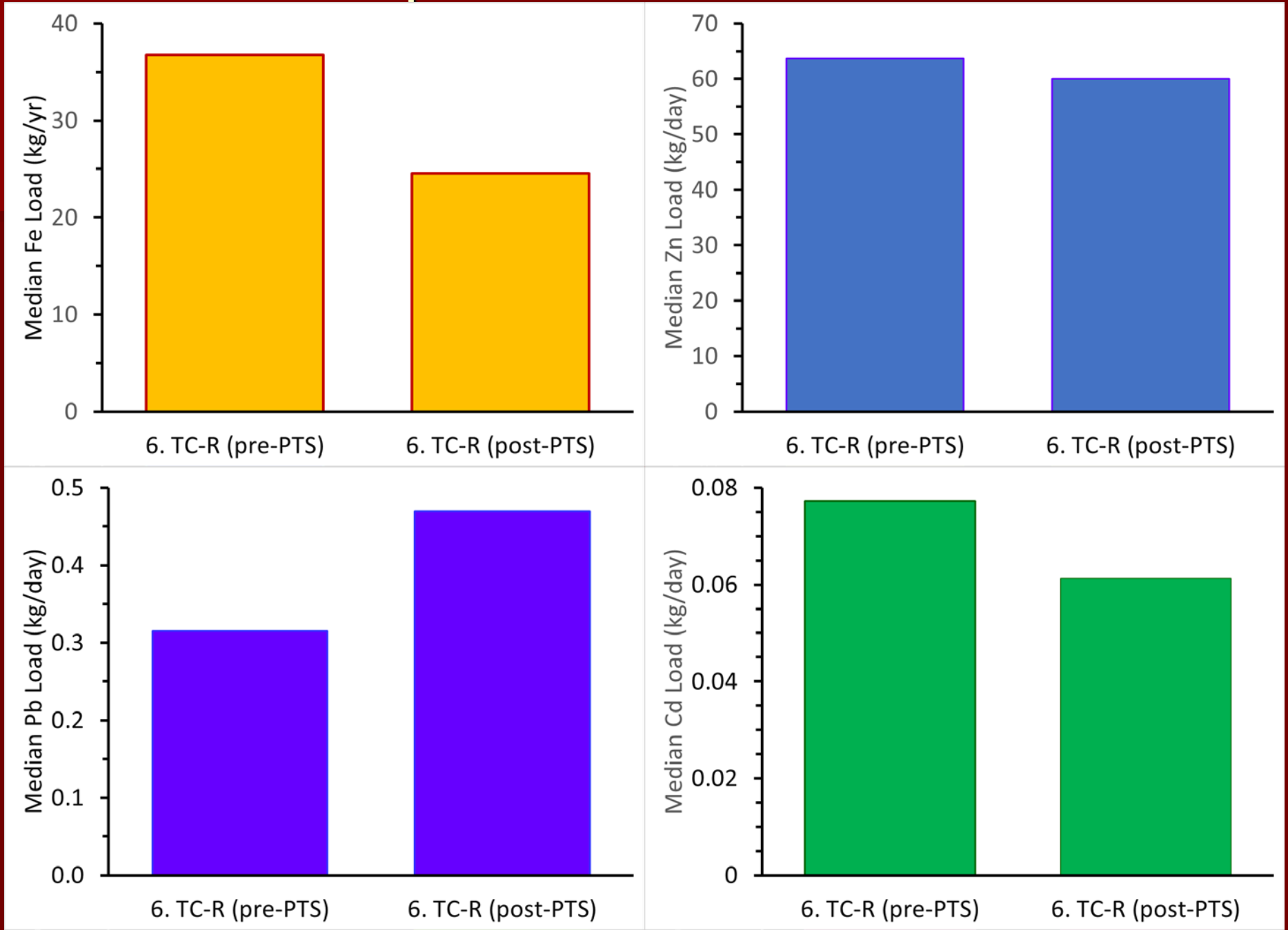
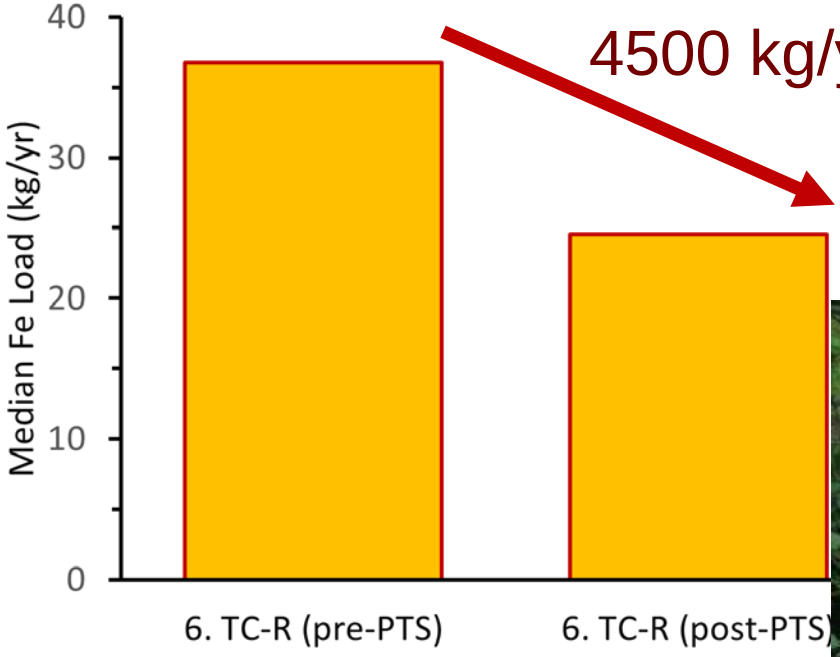
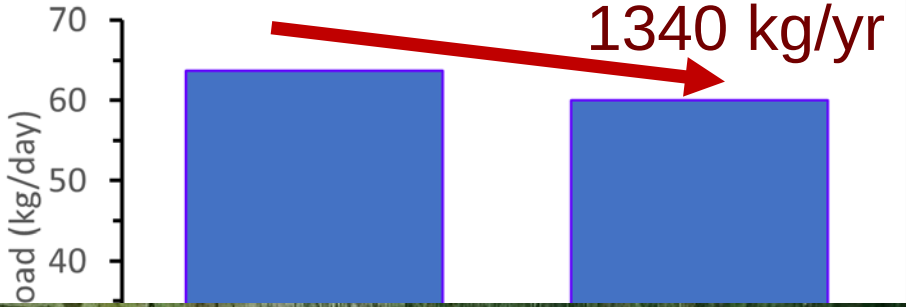
Any impact to Tar Creek main stem?

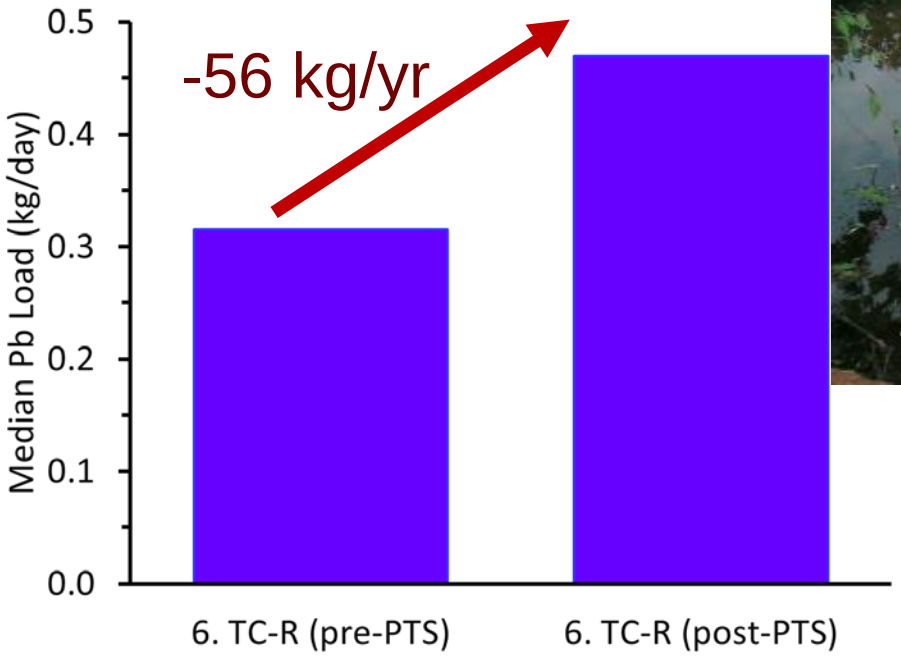
PTS Impacts to TC-R Mass Loads

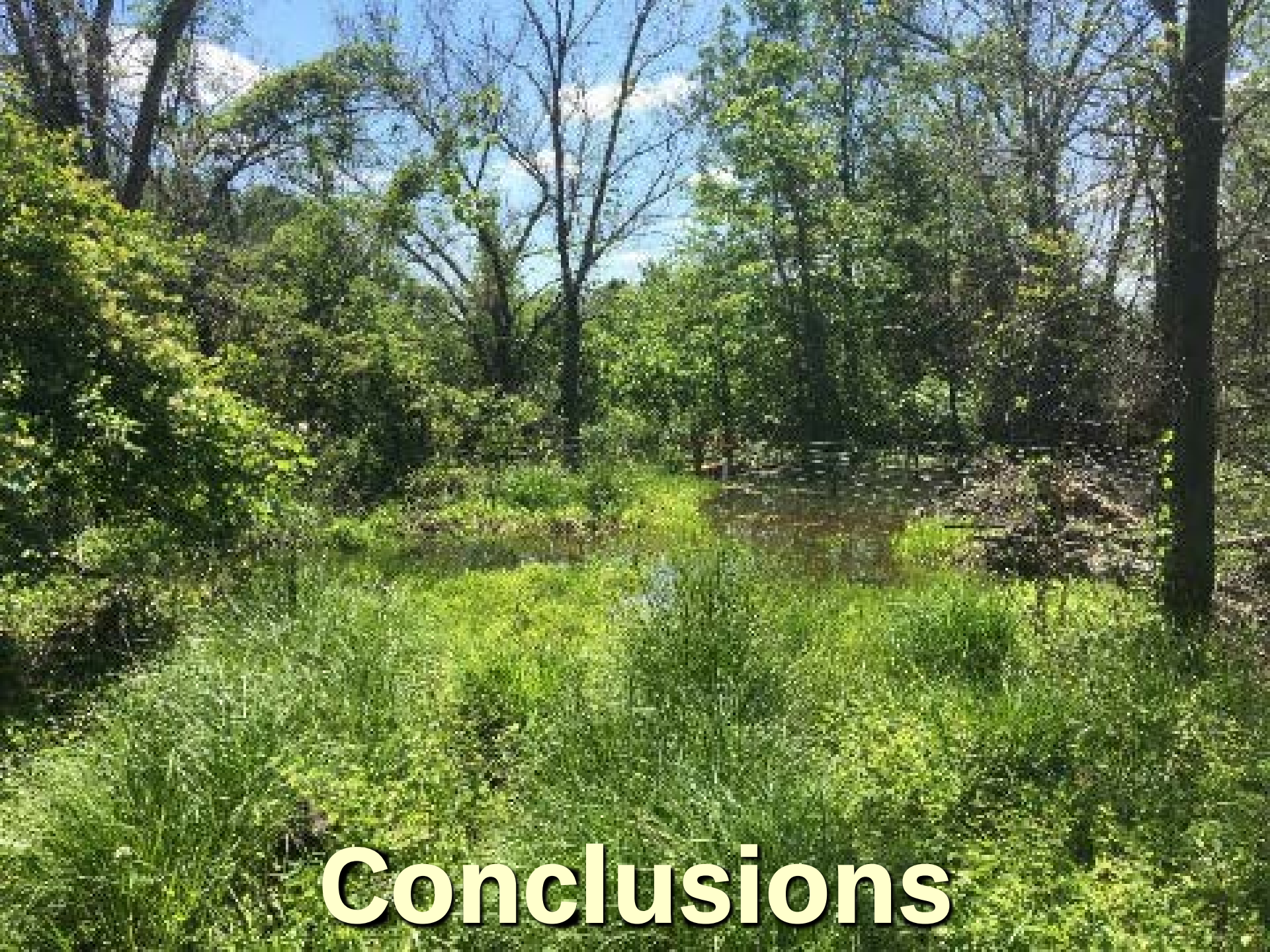


PTS Impacts to TC-R Mass Loads





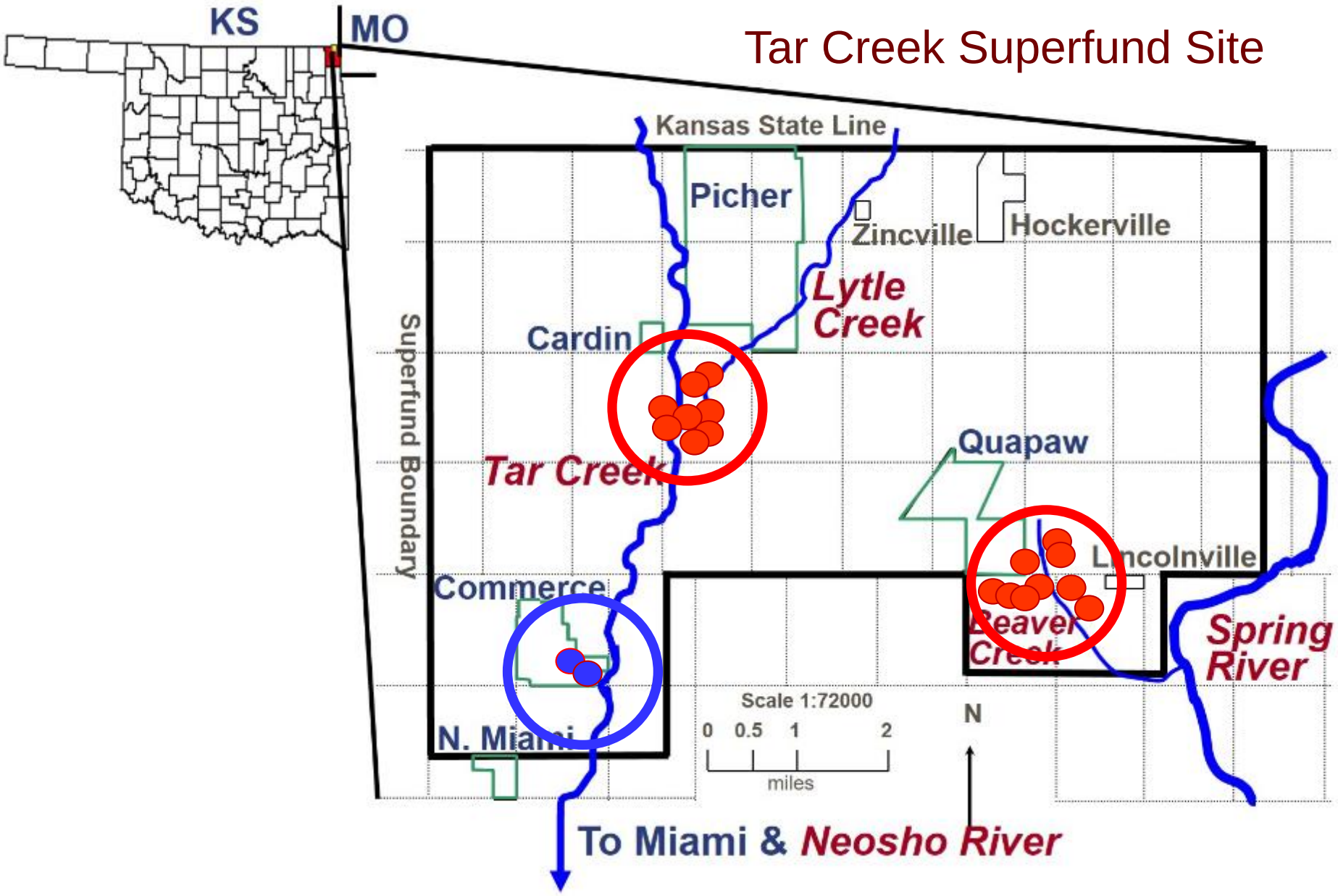



Conclusions

Conclusions

- MRPTS shows sustained mass retention 10 years
- SECPTS first year performance similar
- Drastic improvements in receiving stream

Artesian Mine Water Discharges




Petersburg Discharge,
Beaver Creek
Lavrion Discharge,
Tar Creek, Douthat
Two down…
Many More To Go…

Acknowledgements

- Our private landowners
  - Mayer, Pritchard, Martin and Corbus families
- Our funding sources
  - ODEQ Land Protection Division
  - Grand River Dam Authority Ecosystems Management
  - USEPA Water Division
  - USGS Toxic Substances Hydrology Program
- Our partners
  - OU CREW, CEES and Biology
  - Quapaw Tribe of Oklahoma
  - City of Commerce
  - Northeastern Oklahoma A&M College
  - CH2M-Hill team and subcontractors
  - BioMost Inc. and Riverman Engineering
  - LEAD Agency
- Tim Danehy and Buck Neely (BioMost Inc.)

The CREW

K Strevett, R Knox, W Matthews, E Bergey, J Basara, J LaBar, C Kellogg, A O'Sullivan, B Holzbauer-Schweitzer, D Nguyen, B Page, A Sikora, Z Tang, T Wall, E Fielding, E Thornton, K Steele, S Yepez, A Smith, J McAllister, W Andrews, A Brewer, B Santamaria, C Neely, A Garrido, W Strosnider, D Lutes, M Roberts, D Hensley, R White, C Gause, T Traw, J Coffey, C Porter, D Athay, B Winter, N Iverson, V Arvidson, R Garrett, C DuBois, E Breetzke, M Mercer, J Arango Calderon, N Berg-Mattson, J Brumley, B Furneaux, M Rice, R Dutnell, L Oxenford, A Strevett, Z Sansom, L Mignogna, W Runyon, K Ryan, P Eger, J Clifton, A Donaldson, H Bragg, A Danielson, A Oberst, D Tepo, K Swanson, D Miller, E Spargo, K Wahnee, J Fowler, S Guzman, N Shepherd, V Nadiq, A Marsh, S Zawrotny, T Bisanar, B. Winfrey, I Gray, M Cogburn, K Walker, D Morris, D Ertegrul, P Baczynski, B Johnson, A Sutter, K Kauk, C Turley, E Shaw, T Verlander, J Ingendorf, **et al.**

Questions?

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