Comprehensive Watershed Restoration via Ecological Engineering: The Role of Passive Treatment

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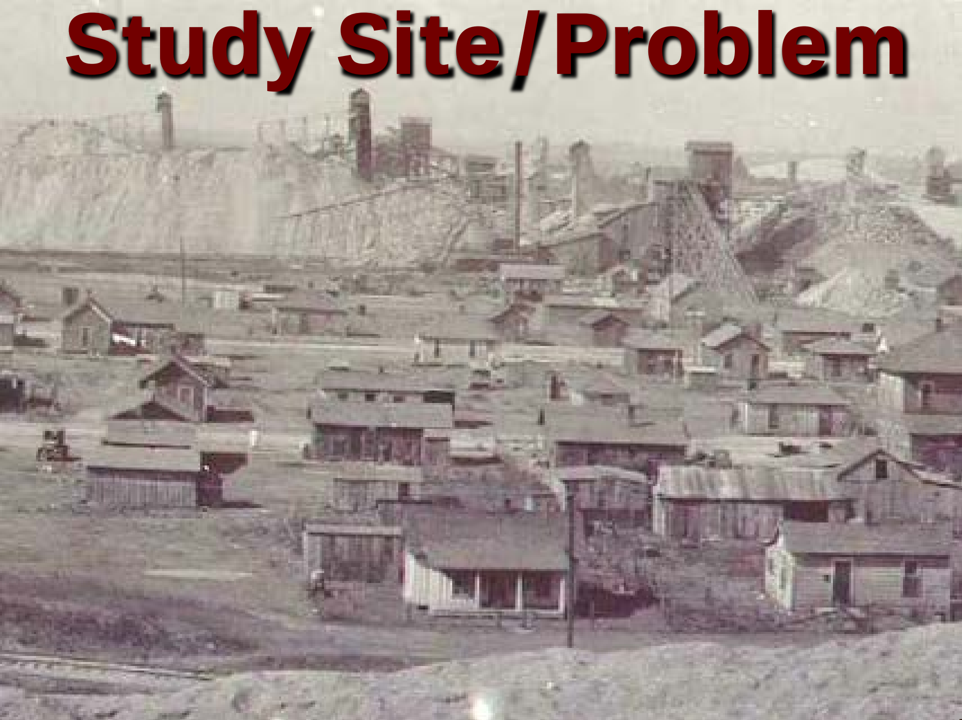
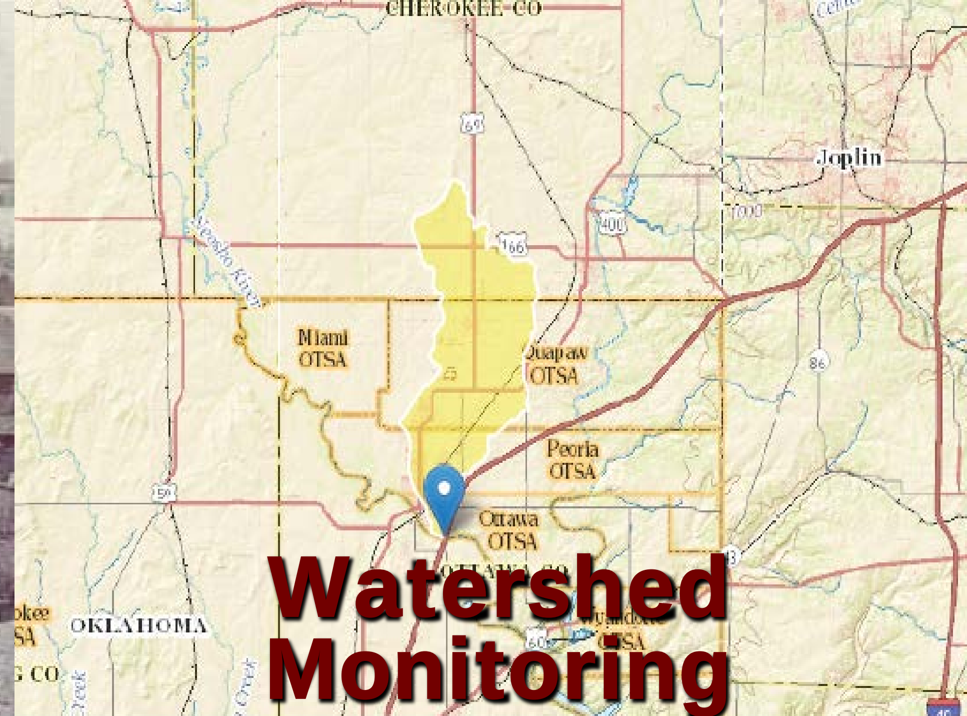
The University of Oklahoma, Norman, OK

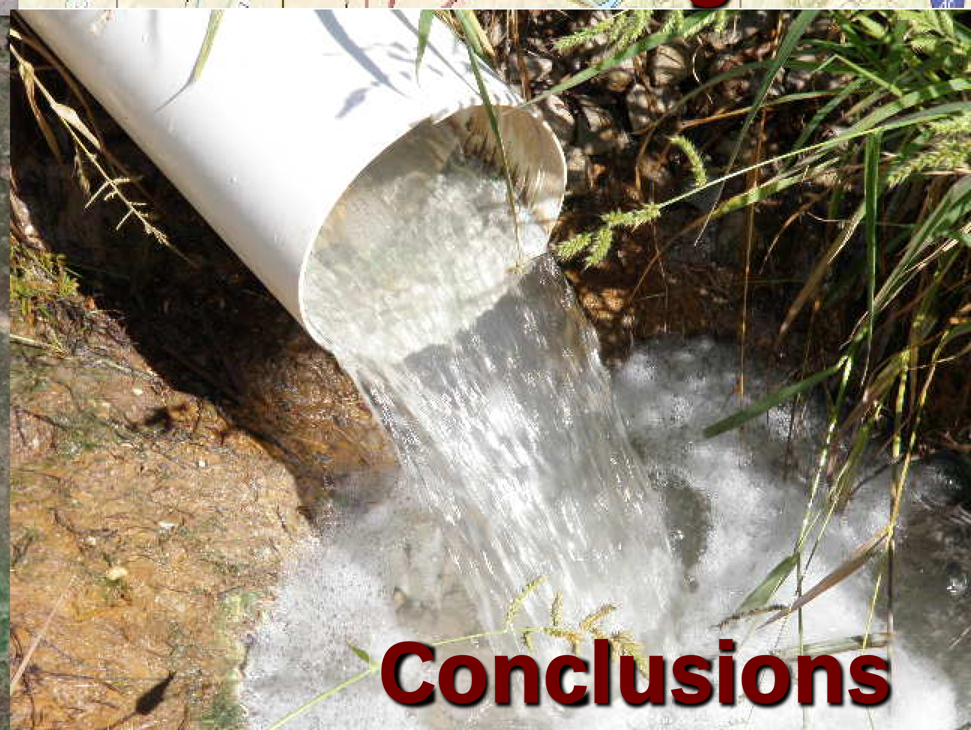
The CREW

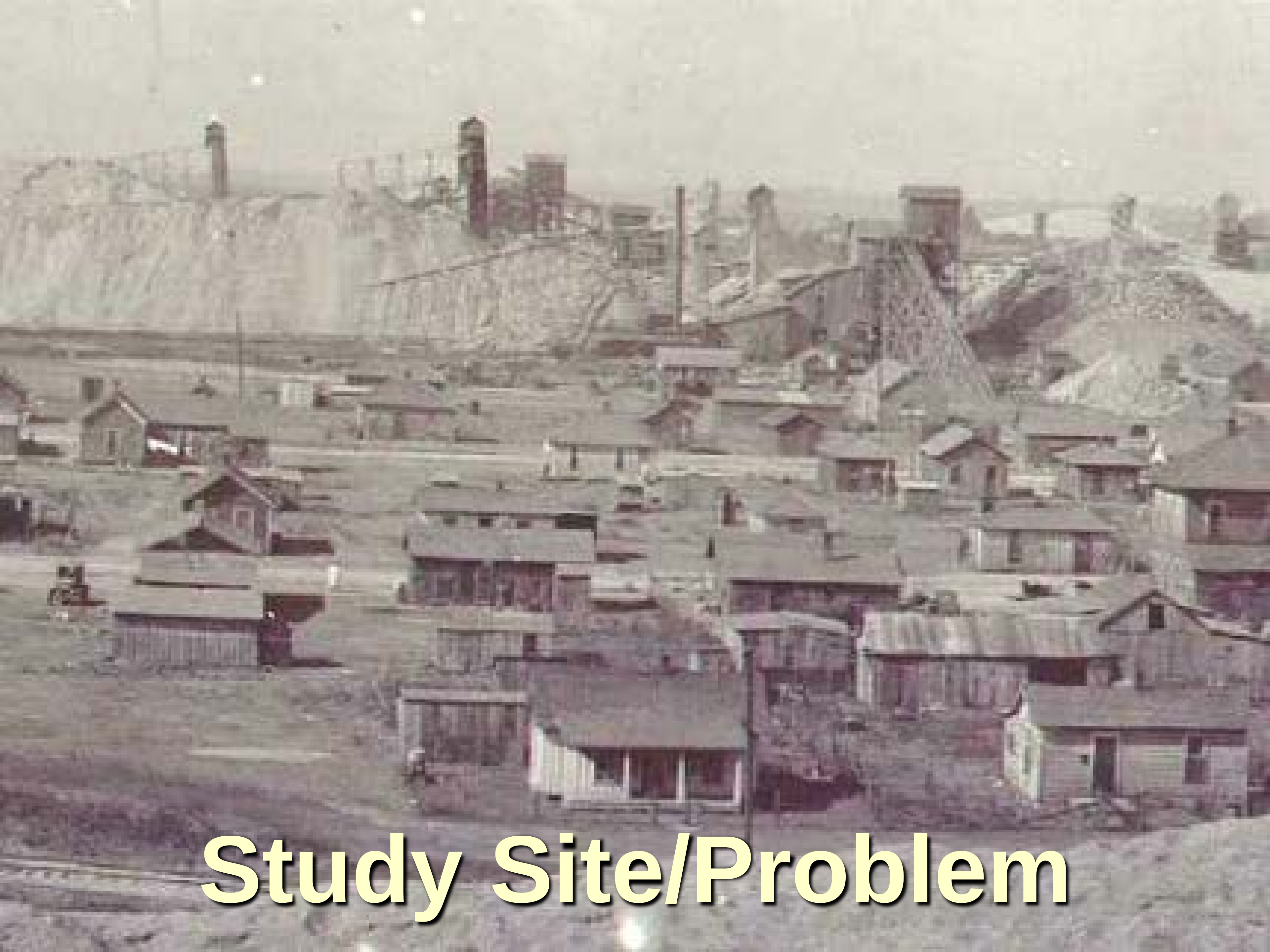
R. Knox, K. Strevett, W. Matthews, E. Bergey, J. Basara, J. LaBar, B. Holzbauer-Schweitzer, B. Page, N. Shepherd, E. Thornton, N. Berg-Mattson, E. Fielding, L. Oxenford, A. Marsh, D. Nguyen, A. Sikora, K. Steele, Z. Tang, J. Arango, C. Kellogg, A.D. O'Sullivan, R. Dutnell, M. Rice, B. Furneaux, J. Brumley, 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, 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, V. Nadiq, 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, et al.


Study Site/Problem


CHEROKEE CO
Joplin
Neosho River
Miami
OTSA
Quapaw
OTSA
Peoria
OTSA
Ottawa
OTSA
OKLAHOMA
Watershed
Monitoring


Treatment Options


Conclusions



Study Site/Problem

Tri-State Lead-Zinc Mining District

- >3000 km^2 mined ~1838-1971
- Mississippian sulfides
  - – Galena (PbS)
  - – Sphalerite (ZnS)
- ~26% of U.S. production in OK
- Significant environmental legacy

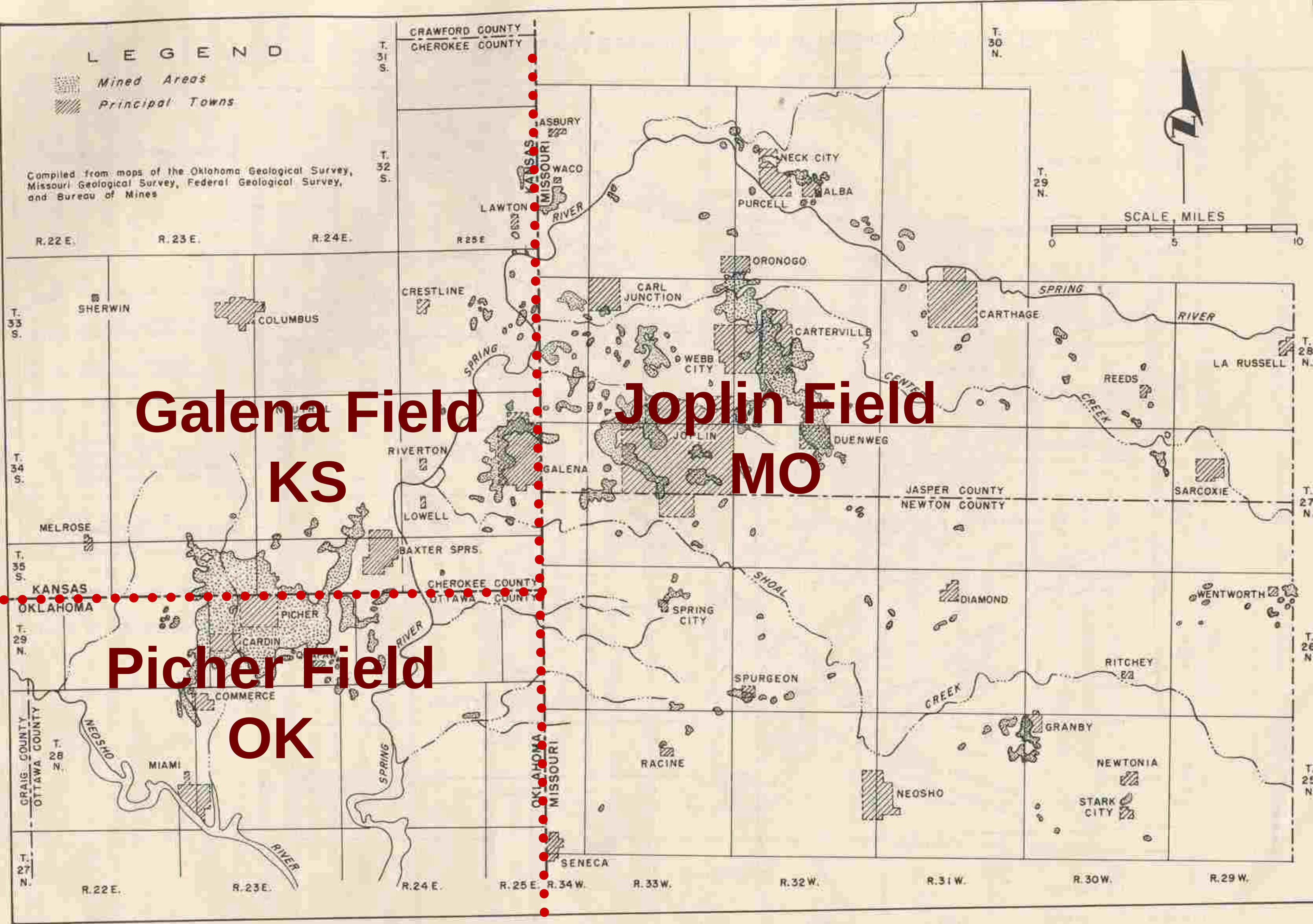


FIGURE 1. - Principal Part of Tri-State Zinc-Lead District, Showing Mined Areas.

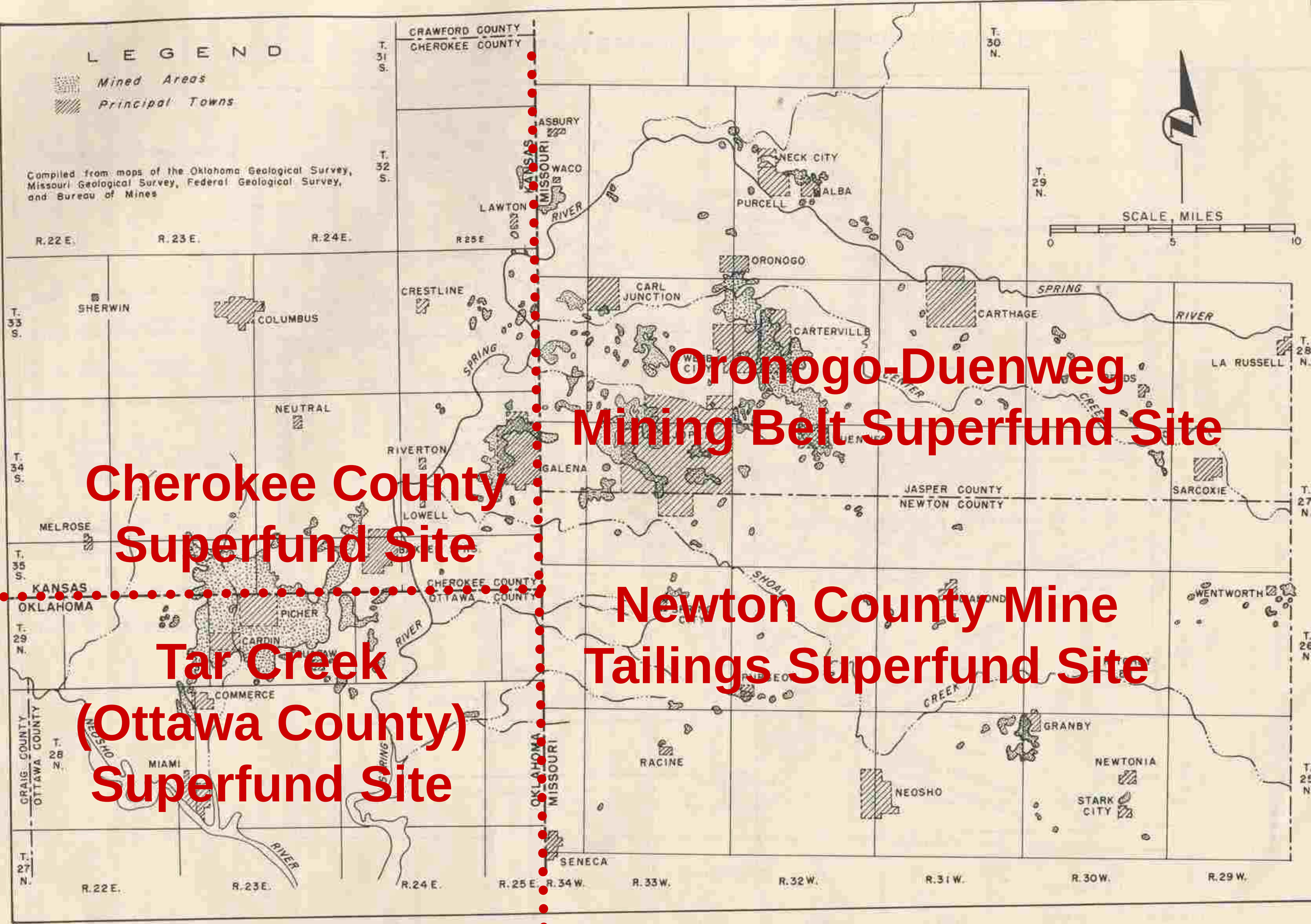
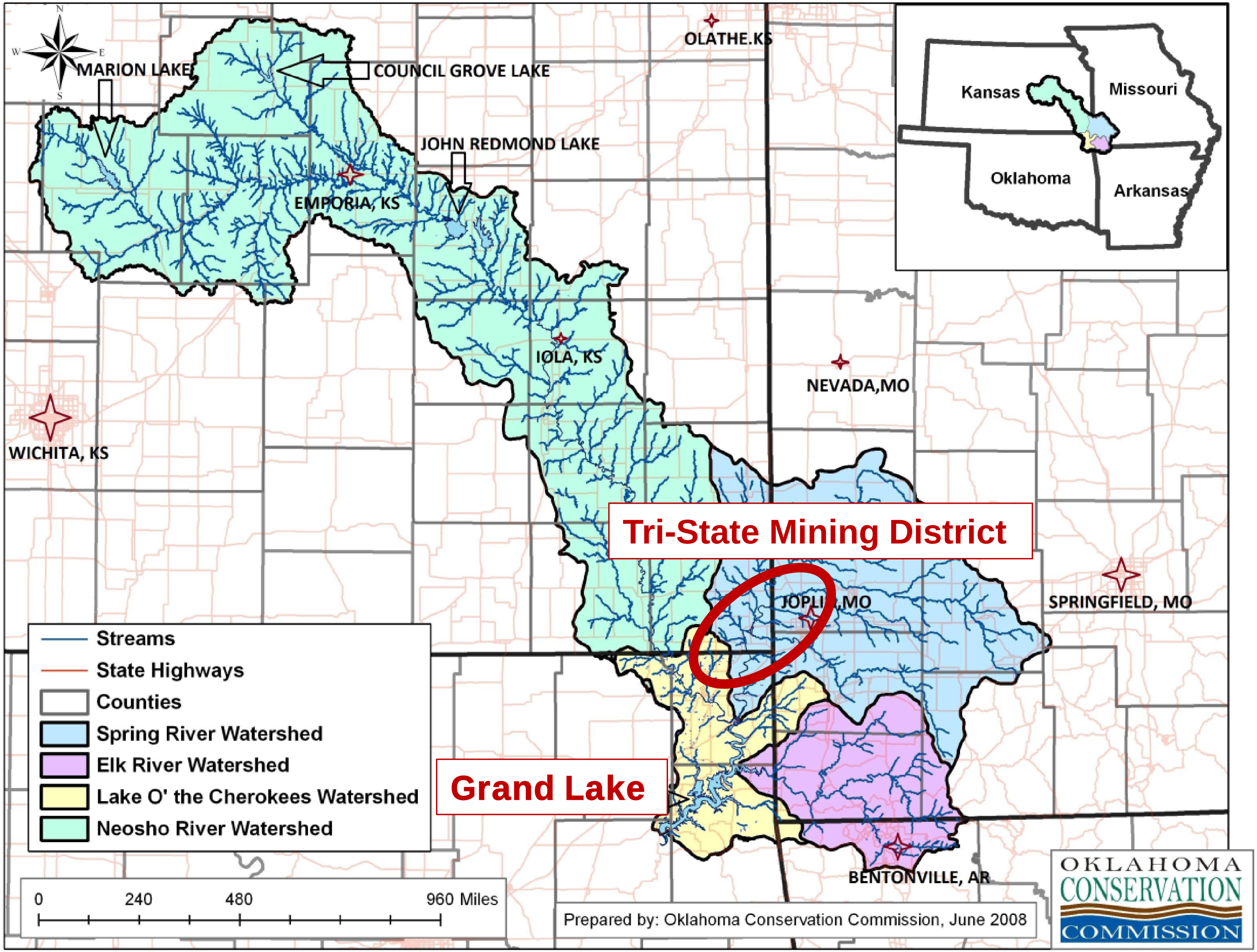


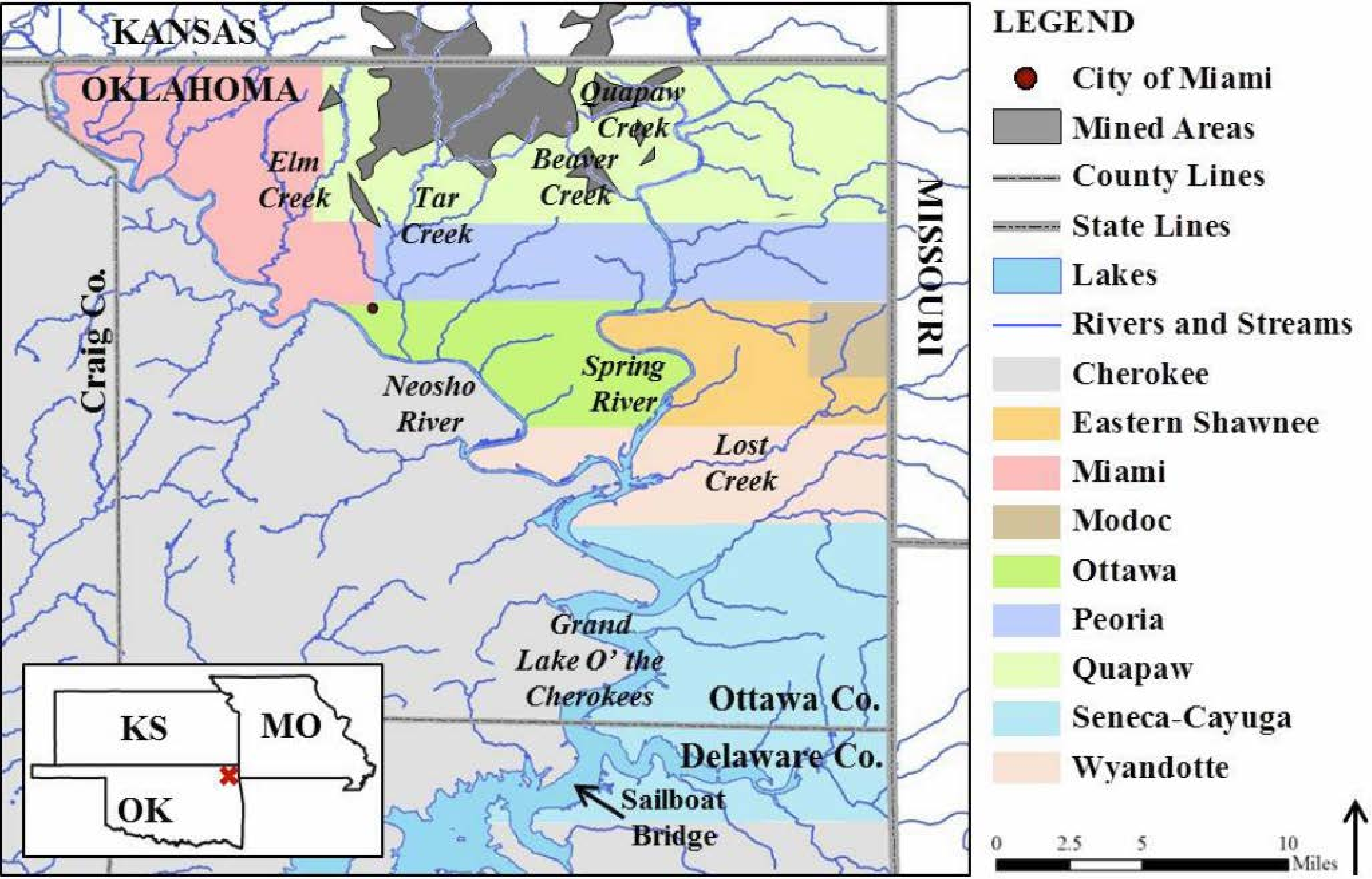
FIGURE 1. - Principal Part of Tri-State Zinc-Lead District, Showing Mined Areas.

Grand Lake Watershed



Tar Creek (OK) Superfund Site

- National Priorities List (since 1983)
- 105 km^2, included 6 communities
- Elevated Fe, Zn, Cd, Pb, As in water, chat, soils and biota
- Ten Native American Tribes


KANSAS
OKLAHOMA
Quapaw Creek
Elm Creek
Tar Creek
Beaver Creek
MISSOURI
Craig Co.
Neosho River
Spring River
Lost Creek
Grand Lake O' the Cherokees
Ottawa Co.
Delaware Co.
Sailboat Bridge
KS
MO
OK
LEGEND
City of Miami
Mined Areas
County Lines
State Lines
Lakes
Rivers and Streams
Cherokee
Eastern Shawnee
Miami
Modoc
Ottawa
Peoria
Quapaw
Seneca-Cayuga
Wyandotte
0 2.5 5 10
Miles

Tar Creek CERCLA Operable Units

- **OU 1 – Surface and Groundwater**
- OU 2 – Residential Soils
- OU 3 – Industrial Properties
- OU 4 – Non-Residential Source Materials
- OU 5 – Stream Sediments

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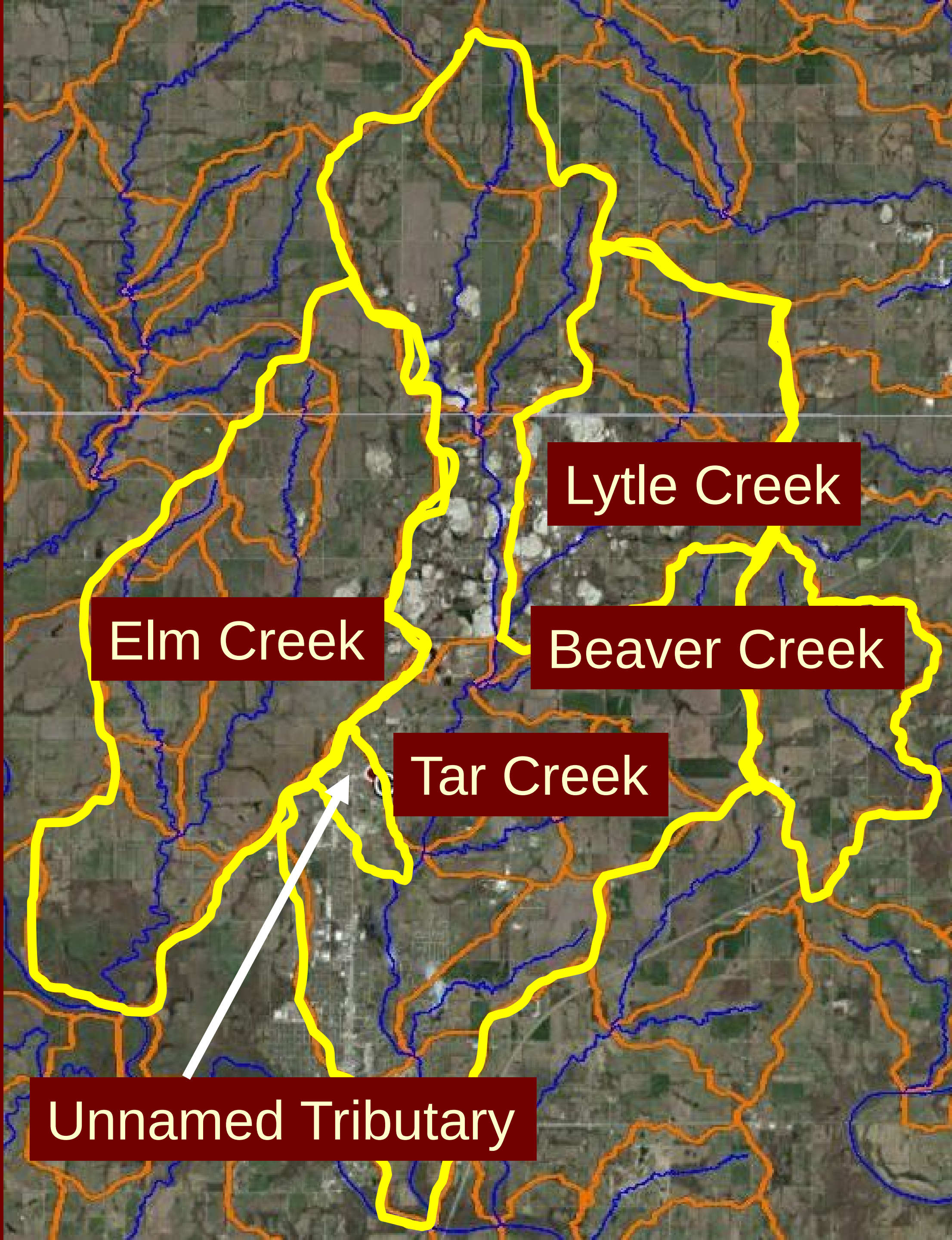
Tar Creek Surface and Ground Water Decision

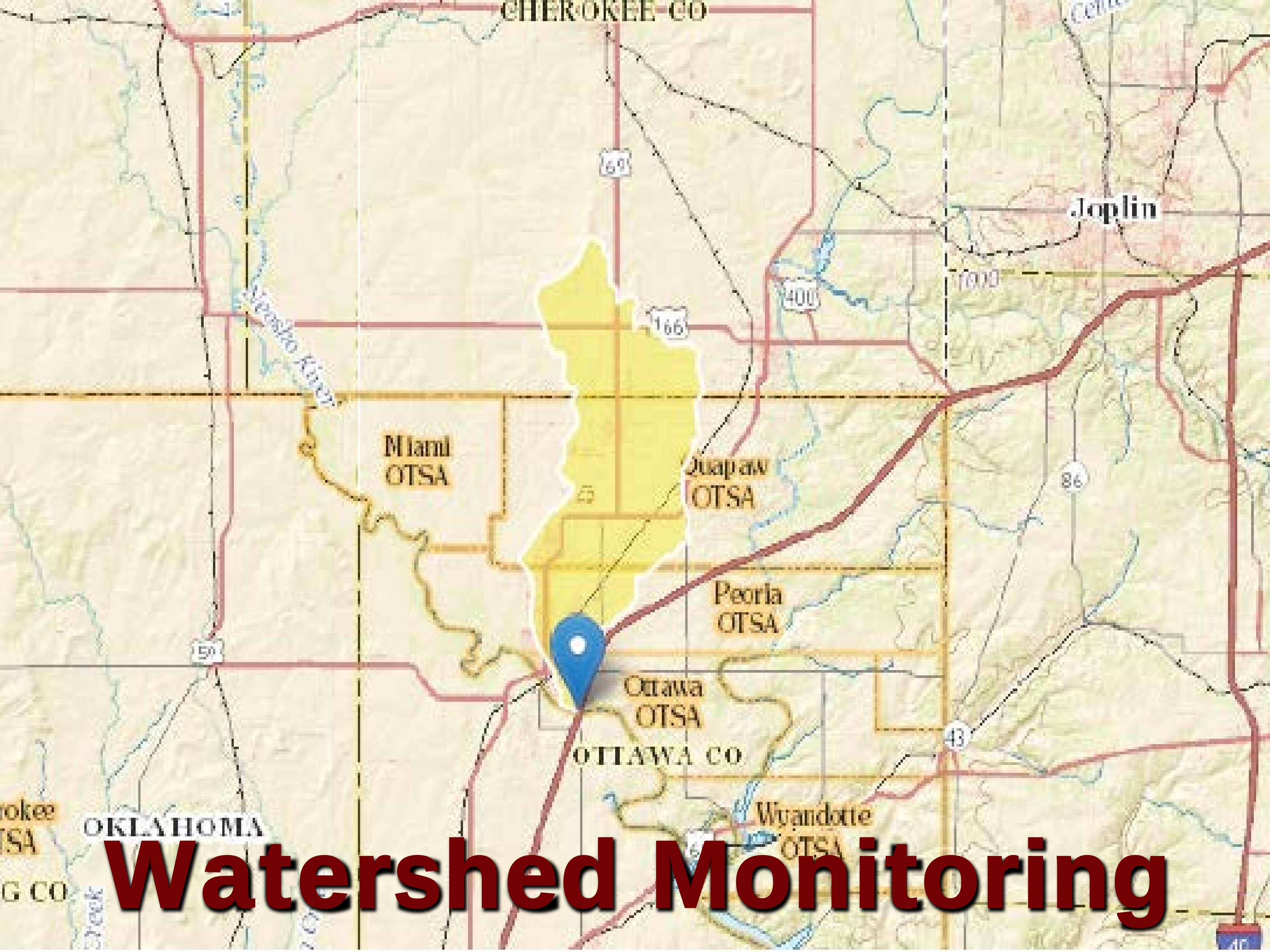
- Initial artesian discharges (1979)
- USEPA concluded that (1984):

  "impacts to (surface waters) are due to ***irreversible man-made damages*** *resulting from past mining operations at the site"*
- Fund-balancing waiver used
  - Costs prohibitively high to address surface water contamination

- Comprehensive watershed monitoring
- 2004-2016
- Focus on point of discharge passive treatment

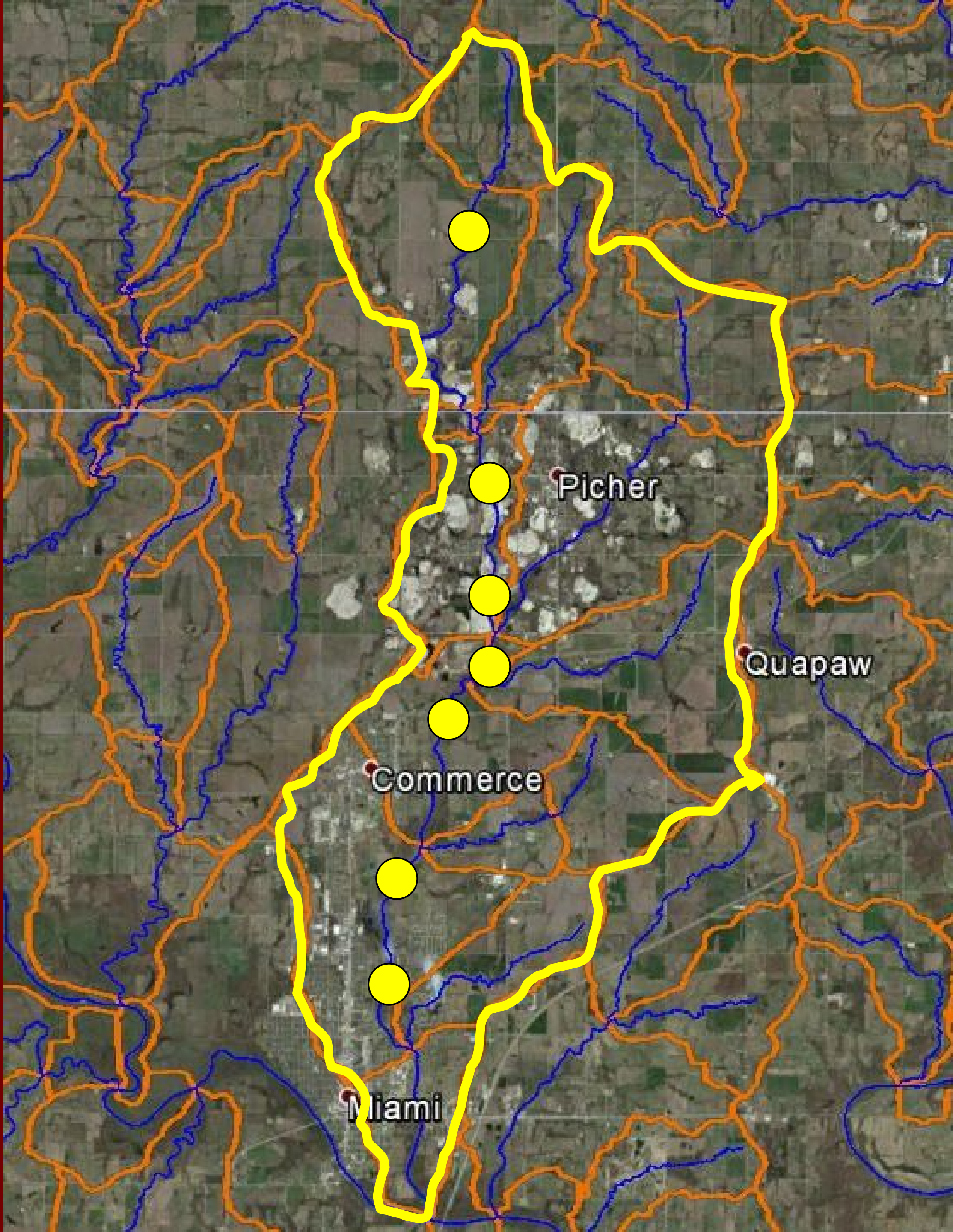


Watershed Monitoring



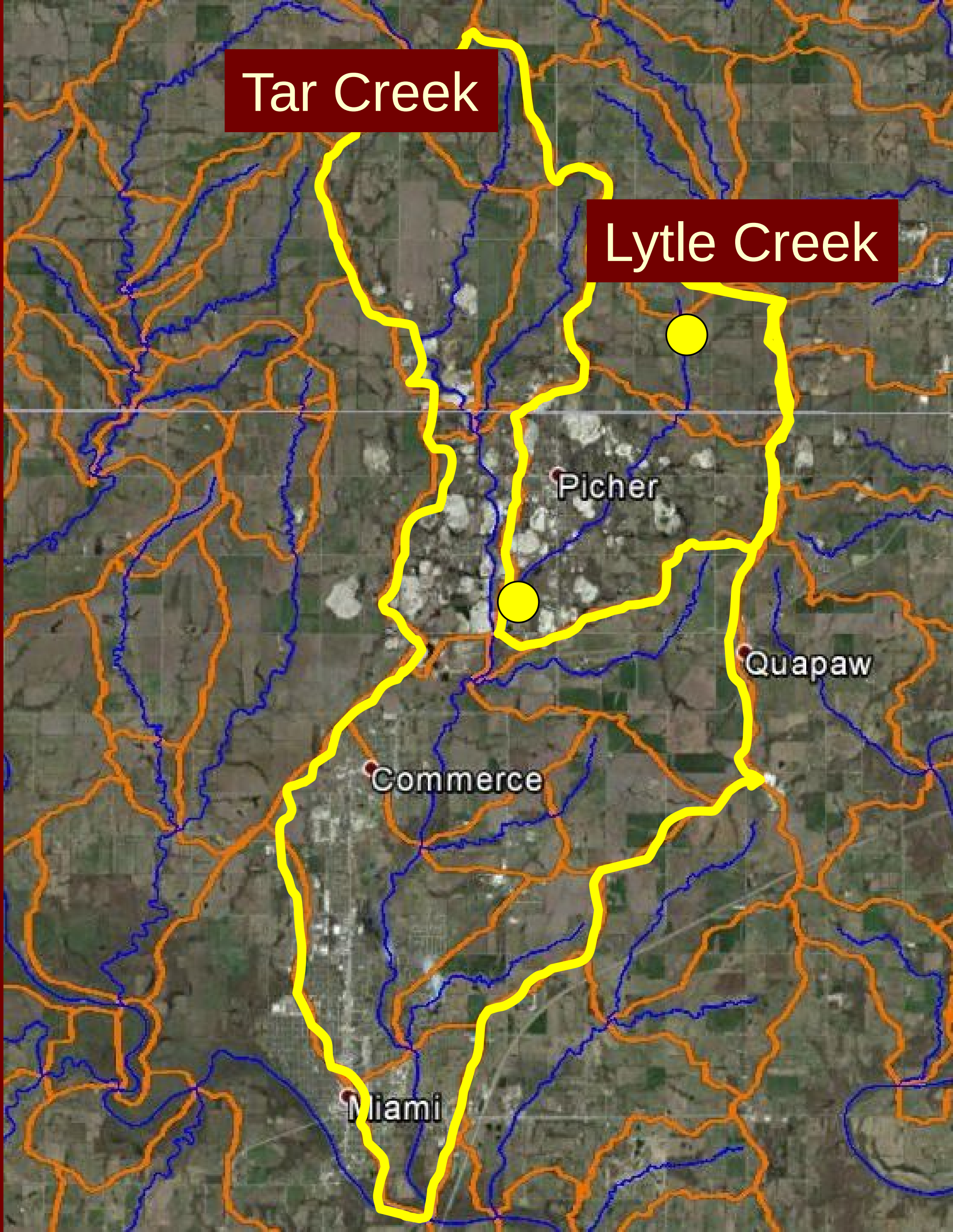
Tar Creek Watershed

- 53 mi^2
- Multiple seasonal and perennial artesian discharges
- Significant surface disturbance and leachate/runoff
- Discharge to Neosho River



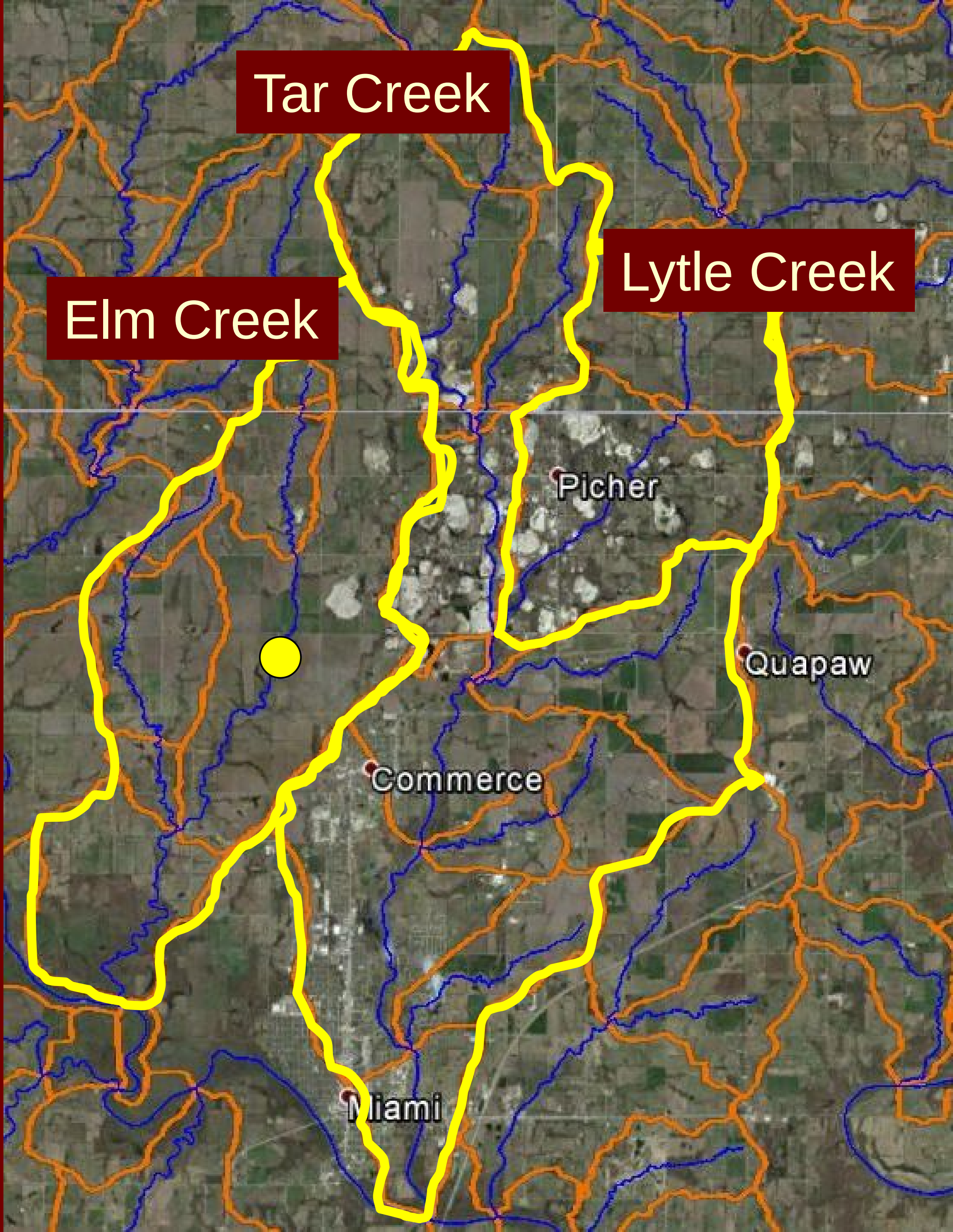
Lytle Creek Watershed

- $12\ mi^2$
- Minimal seasonal artesian flows
- Significant surface disturbance
- TC sub-basin



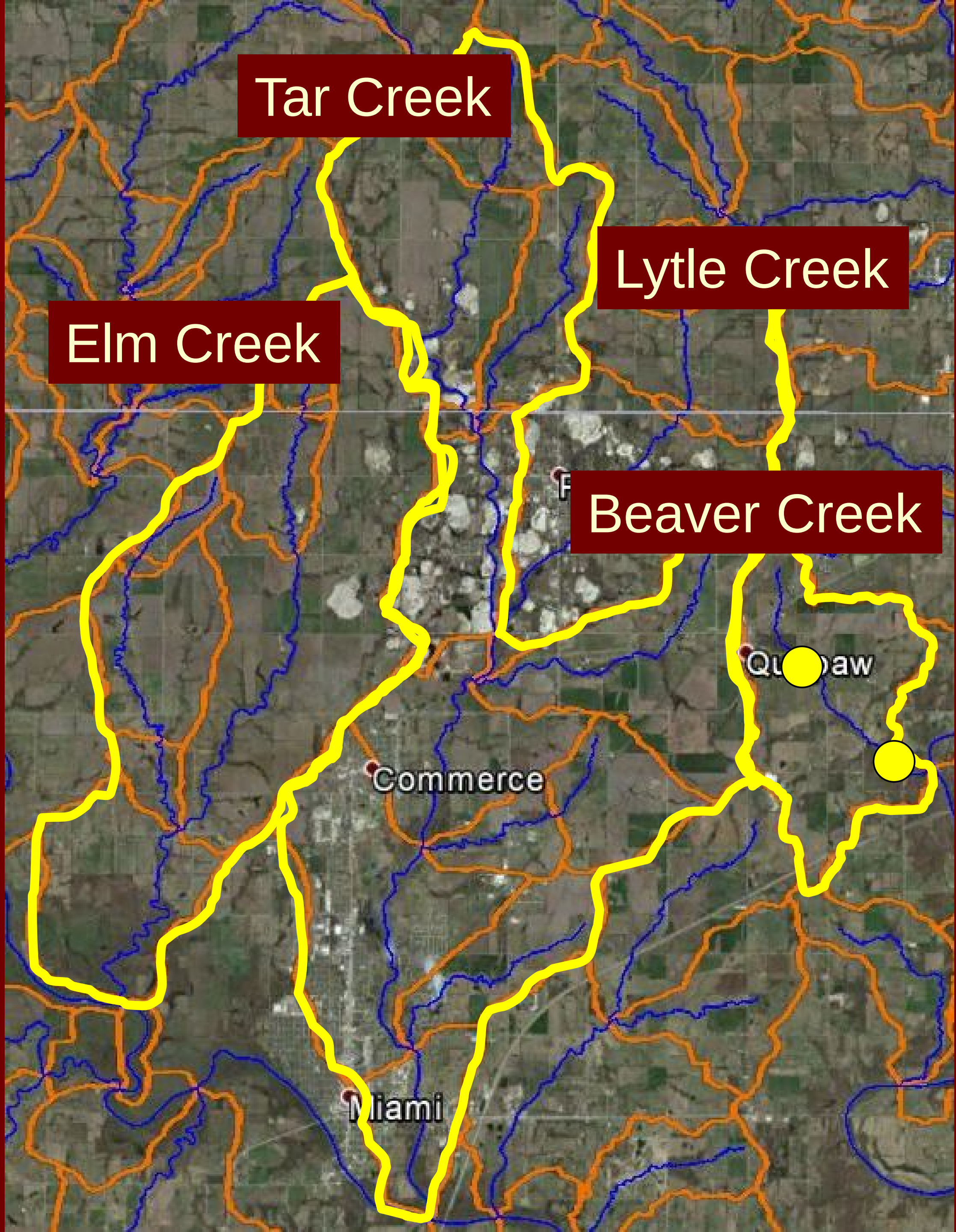
Elm Creek Watershed

- 23 mi^2
- No known artesian flows
- Minimal surface disturbance
- Discharge to Neosho River



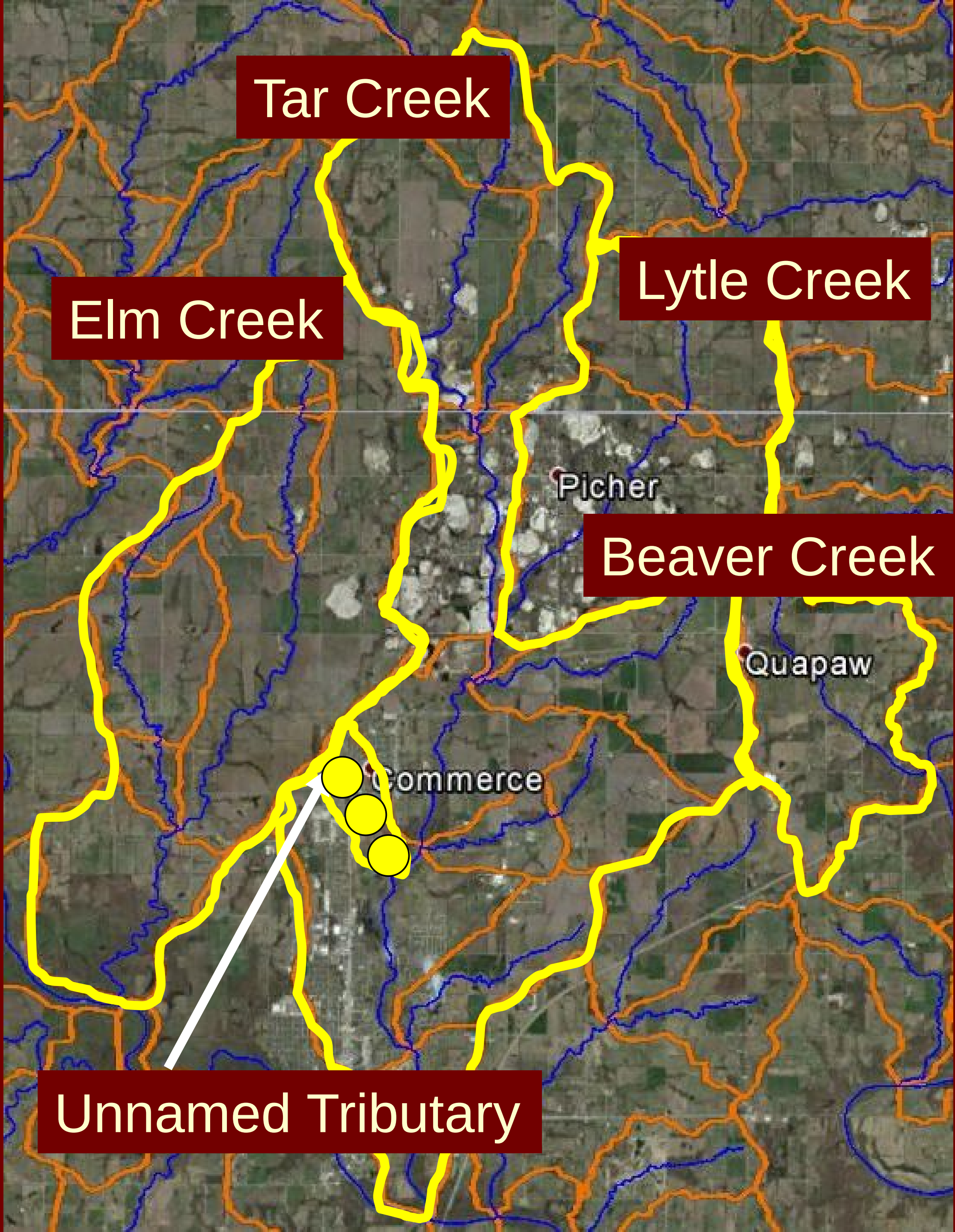
Beaver Creek Watershed

- 7 mi^2
- Multiple seasonal and perennial artesian flows
- Moderate surface disturbance
- Discharge to Spring River



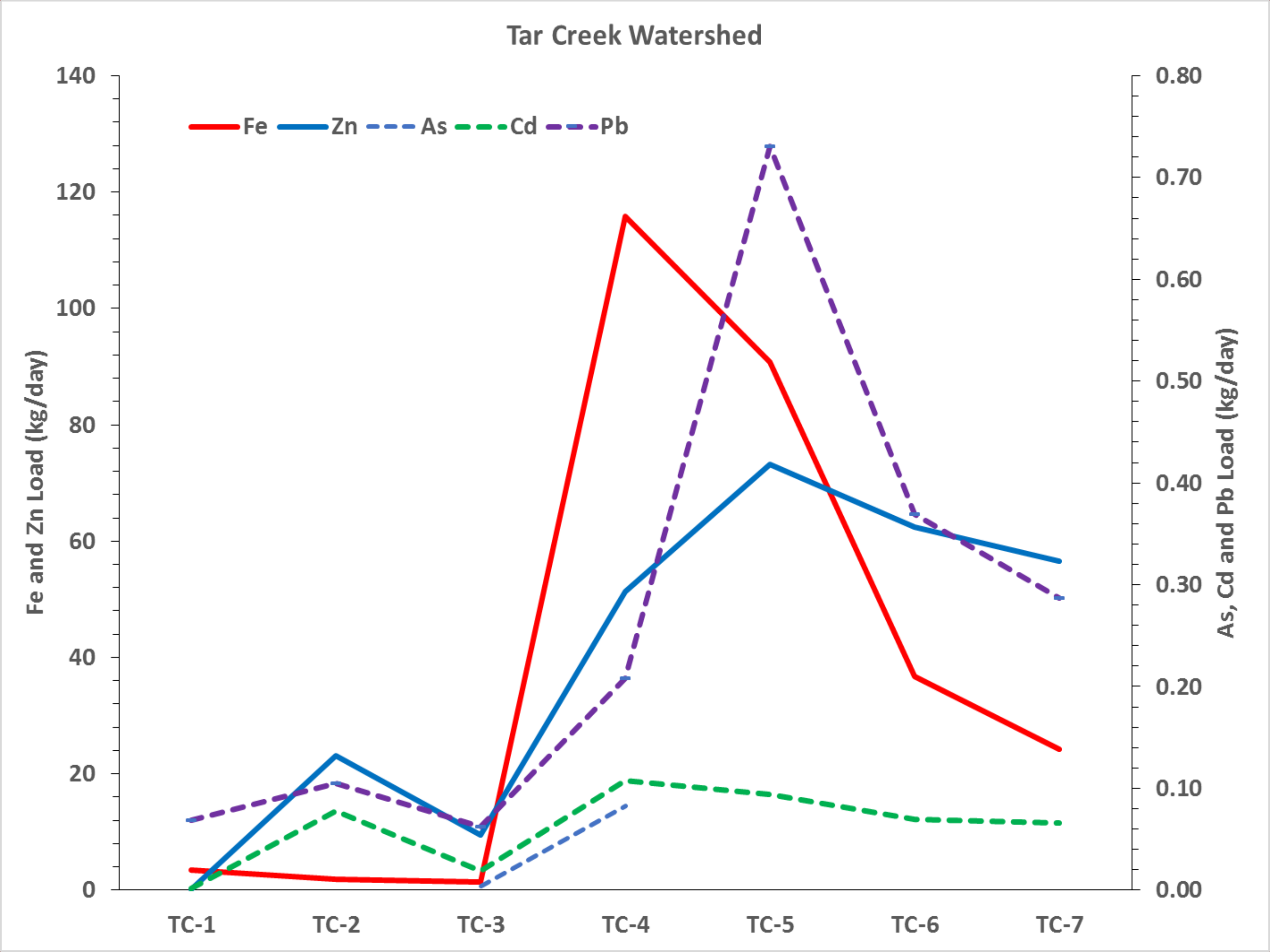
Unnamed Tributary Watershed

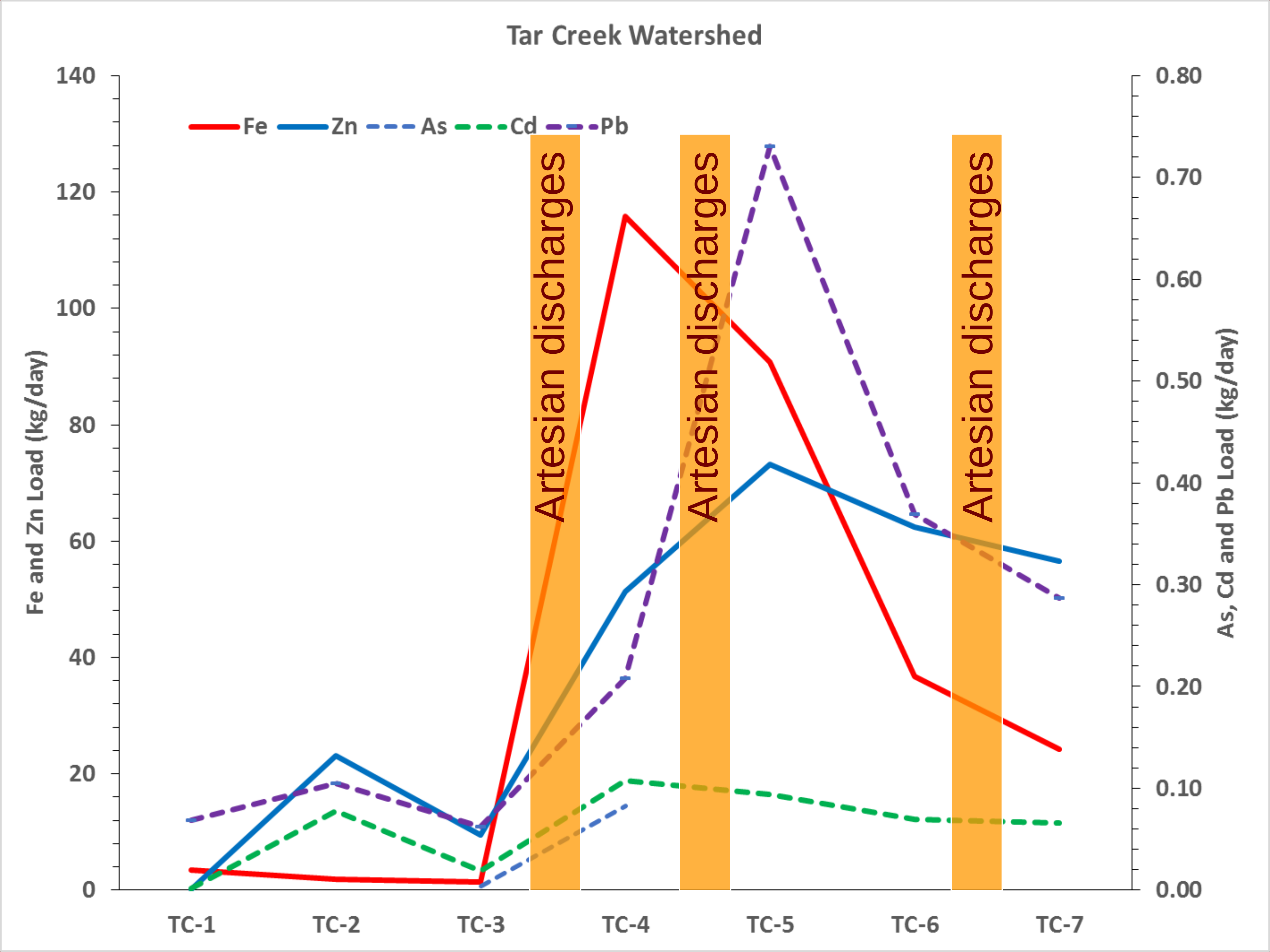
- 1.5 mi^2
- Multiple artesian flows
- Minimal surface disturbance
- TC sub-basin



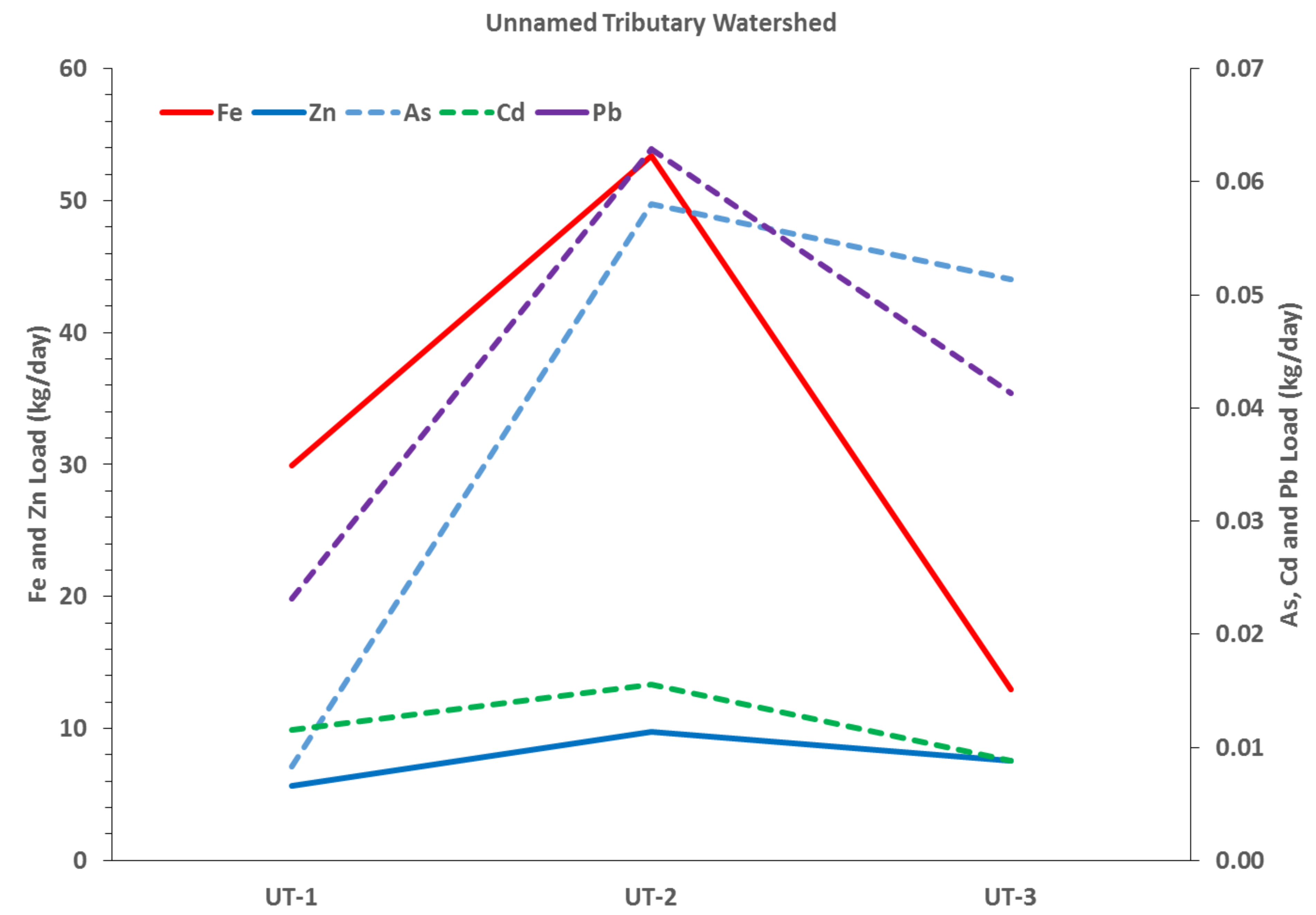
Watershed Pollution Sources

	Artesian Discharges	Leachate / Runoff
Tar Creek (TC)	High	High
Lytle Creek (LC)	Low	High
Elm Creek (EC)	Low	Moderate
Beaver Creek (BC)	High	Moderate
Unnamed Tributary (UT)	High	Low

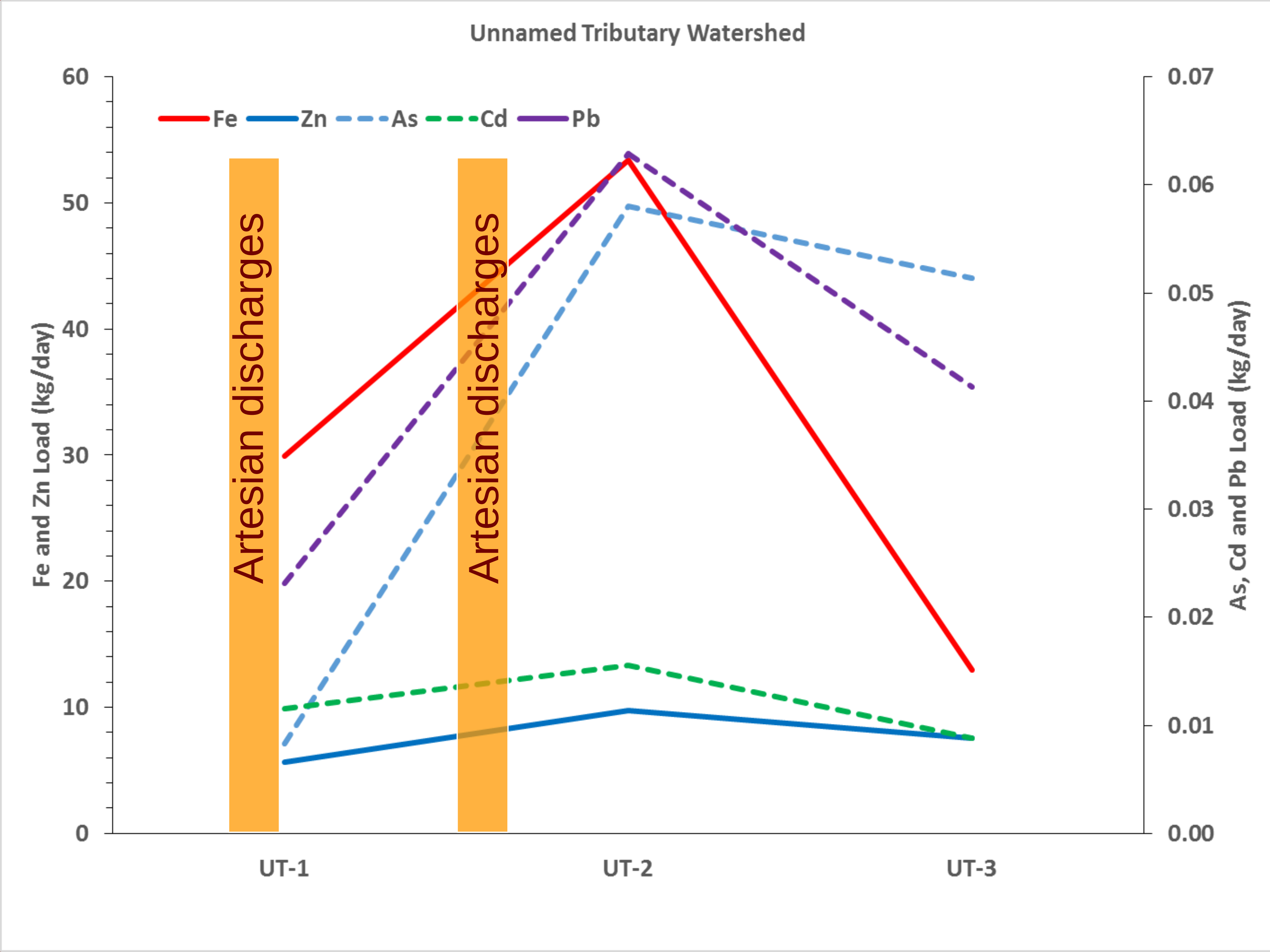

Tar Creek Watershed
Fe
Zn
As
Cd
Pb
Fe and Zn Load (kg/day)
As, Cd and Pb Load (kg/day)
0
20
40
60
80
100
120
140
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
TC-1
TC-2
TC-3
TC-4
TC-5
TC-6
TC-7



Tar Creek Watershed
Fe
Zn
As
Cd
Pb
Artesian discharges
Artesian discharges
Artesian discharges
Fe and Zn Load (kg/day)
As, Cd and Pb Load (kg/day)
140
120
100
80
60
40
20
0
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
TC-1
TC-2
TC-3
TC-4
TC-5
TC-6
TC-7



Unnamed Tributary Watershed
Fe
Zn
As
Cd
Pb
Fe and Zn Load (kg/day)
As, Cd and Pb Load (kg/day)
60
50
40
30
20
10
0
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
UT-1
UT-2
UT-3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Fe
Zn
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Cd
Pb
Artesian discharges
Artesian discharges
Fe and Zn Load (kg/day)
As, Cd and Pb Load (kg/day)
0
10
20
30
40
50
60
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
UT-1
UT-2
UT-3

Peak Median Loadings

	TDS	As	Cd	Fe	Pb	Zn
Creek	----------------------kg/day----------------------					
TC (HH)	16560	0.08	0.11	116	0.73	73
LC (LH)	3508	---	0.01	2.18	0.06	2.98
EC (LM)	470	---	0.07	1.04	0.09	8.85
BC (HM)	1341	---	0.01	1.23	0.06	1.28
UT (HL)	2867	0.06	0.02	53.4	0.06	9.77

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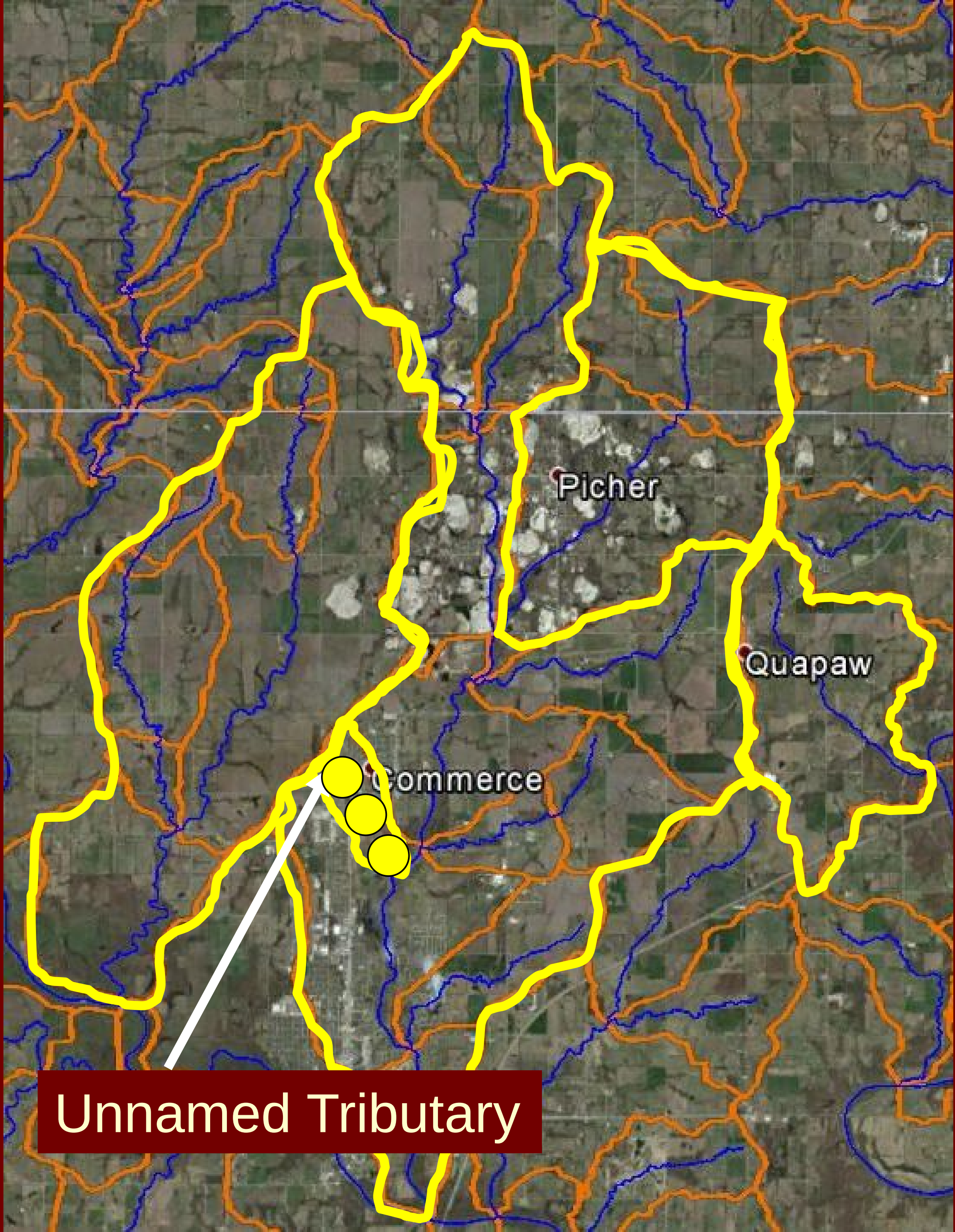
Treatment Options

Watershed-Based Restoration

- Artesian discharge treatment
- Elimination of source materials
- Residual leachate/runoff treatment

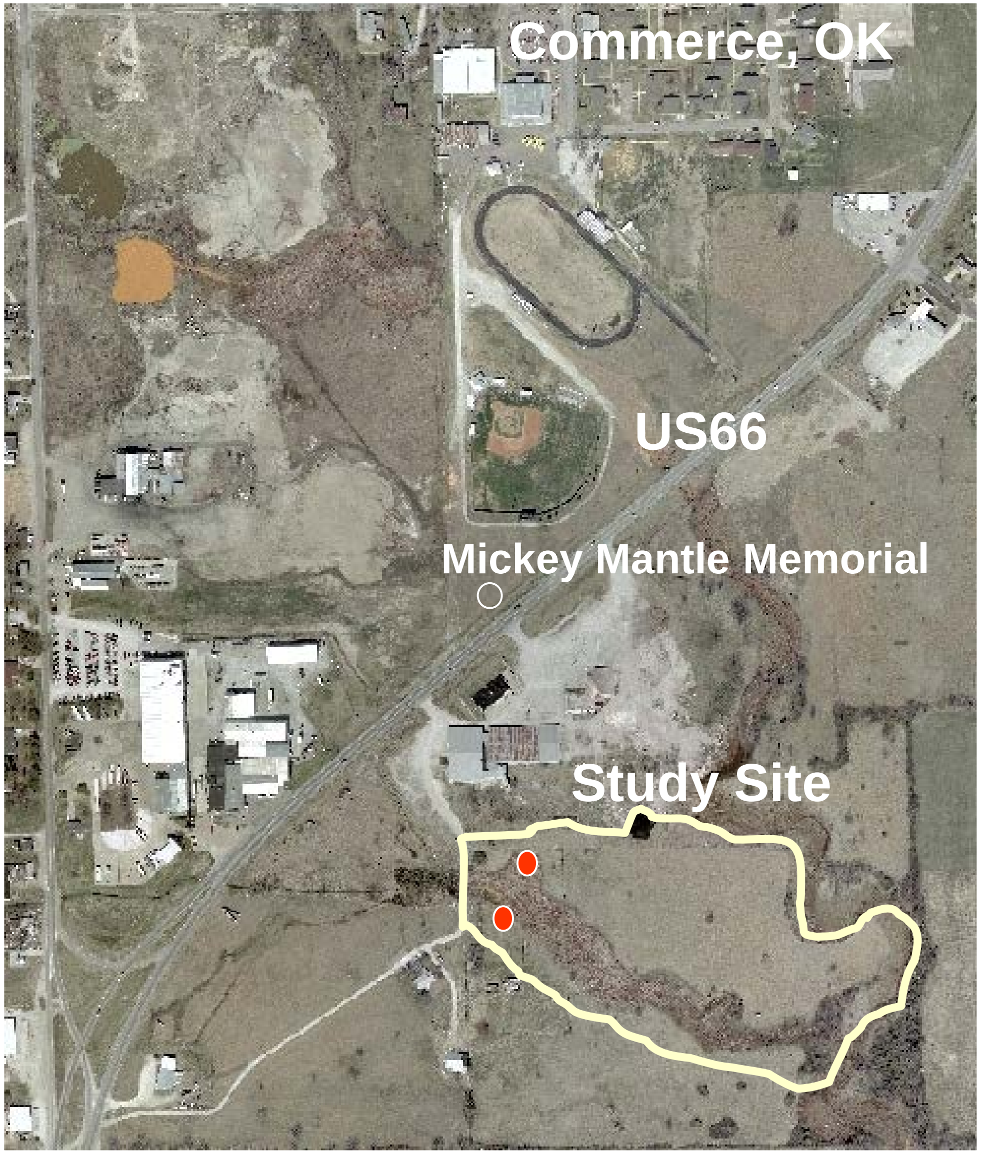
Unnamed Tributary Watershed

- 1.5 mi^2
- Multiple artesian flows
- Minimal surface disturbance
- TC sub-basin



Mayer Ranch Study Site

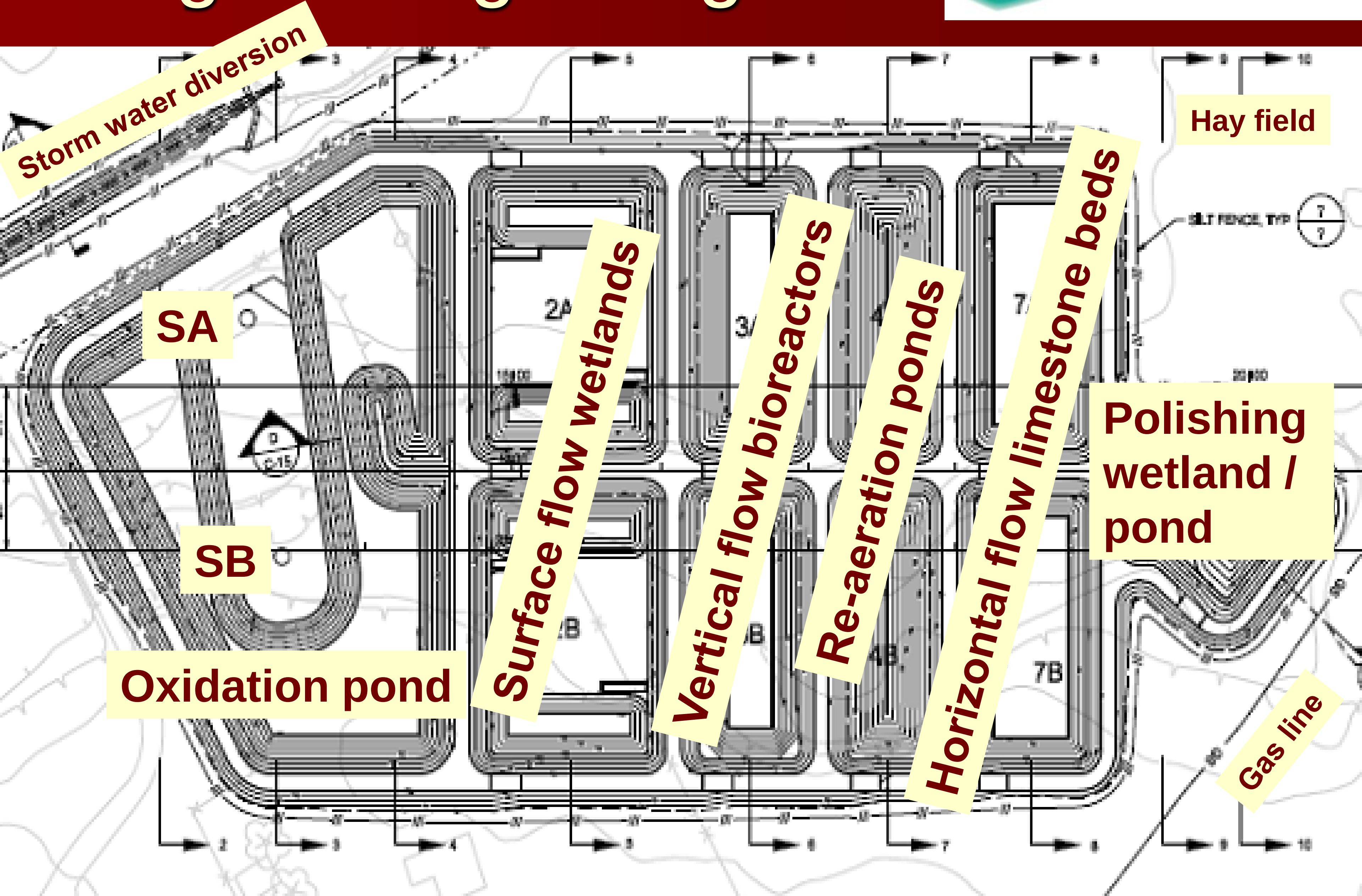
- Artesian discharges from abandoned boreholes
- 100 – 250 gpm
- Represent ~ 10-20% contaminant mass load in watershed

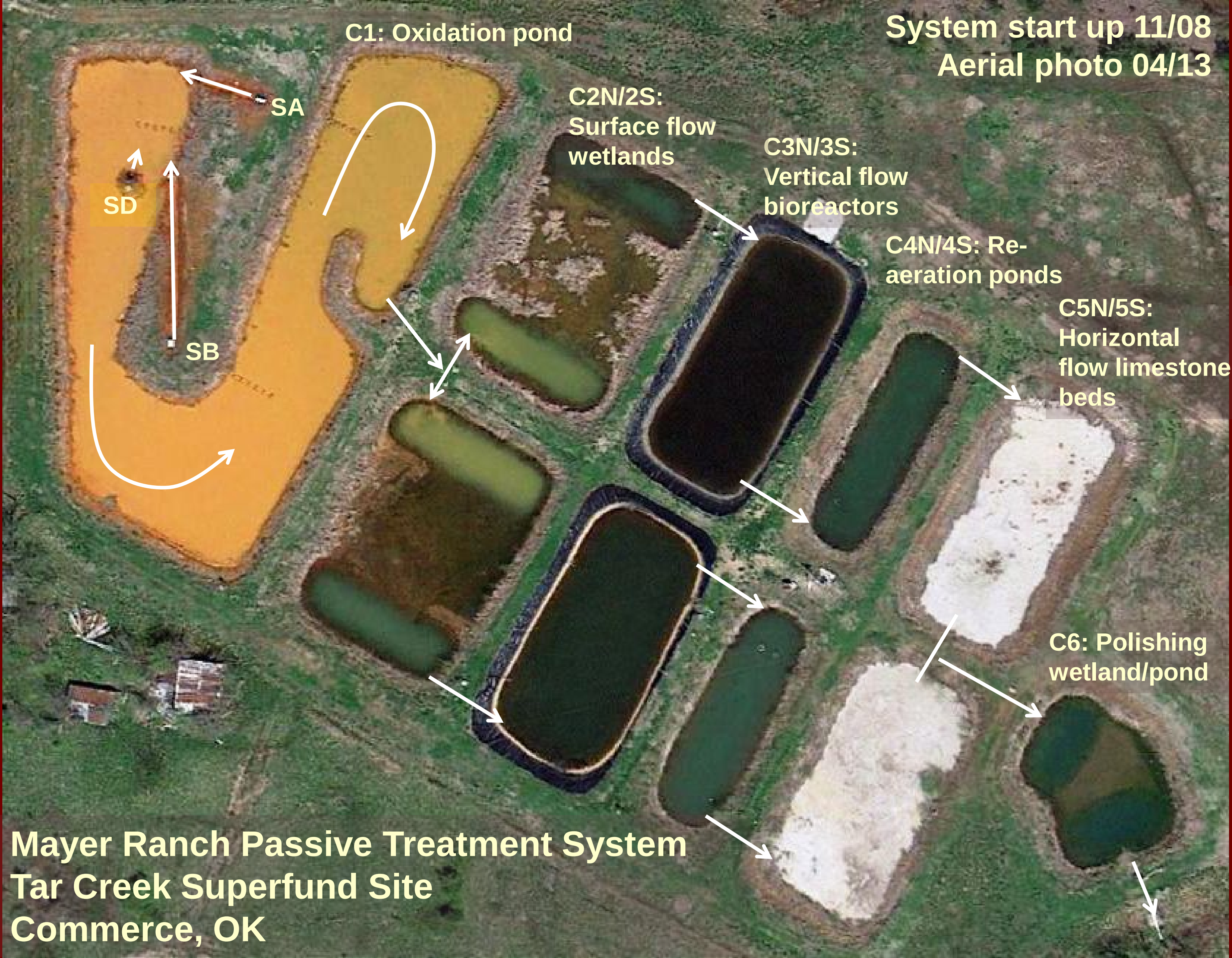


Mayer Ranch Water Quality

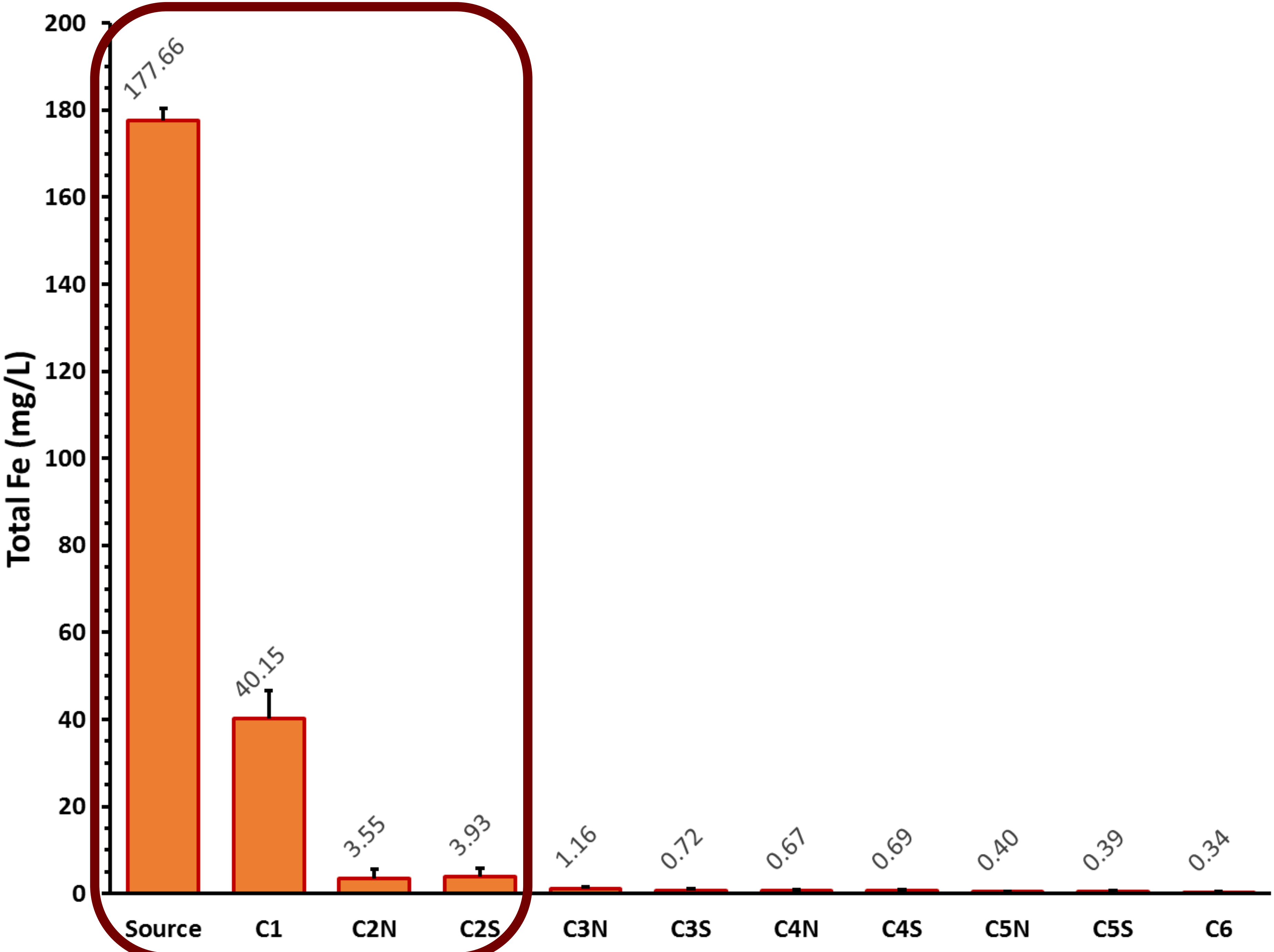
pH	5.95 ± 0.06
Alk. (net)	393 ±18 (29) mg/L
Fe	192 ± 3 mg/L
Zn	11 ± 0.07 mg/L
Ni	0.97 ± 0.02 mg/L
Cd	17 ± 4 μg/L
Pb	60 ± 13 μg/L
As	64 ± 2 μg/L
SO_4^{-2}	2239 ± 26 mg/L

Engineering Design

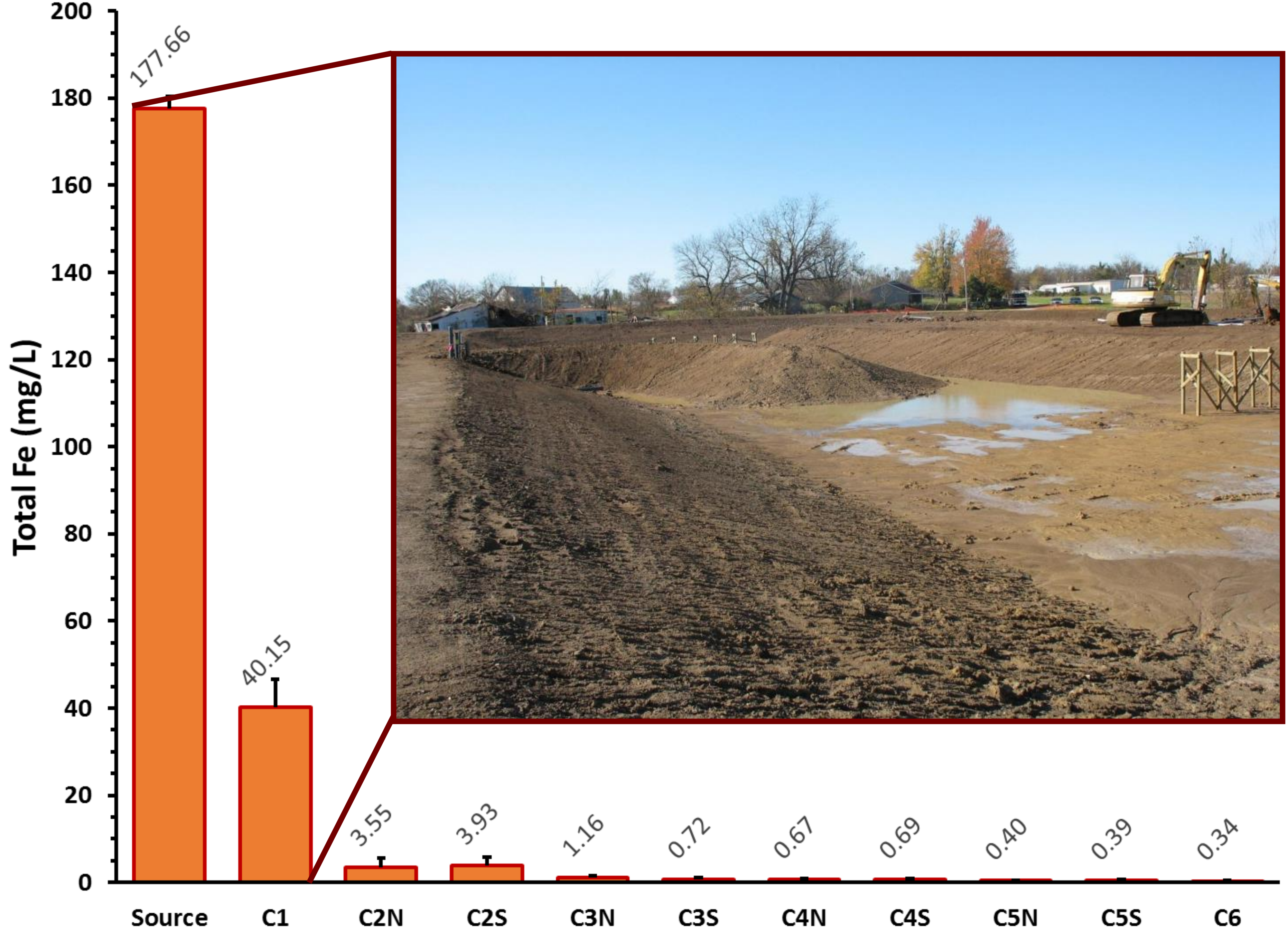




C1: Oxidation pond
System start up 11/08
Aerial photo 04/13
SA
SD
SB
C2N/2S:
Surface flow
wetlands
C3N/3S:
Vertical flow
bioreactors
C4N/4S: Re-
aeration ponds
C5N/5S:
Horizontal
flow limestone
beds
C6: Polishing
wetland/pond
Mayer Ranch Passive Treatment System
Tar Creek Superfund Site
Commerce, OK



Total Fe (mg/L)
200
180
160
140
120
100
80
60
40
20
0
177.66
40.15
3.55
3.93
1.16
0.72
0.67
0.69
0.40
0.39
0.34
Source
C1
C2N
C2S
C3N
C3S
C4N
C4S
C5N
C5S
C6



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C1
C2N
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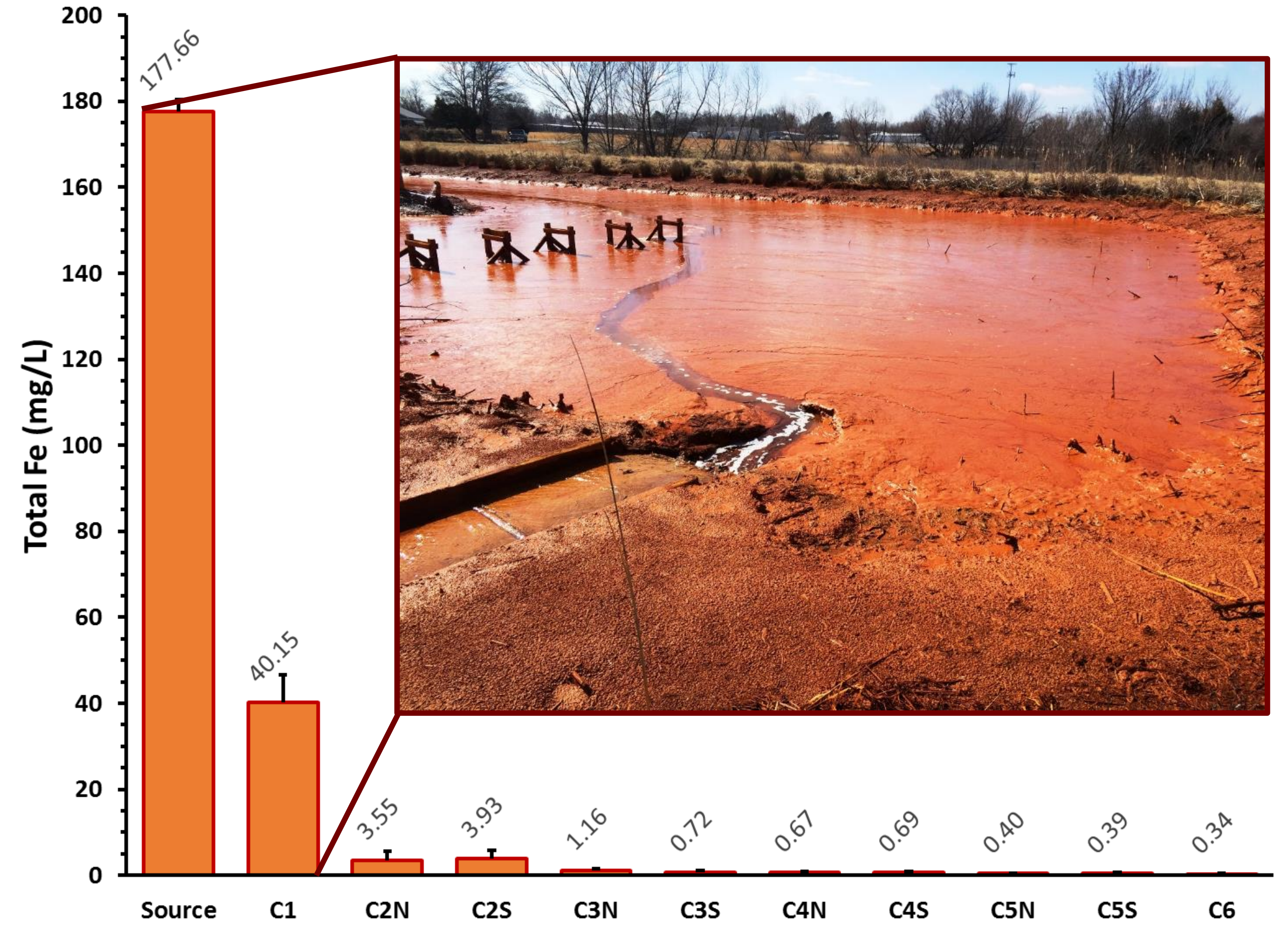
C3S
C4N
C4S
C5N
C5S
C6



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0.40
0.39
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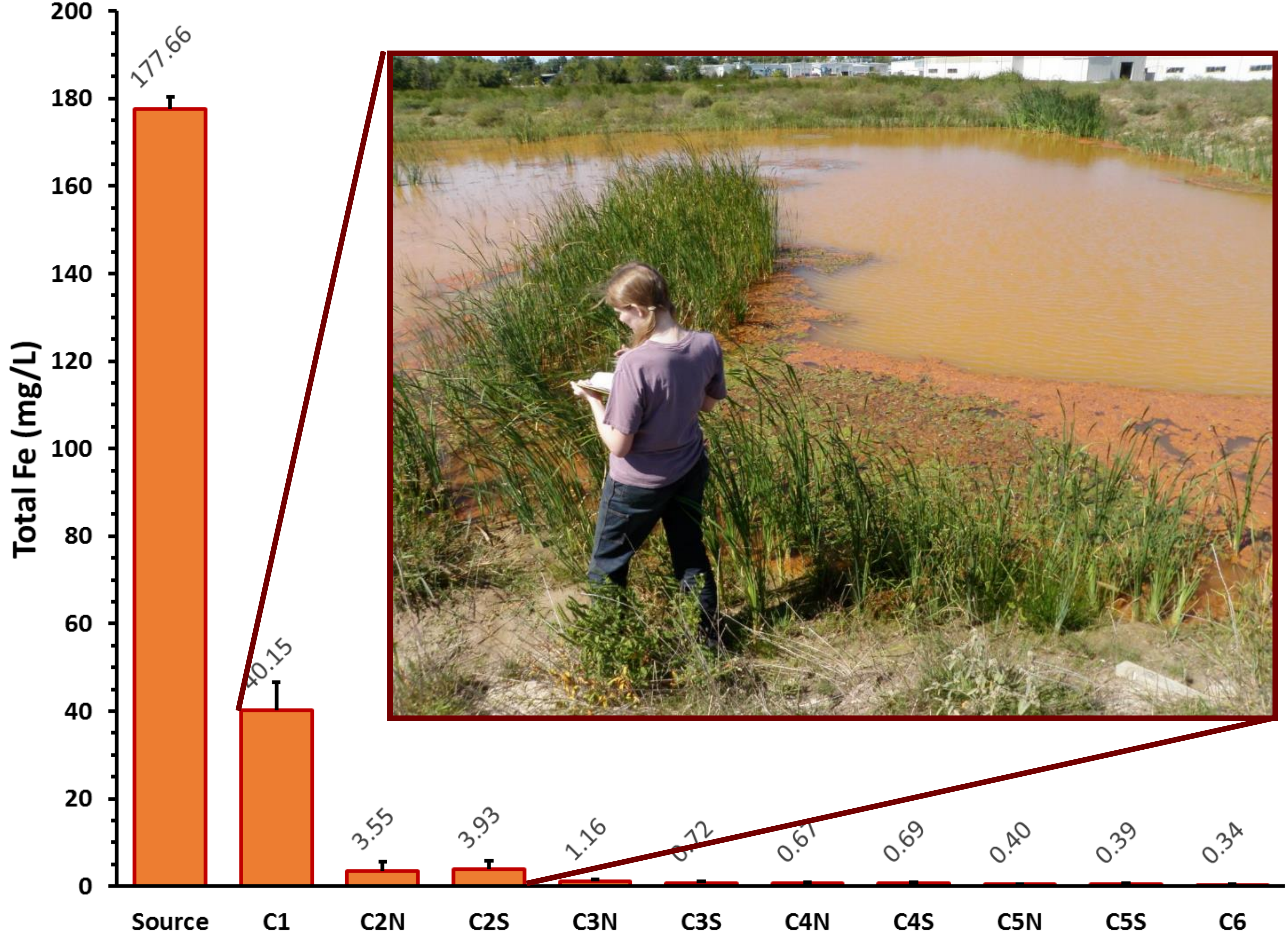
Source
C1
C2N
C2S
C3N
C3S
C4N
C4S
C5N
C5S
C6



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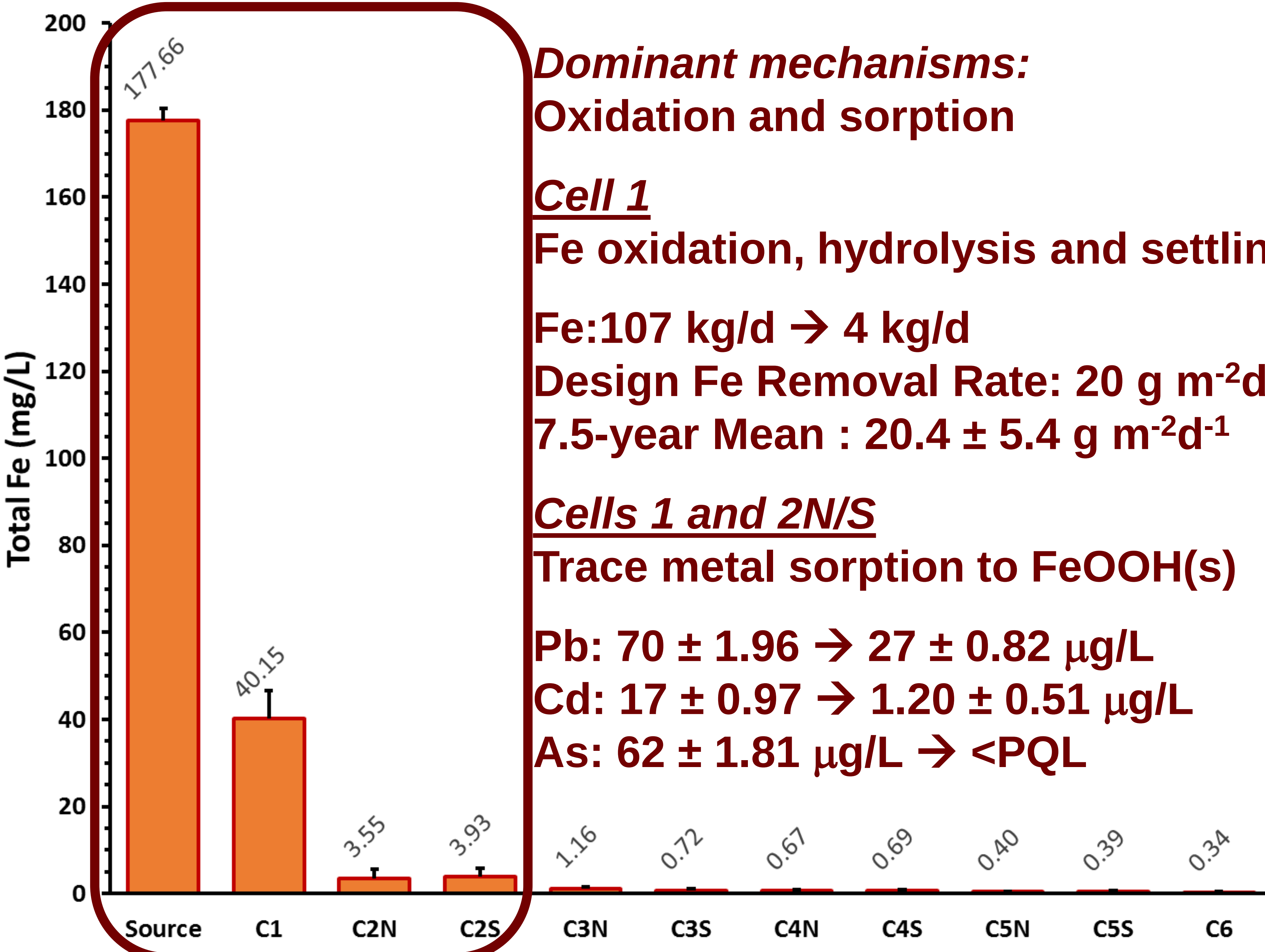
C4N
C4S
C5N
C5S
C6



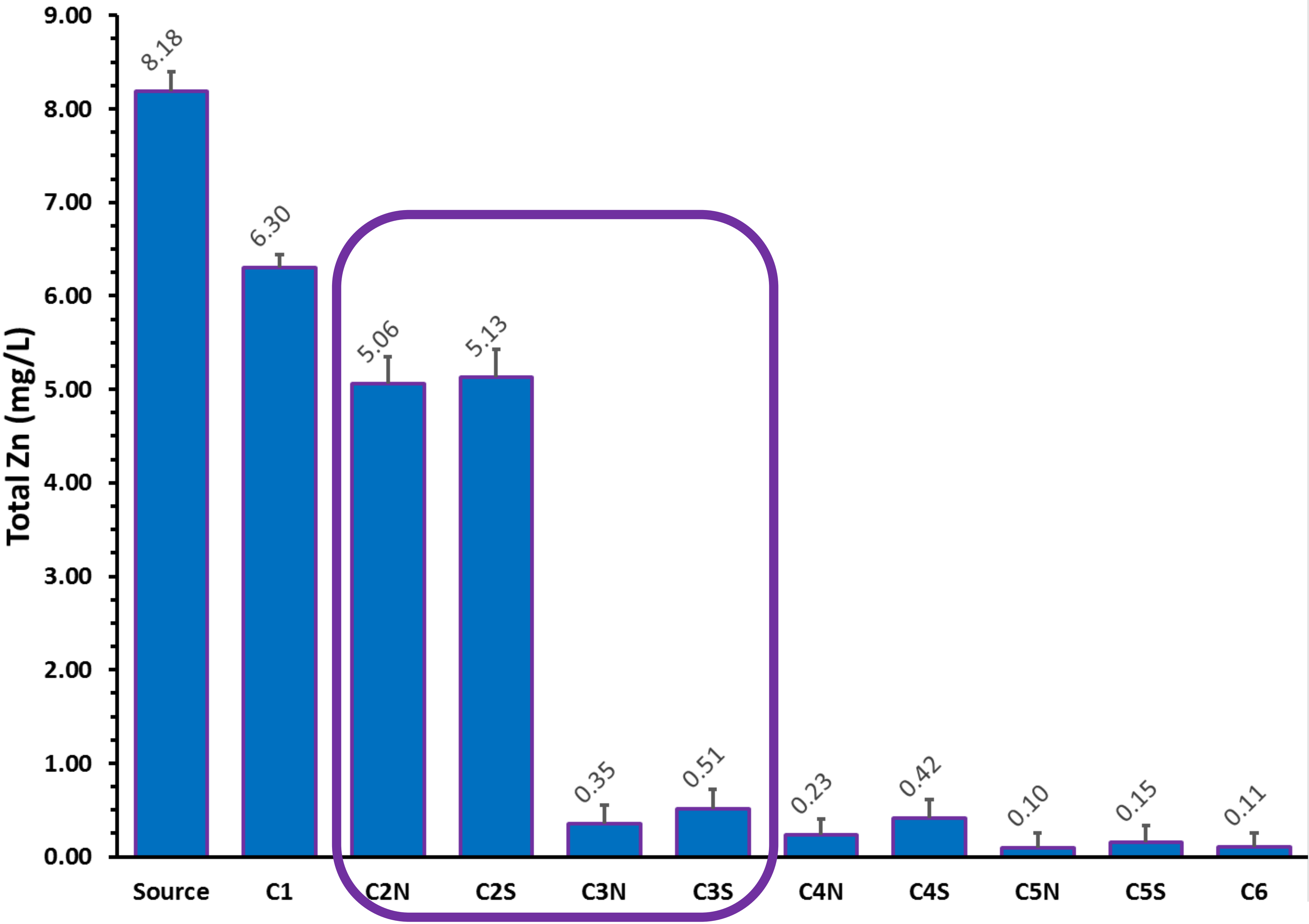
Dominant mechanisms:
Oxidation and sorption

Cell 1
Fe oxidation, hydrolysis and settling

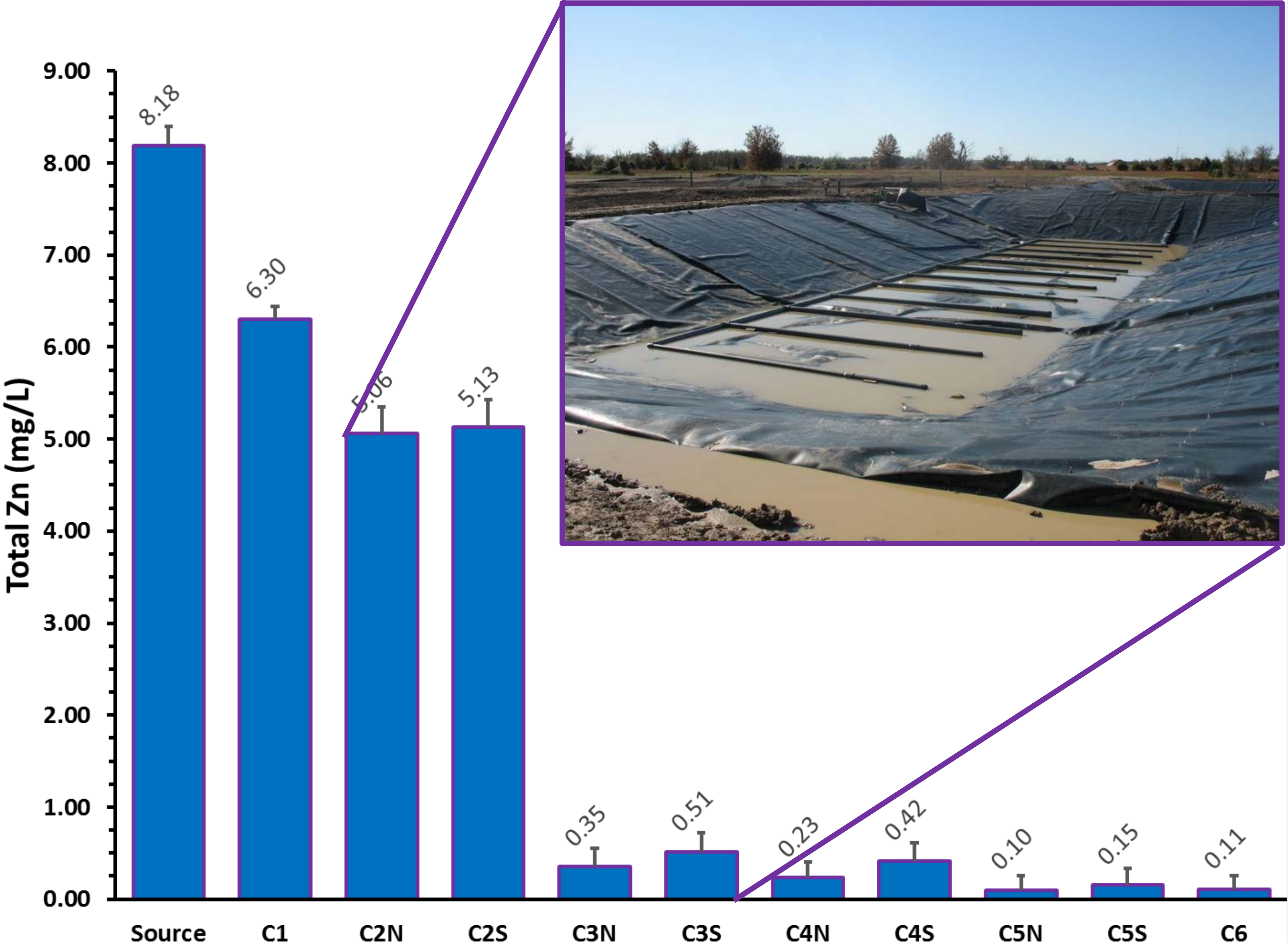
Fe:107 kg/d → 4 kg/d
Design Fe Removal Rate: 20 g $m^{-2}d^{-1}$
7.5-year Mean : 20.4 ± 5.4 g $m^{-2}d^{-1}$

Cells 1 and 2N/S
Trace metal sorption to FeOOH(s)

Pb: 70 ± 1.96 → 27 ± 0.82 μg/L
Cd: 17 ± 0.97 → 1.20 ± 0.51 μg/L
As: 62 ± 1.81 μg/L → <PQL



Total Zn (mg/L)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
8.18
6.30
5.06
5.13
0.35
0.51
0.23
0.42
0.10
0.15
0.11
Source
C1
C2N
C2S
C3N
C3S
C4N
C4S
C5N
C5S
C6



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C4S
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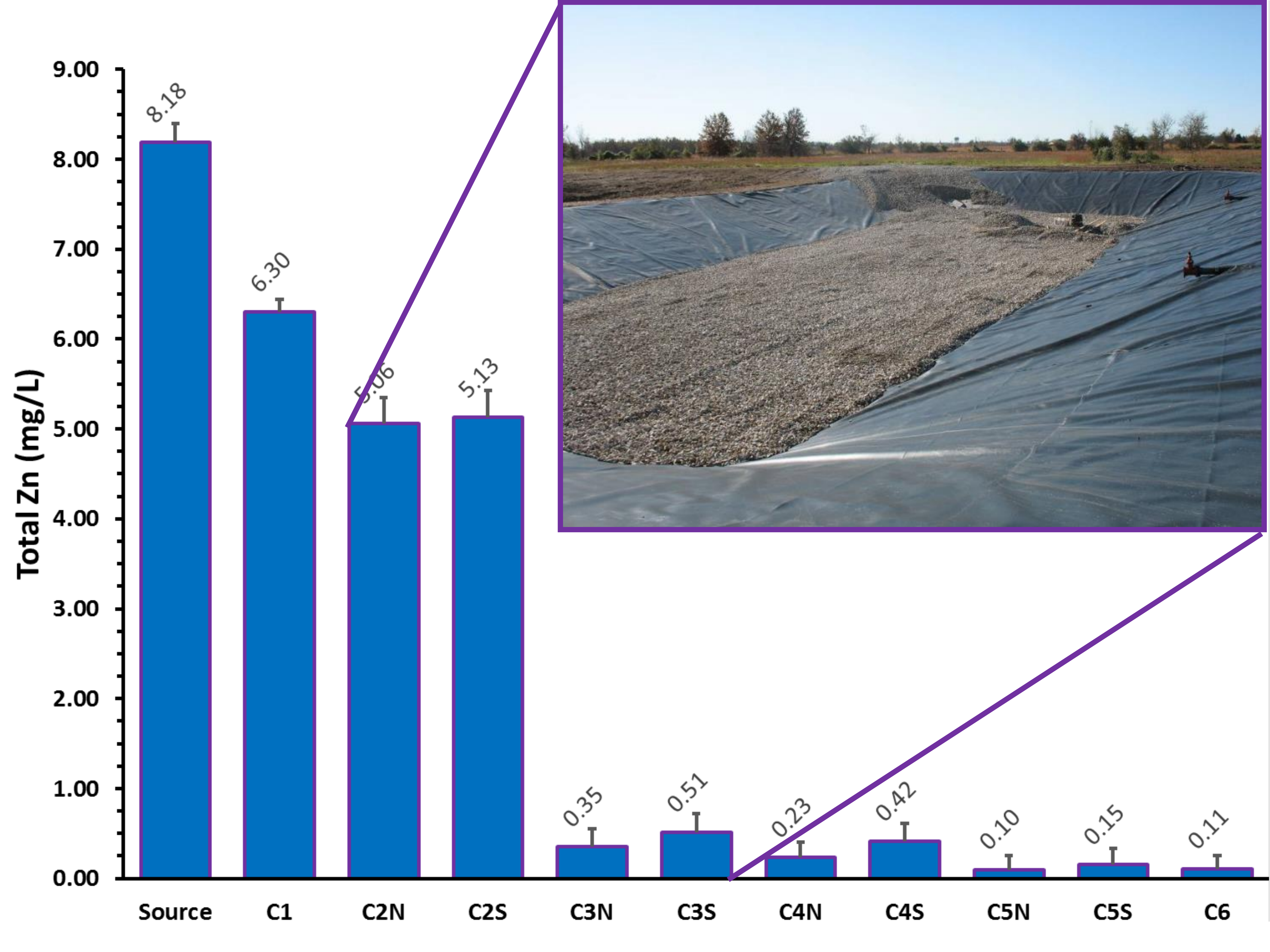
C5S
C6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C4N
C4S
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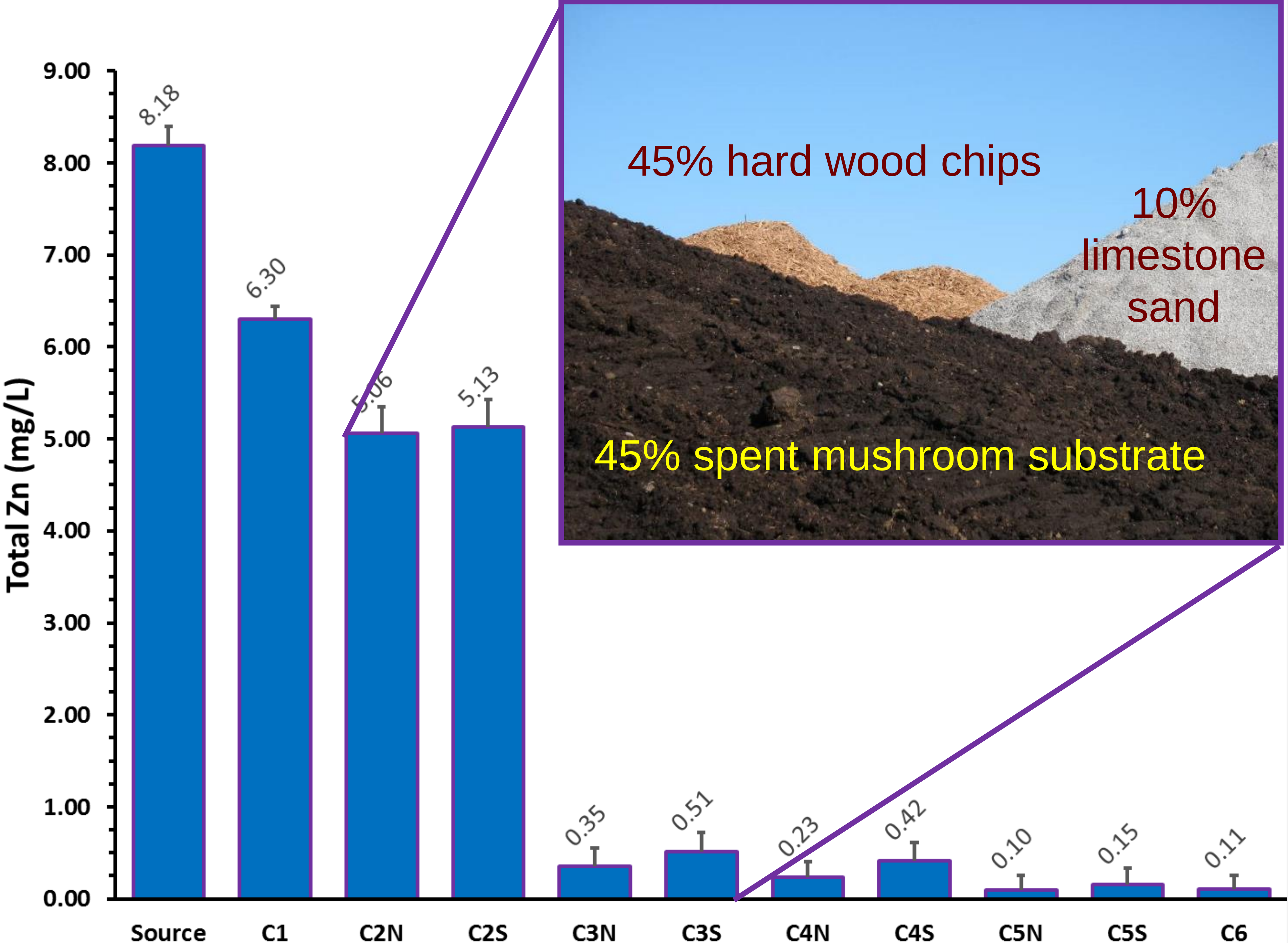
C6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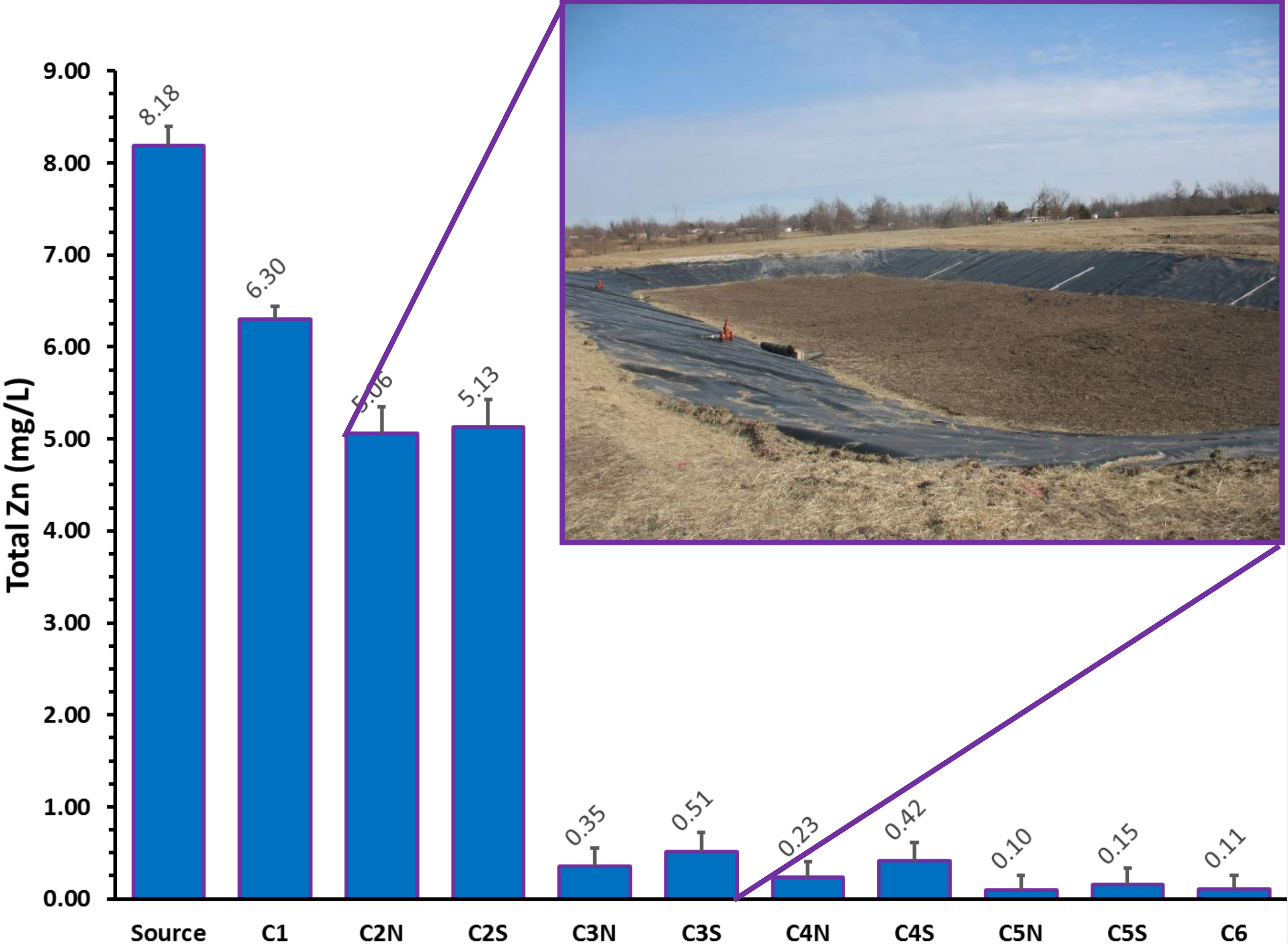
8.18
6.30
5.06
5.13
0.35
0.51
0.23
0.42
0.10
0.15
0.11
Source
C1
C2N
C2S
C3N
C3S
C4N
C4S
C5N
C5S
C6
45% hard wood chips
10% limestone sand
45% spent mushroom substrate



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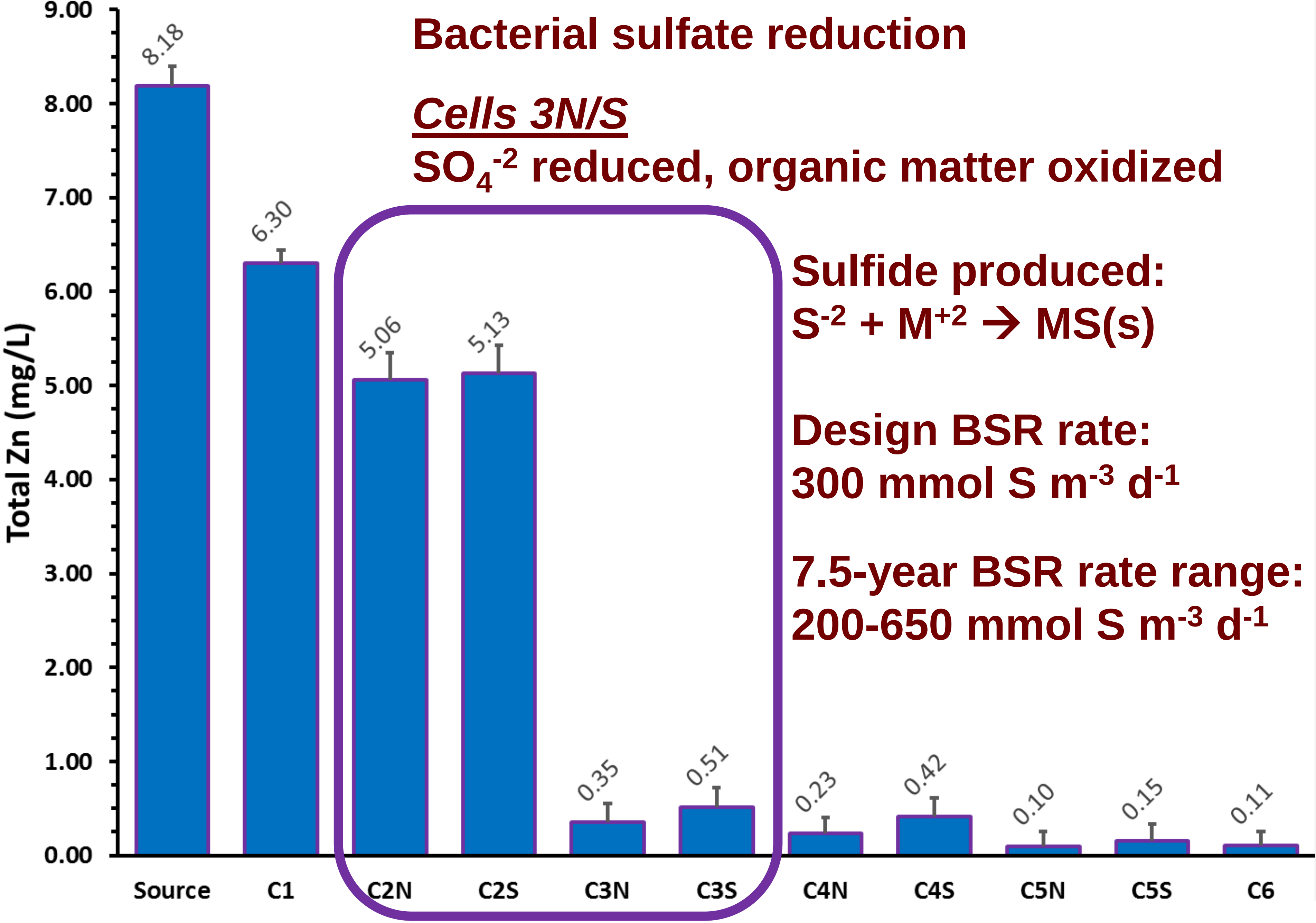
6.30
5.06
5.13
0.35
0.51
0.23
0.42
0.10
0.15
0.11
Source
C1
C2N
C2S
C3N
C3S
C4N
C4S
C5N
C5S
C6

Dominant mechanism:
Bacterial sulfate reduction

Cells 3N/S
SO_4^{-2} reduced, organic matter oxidized



Sulfide produced:
$S^{-2} + M^{+2} \rightarrow MS(s)$

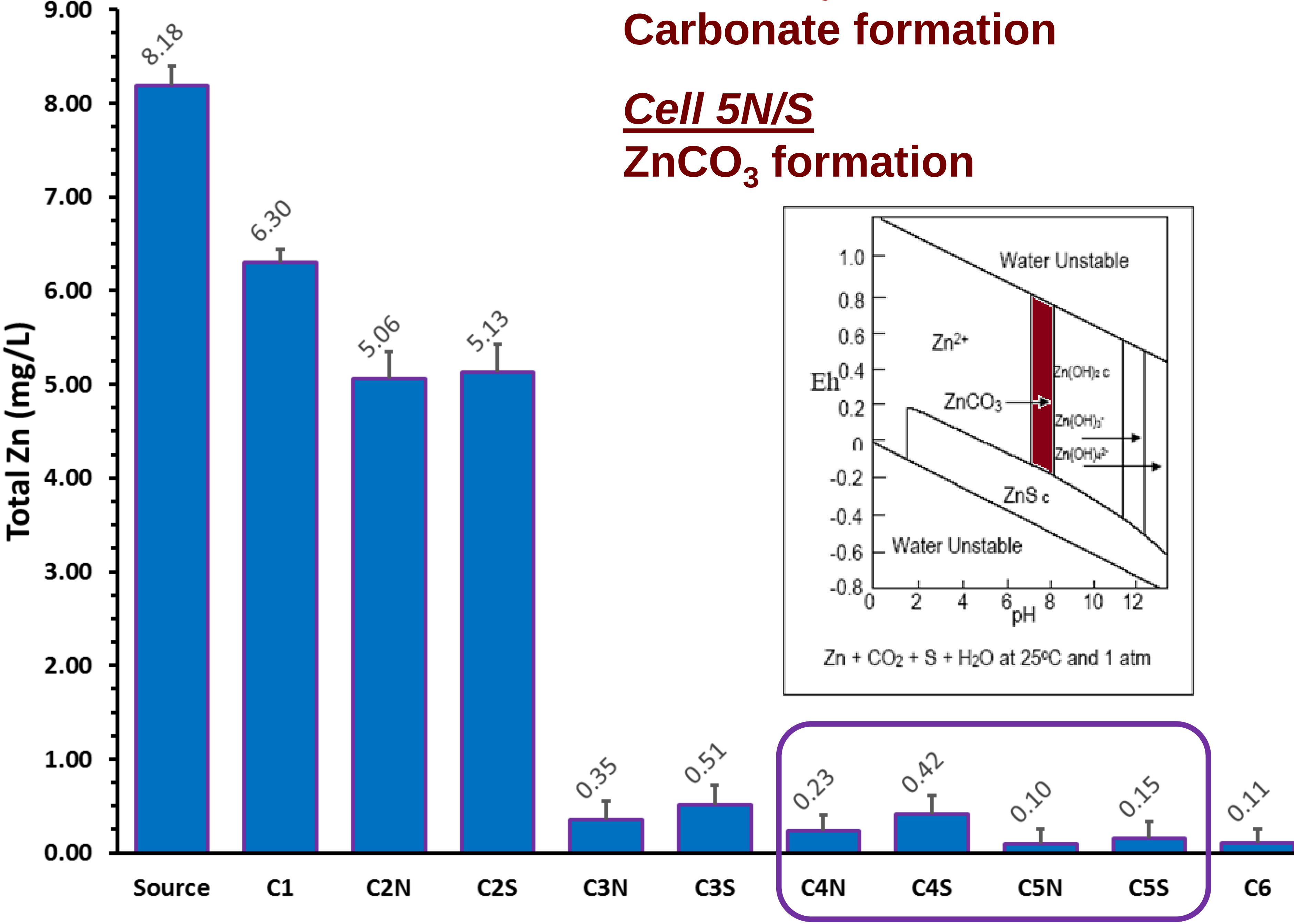
Design BSR rate:
300 mmol S m^{-3} d^{-1}

7.5-year BSR rate range:
200-650 mmol S m^{-3} d^{-1}

Secondary mechanism: Carbonate formation

Cell 5N/S

$ZnCO_3$ formation



Overall Water Quality Changes

	In	Out
pH	5.90	7.03
Total Alkalinity (mg/L)	393	183
Fe (μg/L)	178,000	335
Zn (μg/L)	8,183	106
Pb (μg/L)	70	<PQL
Cd (μg/L)	17	<PQL
Mn (μg/L)	1483	1015
Ni (μg/L)	906	39
As (μg/L)	62	<PQL
Co (μg/L)	54	<PQL
Cr (μg/L)	2.53	<PQL
Cu (μg/L)	3.36	3.10
SO_4^{-2} (mg/L)	2270	2160

MRPTS Water Quality Changes

	In	Out
pH	5.90	7.03
Total Alkalinity (mg/L)	393	183
Fe (μg/L)	178,000	335
Zn (μg/L)	8,183	106
Pb (μg/L)	70	<PQL
Cd (μg/L)	17	<PQL
Mn (μg/L)	1483	1015
Ni (μg/L)	906	39
As (μg/L)	62	<PQL
Co (μg/L)	54	<PQL
Cr (μg/L)	2.53	<PQL
Cu (μg/L)	3.36	3.10
SO_4^{-2} (mg/L)	2270	2160

Overall Water Quality Changes

	In	Out
pH	5.90	7.03
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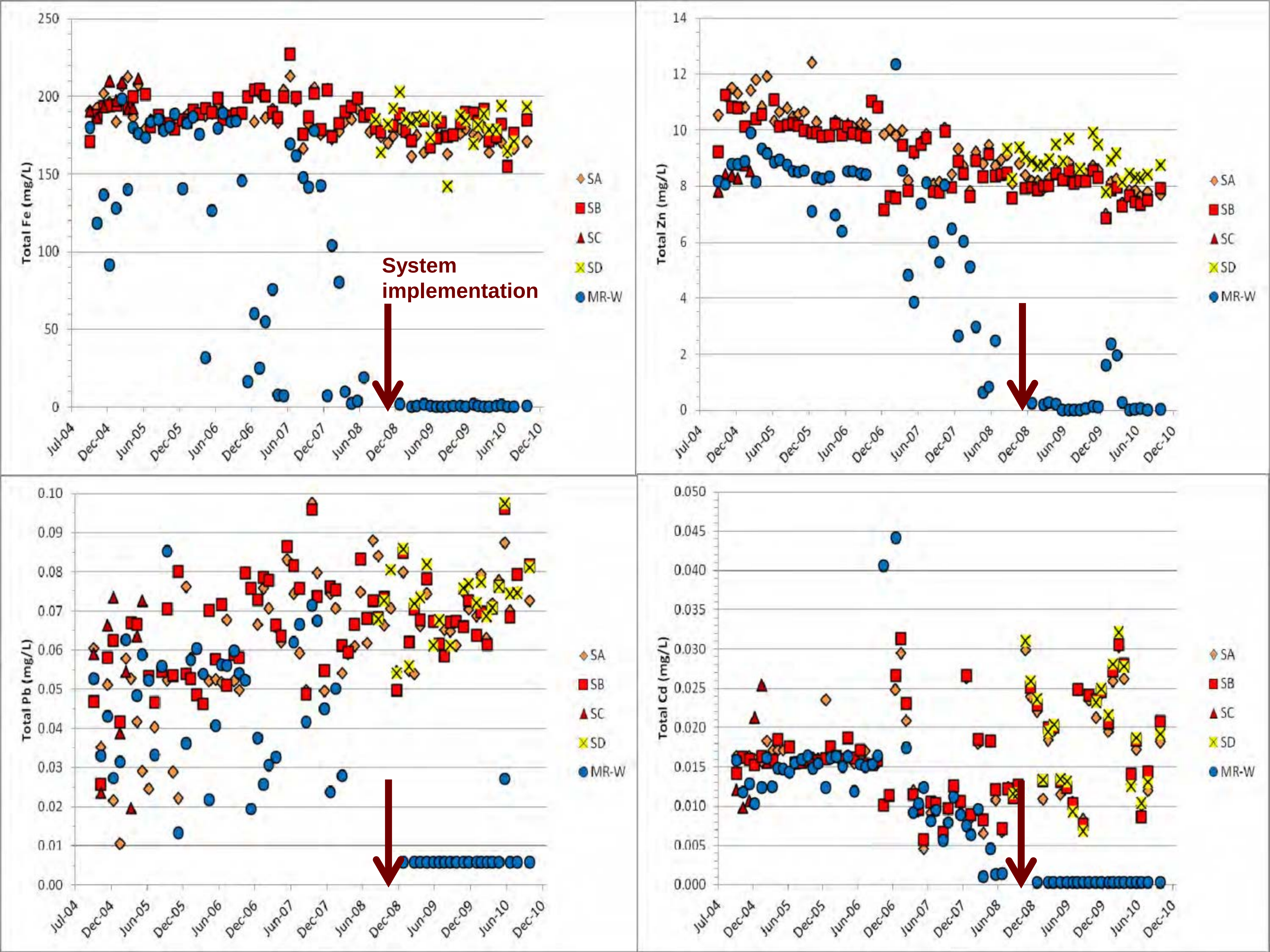
Cu (μg/L)	3.36	3.10
SO_4^{-2} (mg/L)	2270	2160


Total Fe (mg/L)
250
200
150
100
50
0
System implementation
SA
SB
SC
SD
MR-W
Jul-04
Dec-04
Jun-05
Dec-05
Jun-06
Dec-06
Jun-07
Dec-07
Jun-08
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10
Total Zn (mg/L)
14
12
10
8
6
4
2
0
Total Pb (mg/L)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Total Cd (mg/L)
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000

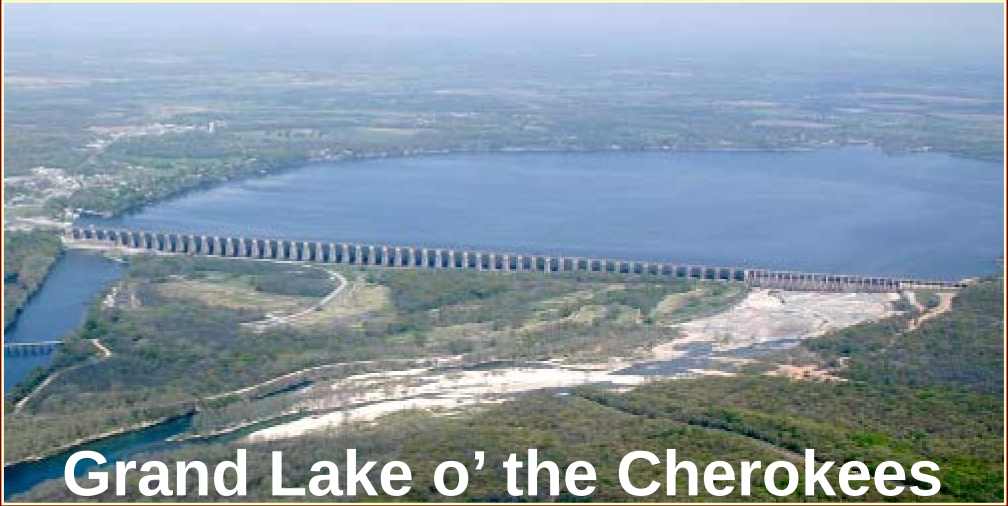
Receiving Stream Fish Community

Selected Unnamed Tributary fish data (W.J. Matthews, OU Biology)

		Catch per unit effort (CPUE)	
Scientific name	Common name	2005-07	2009-12
Gambusia affinis	Western mosquitofish	39.24	187.60
Lepomis cyanellus	Green sunfish	0.81	16.80
Lepomis macrochirus	Bluegill	1.00	3.00
Lepomis megalotis	Longear sunfish	0.02	6.80
Notemigonus crysoleucas	Golden shiner	0.17	0.60
Lepomis gulosus	Warmouth	0.07	0.20
Etheostoma gracile	Slough darter	0	0.80
Ameiurus melas	Black bullhead	0	0.40
Fundulus notatus	Blackstriped topminnow	0	0.40
Micropterus salmoides	Largemouth bass	0	0.20
	Species richness	6	10

On-Site Mass Retention

	Mass retained (kg/year)
Fe	57000
Zn	3300
Ni	300
Cd	5
Pb	17
As	18




2005 5 29


2005 11 10


2005 11 10


2005 5 29

Grand River Dam Authority

Ecosystems & Education Center

PARTNERS IN CONSERVATION AND RESTORATION

OU

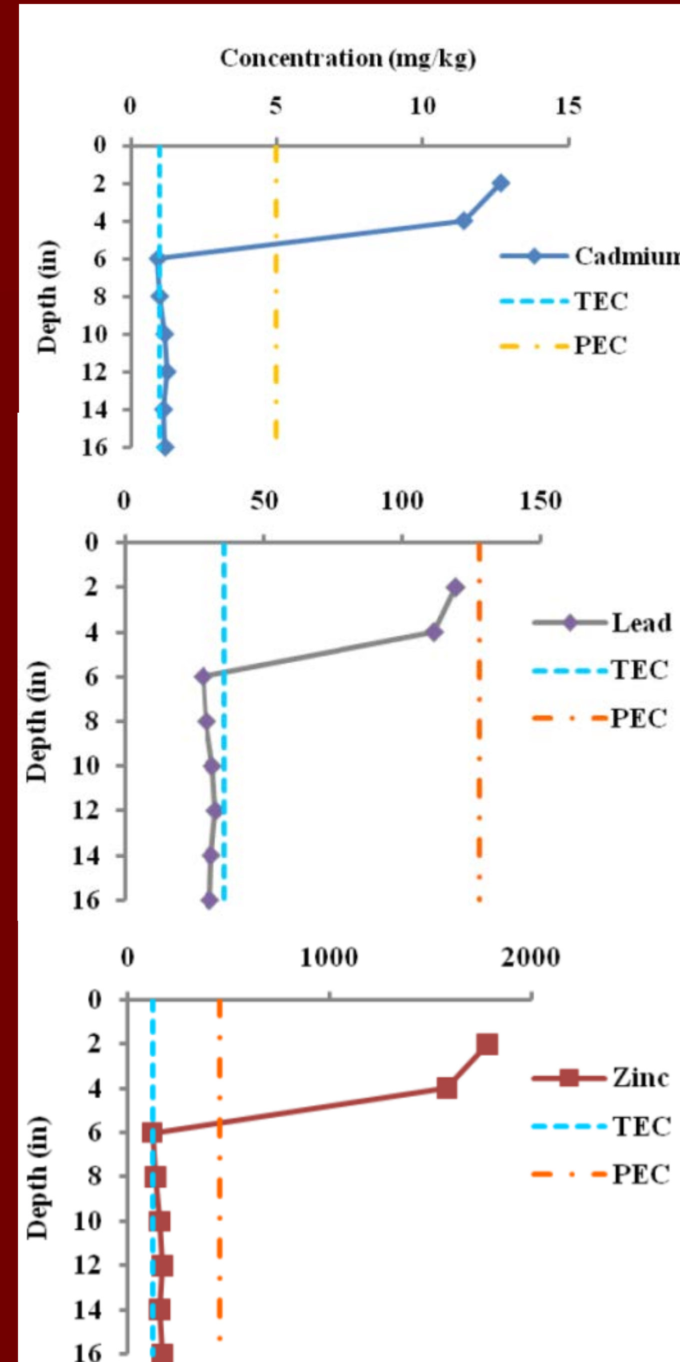
GRDA

Grand River Dam Authority

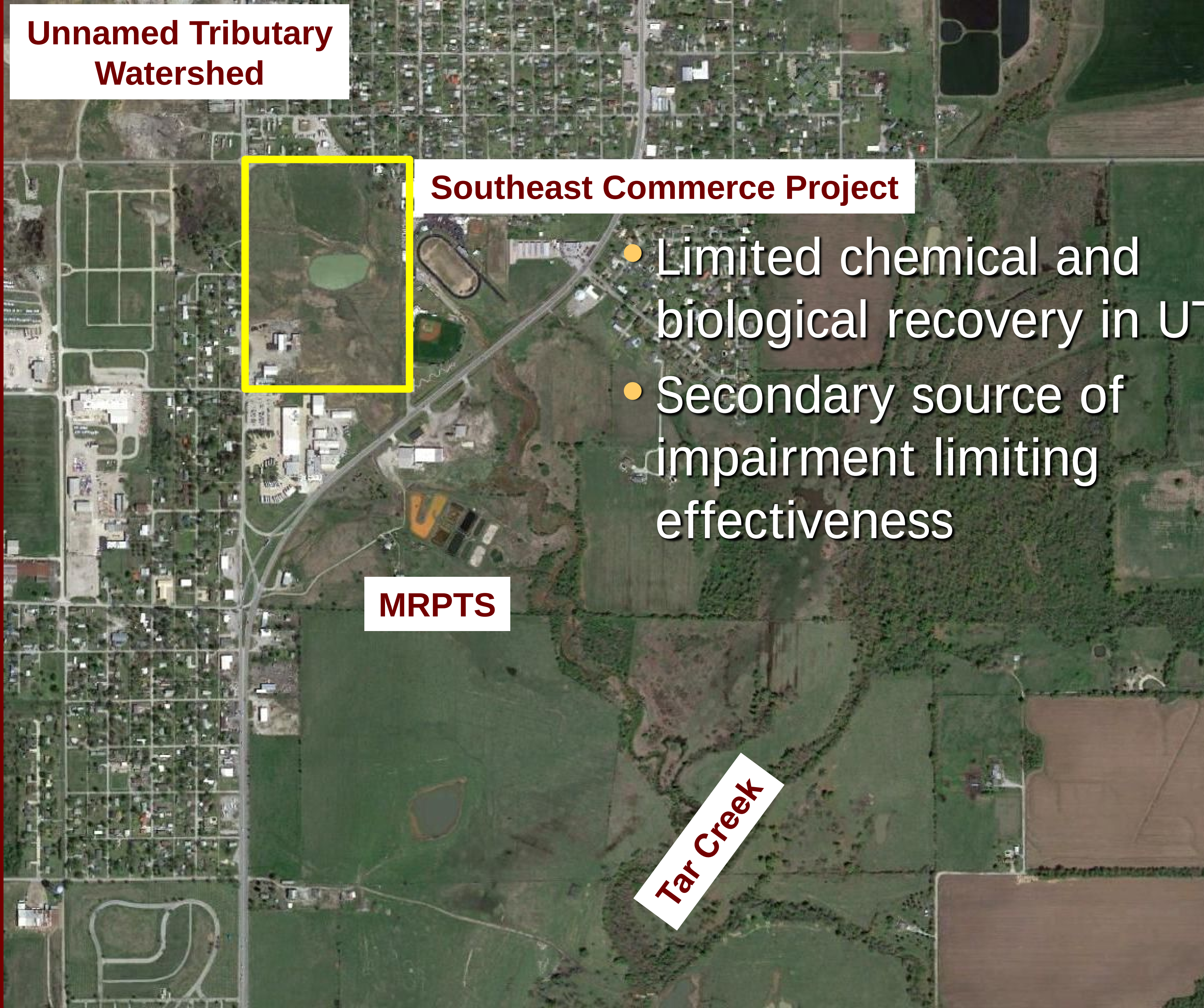
Oklahoma State University

GLOC Sediments

- Surficial sediments show elevated metals
- Dredging management for dock placement



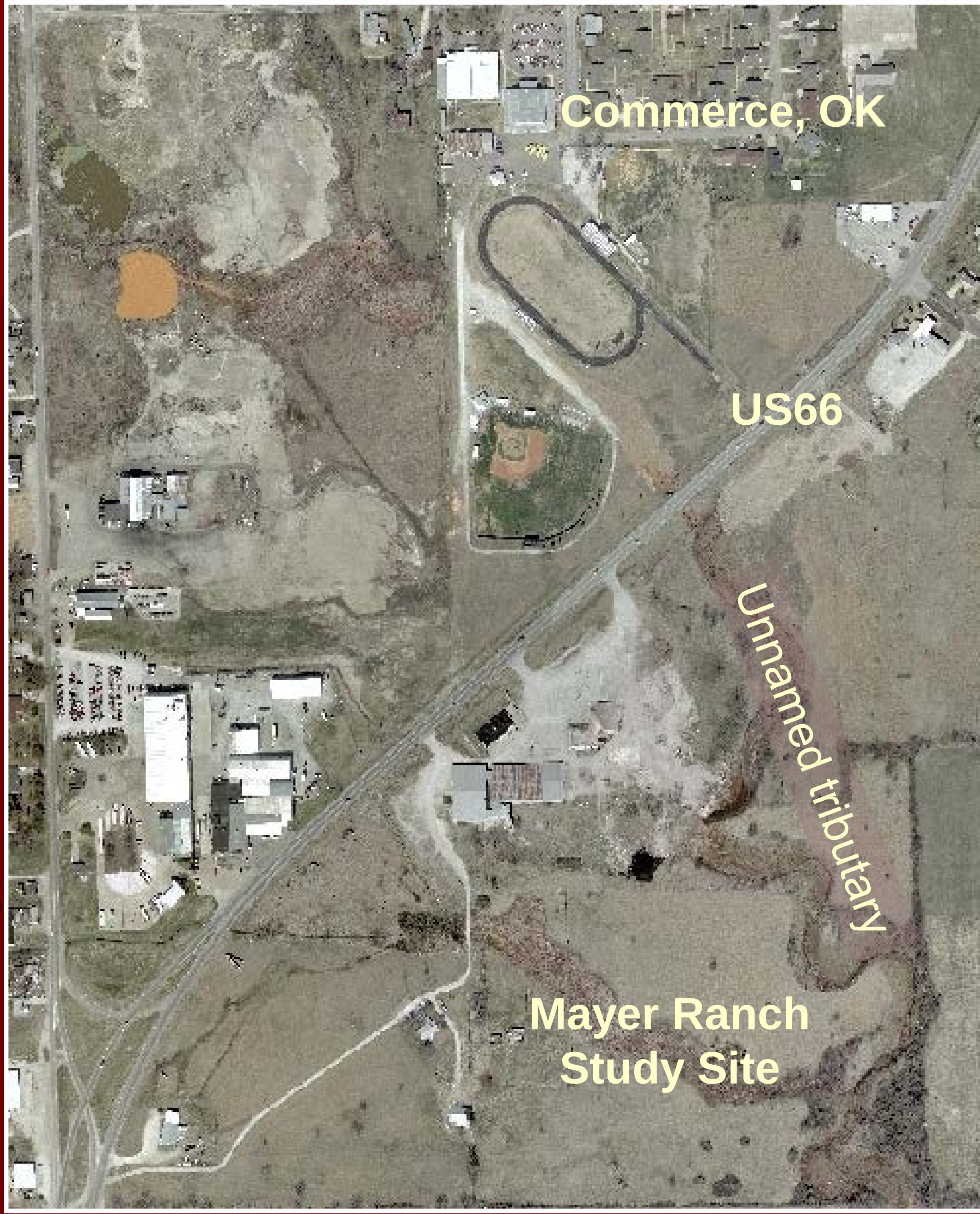
Unnamed Tributary Watershed



- Limited chemical and biological recovery in UT
- Secondary source of impairment limiting effectiveness

SE Commerce

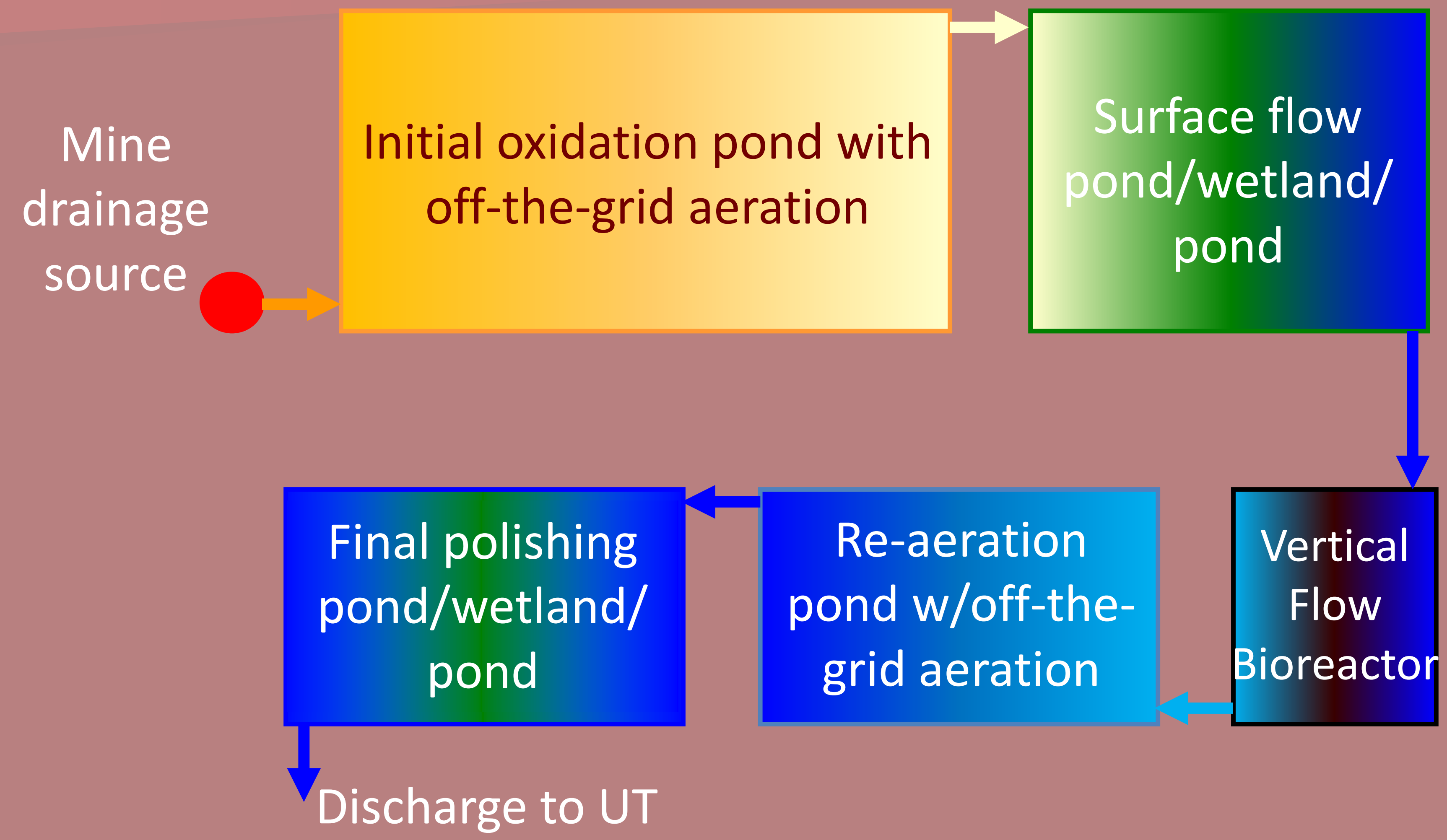
- "Red Hole" and "Green Hole" collapses
- Surface reclaimed ~ 2006
- Water discharges untreated into Unnamed Tributary



SE Commerce

- Flow: 100 gpm
  - Fe: 138 mg/L
  - Zn: 6 mg/L
  - Pb: 81 μg/L
  - Cd: 20 μg/L

SE Commerce Conceptual Design



SE Commerce Status

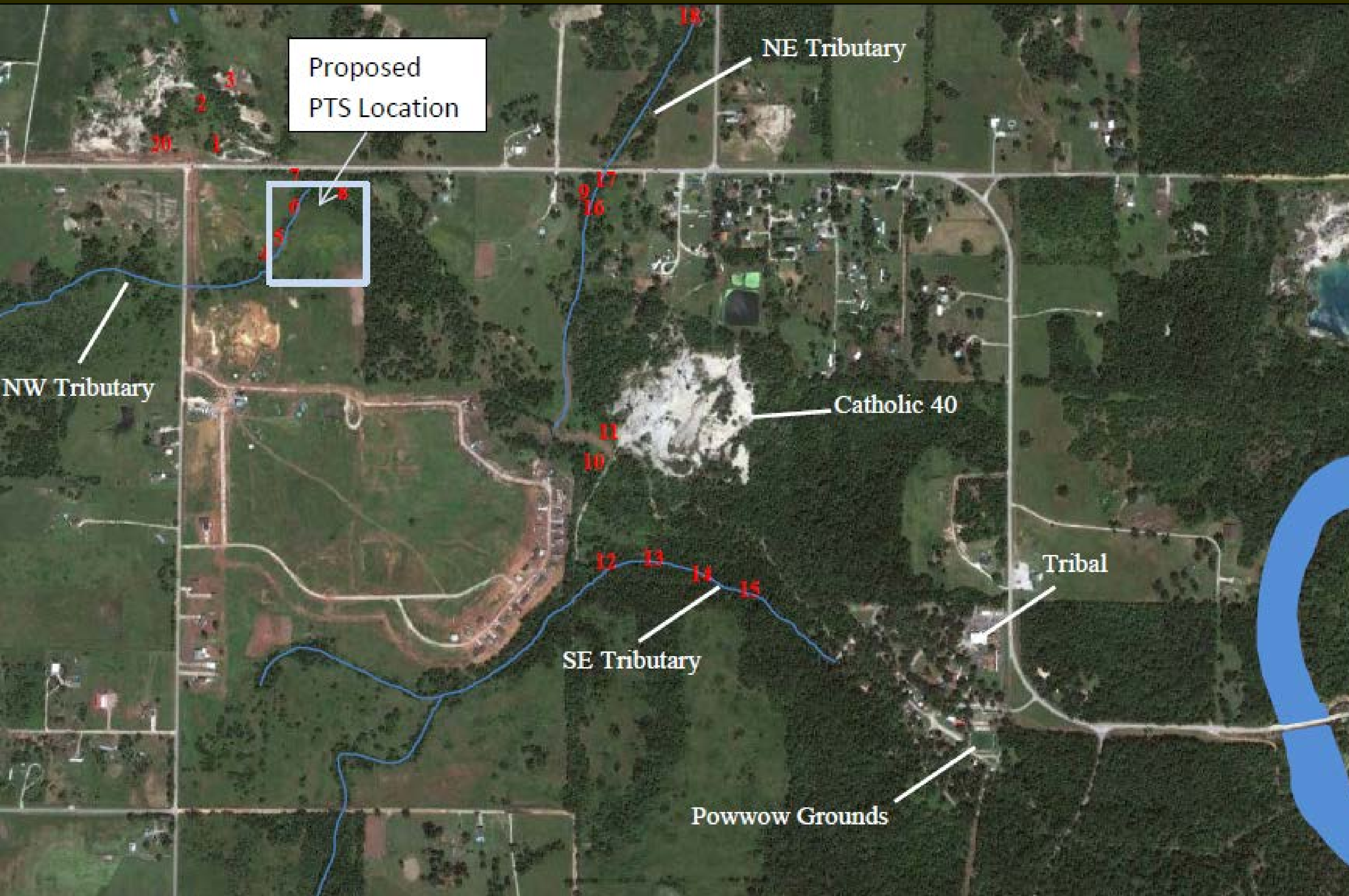
- Request for Design/Build Proposals issued August 4, 2015
- Proposals received September 15, 2015
- Design/build awarded December 1, 2015
- Construction summer 2016

BioMost, Inc.
Mining & Reclamation Services

Beaver Creek

- Culturally significant to the Quapaw Tribe
- Multiple discharges
- Interconnected and variable flows

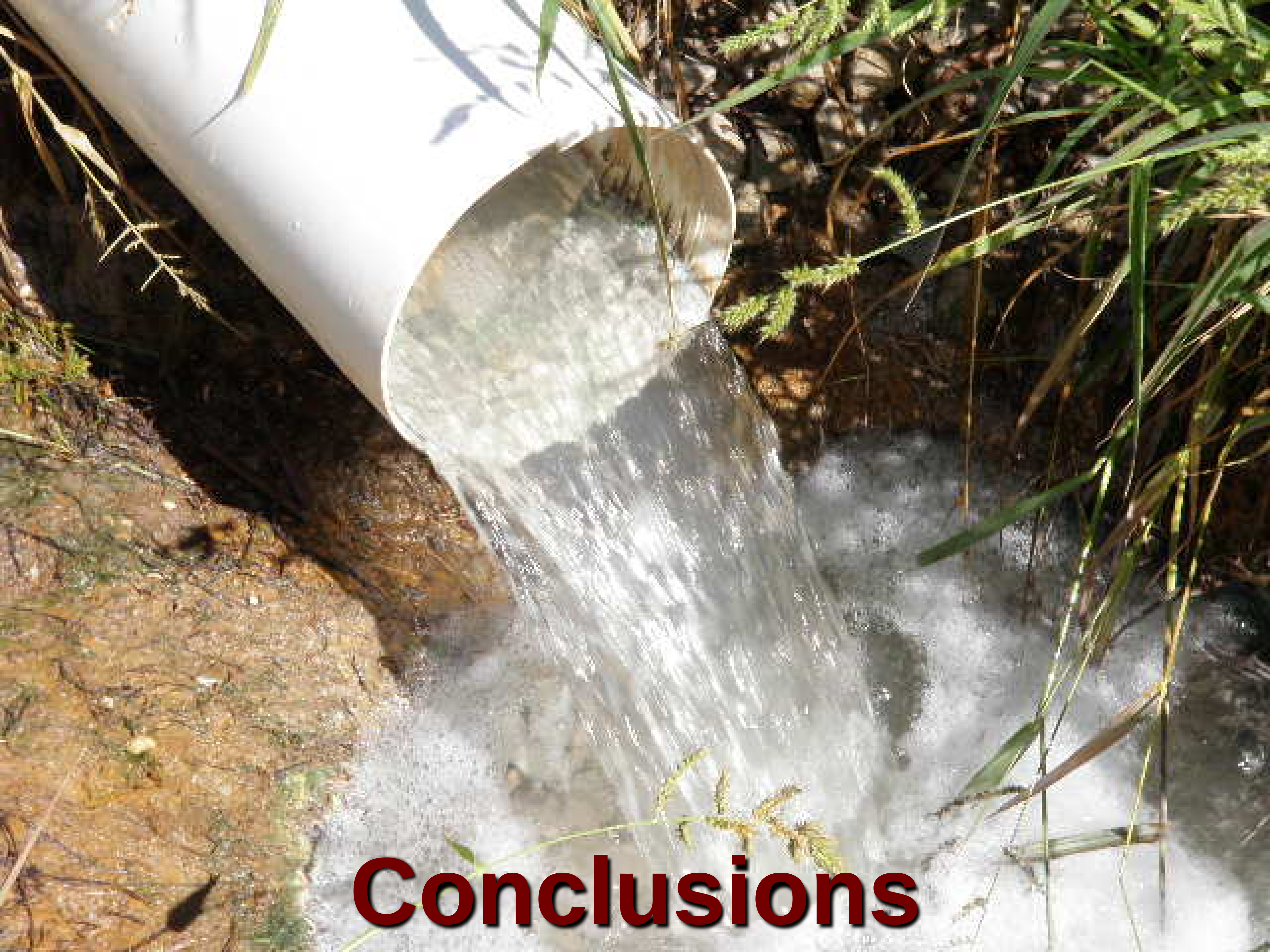
	BC MD8
pH	6.62
Fe (mg/L)	9.28
Zn (mg/L)	1.60
Pb (μg/L)	15
Cd (μg/L)	1


Proposed
PTS Location
NE Tributary
NW Tributary
Catholic 40
Tribal
SE Tributary
Powwow Grounds
18
3
2
20
1
7
8
6
5
4
17
9
16
11
10
12
13
14
15

Chat Pile Leachate and Runoff

- Substantial metal source
- Seasonal and episodic loads
- Cope et al. 2008 (USGS SIR 2007-5115)

	Leachate load (kg/day)	Mine outflow load (kg/day)
Fe	0.207	70.31
Zn	11.88	18.05
Pb	0.006	0.006
Cd	0.047	0.019



Conclusions

Conclusions

- Oklahoma has one of the most challenging hazardous waste remediation *opportunities* in the world
- Passive treatment represents effective and sustainable mechanism for watershed restoration
- Technology transferable to other mine water discharges
- Reconsideration of previous administrative decisions warranted

Can we reverse the irreversible?

Acknowledgements

- Mayer, Martin and Pritchard families
- OU students, faculty and staff especially CREW, CEES, Zoology and OCS
- Quapaw Tribe of Oklahoma
- City of Commerce
- Northeastern Oklahoma A&M College
- ODEQ Land Protection Division
- CH2M-Hill team and subcontractors
- Grand River Dam Authority
- USEPA Water Division Agreement X7-97682001-0
- USGS Toxic Substances Hydrology Program Agreement DOI-USG 04HQAG0131
- ODEQ Agreement PO2929019163

Questions?

http://CREW.ou.edu

nairn@ou.edu