Restoring a Severely Disturbed Watershed via Ecological Engineering: The Role of Passive Treatment Technologies

R.W. Nairn, J.A. LaBar, L.R. Oxenford, B.J. Page, N.L. Shepherd, J. Arango and R.C. Knox

Center for Restoration of Ecosystems and Watersheds

School of Civil Engineering and Environmental Science
The University of Oklahoma, Norman, OK

Red Water at Tar Creek

"Water boiled out of a red wound in the pasture and spilled across the grass...

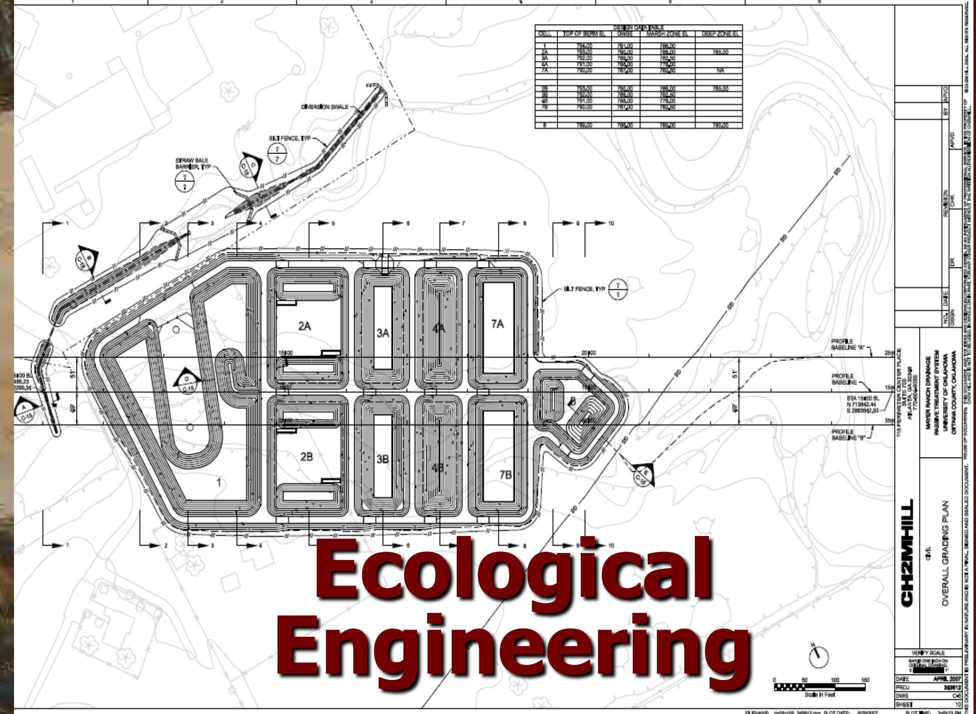
...George Mayer knew in an instant what it was.

The damn mines," he said to himself.

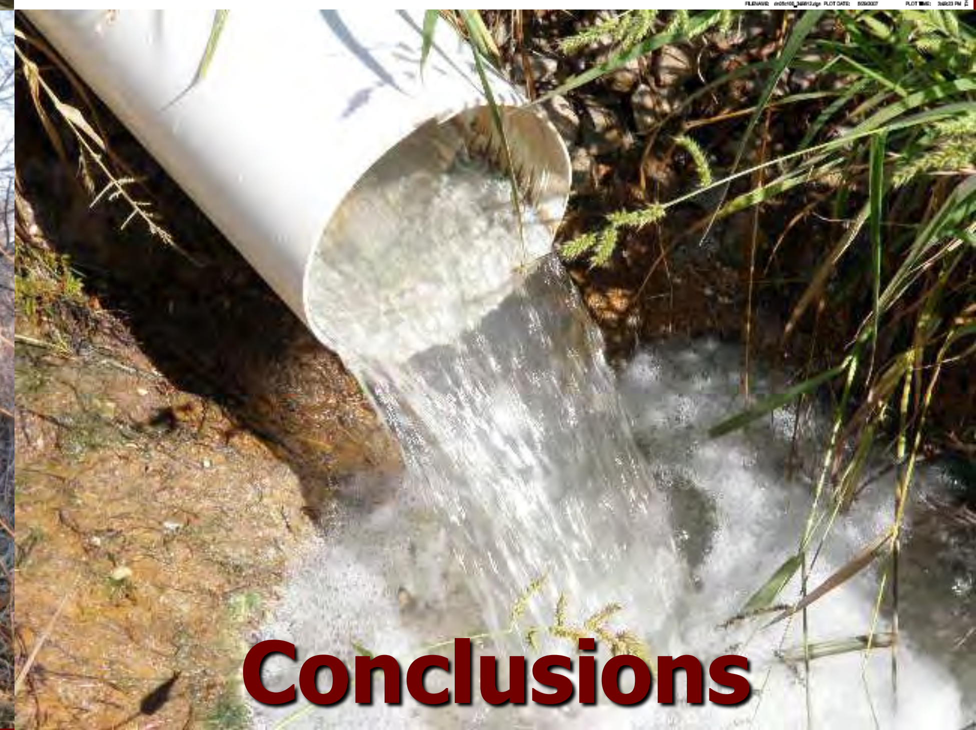
The mines are full, and the water's finally coming out."

Los Angeles Times
February 6, 1983


Watershed Challenges


Ecological
Engineering
CH2MHILL
OVERALL GRADING PLAN


Passive Treatment
Performance


Conclusions

Watershed Challenges

Tri-State Lead-Zinc Mining District

- Mississippian sulfides
  - Galena (PbS)
  - Sphalerite (ZnS)
- Cherty limestone host rock
- Underground works
  - Multiple levels
  - High ceilings
- Surface processing
  - ~5% recovery

Tar Creek (OK)

- National Priorities List (1983)
- Elevated Fe, Zn, Cd, Pb in water, chat, soils and biota
- 95x10^6 m^3 mine pool
- Artesian discharges
- Leachate and runoff


Oklahoma…
…Where the wind comes sweeping down the plain…
Artesian mine water discharges
Collapse features
Communities /infrastructure
Impeded drainage
Dry fines impoundments
Waste ("chat") piles
Wet fines impoundments
Leachate

Tar Creek Surface and Ground Water Decision

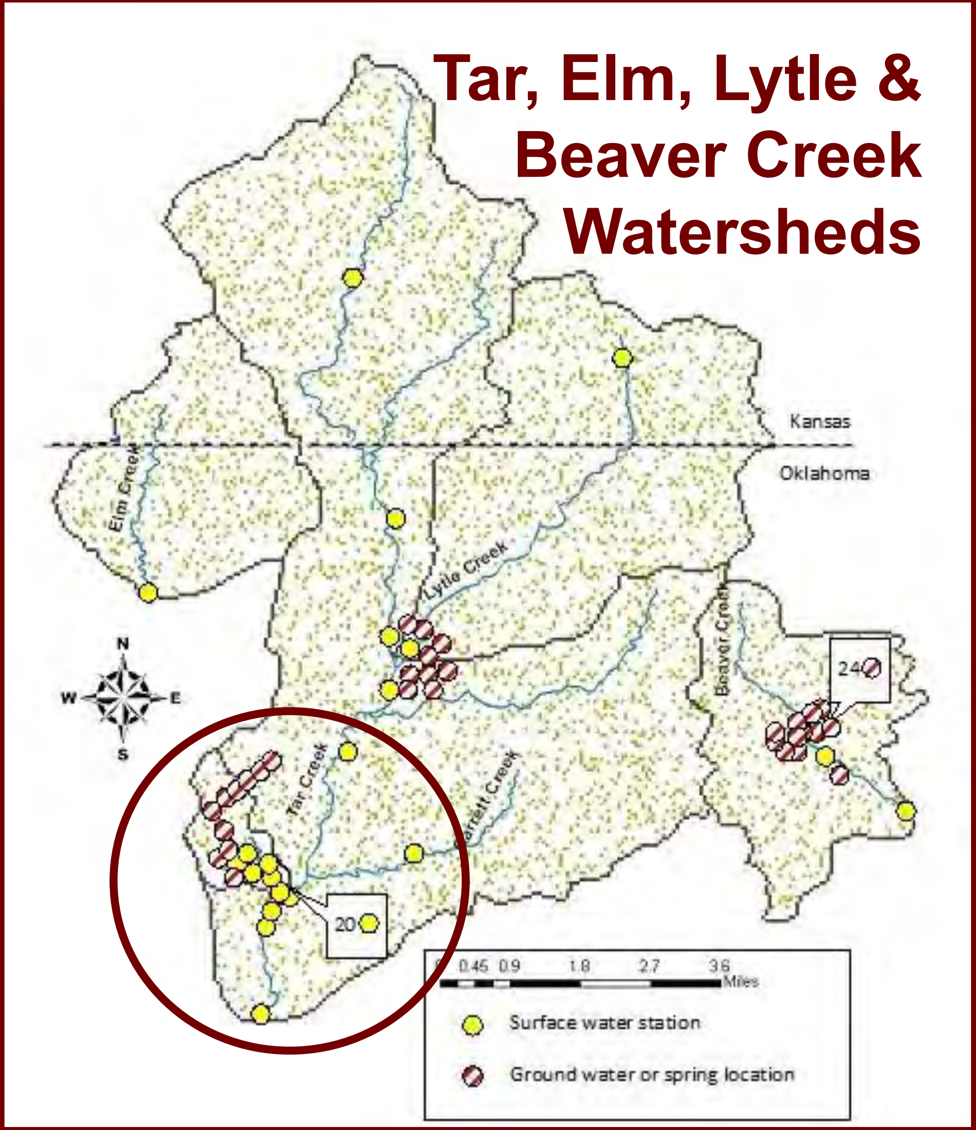
- Initial artesian discharges (1979)
- USEPA concluded that (1984):

  "impacts to (surface waters) are due to ***irreversible man-made damages*** *resulting from past mining operations at the site"*

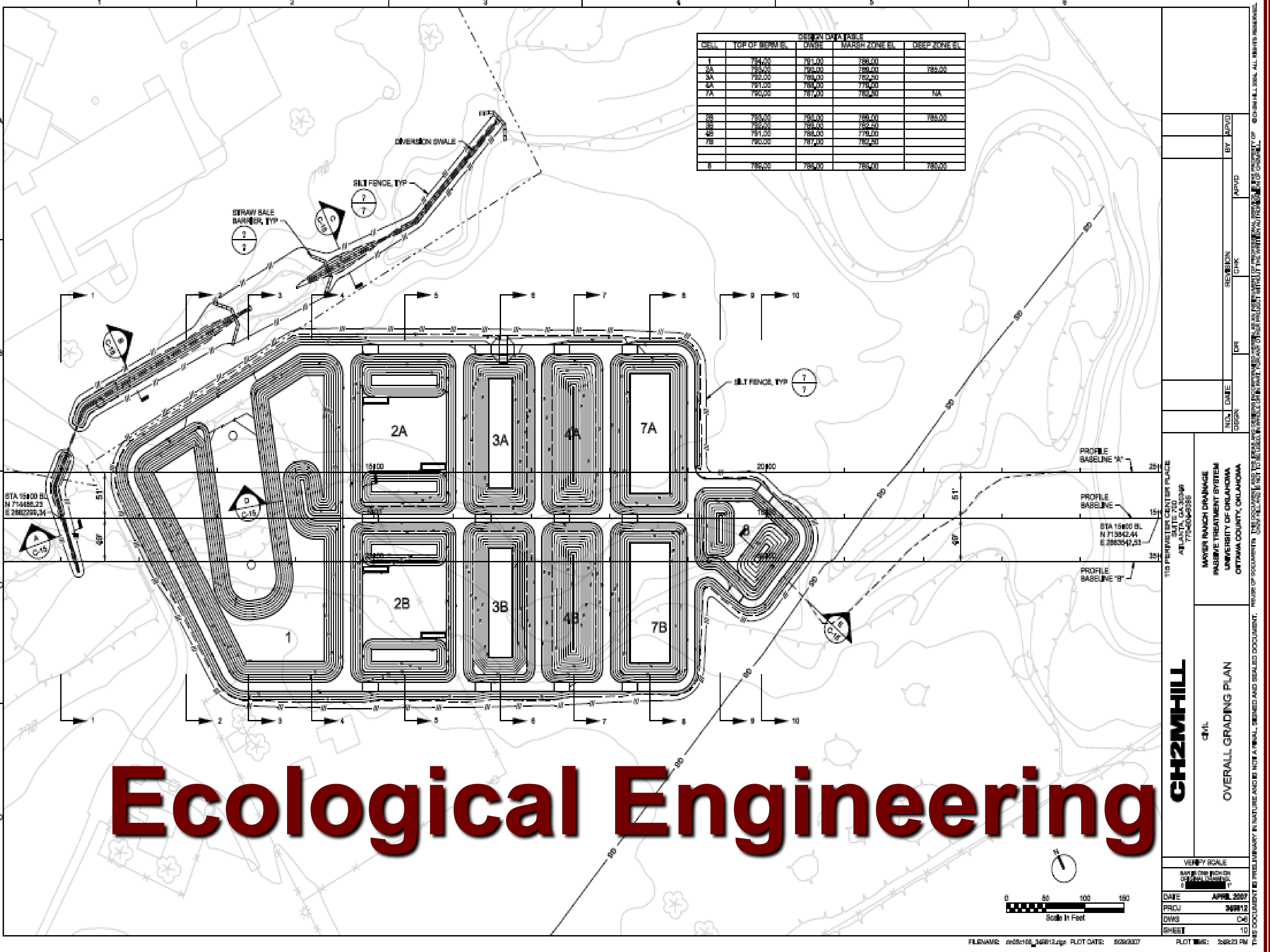
- Fund-balancing waiver used
  - Costs prohibitively high to address surface water contamination

Meeting the Challenge

- Comprehensive watershed monitoring
- Significant artesian discharges
  - Net alkaline
  - Fe, Zn, Pb, Cd, As
- Focus on *point of discharge* treatment



Ecological Engineering



Ecology + Engineering

- Relationships between organisms and environment
- Descriptive science

- Application of science to meet societal needs
- Prescriptive solutions

Ecological Engineering

The design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both

(Mitsch and Jorgenson 2004)

Mine Water Passive Treatment

- Naturally-occurring biogeochemical, microbiological and ecological processes
- Driven by renewable energies
- Natural unprocessed materials
- Lower O&M costs but larger land areas
- 30+ years experience

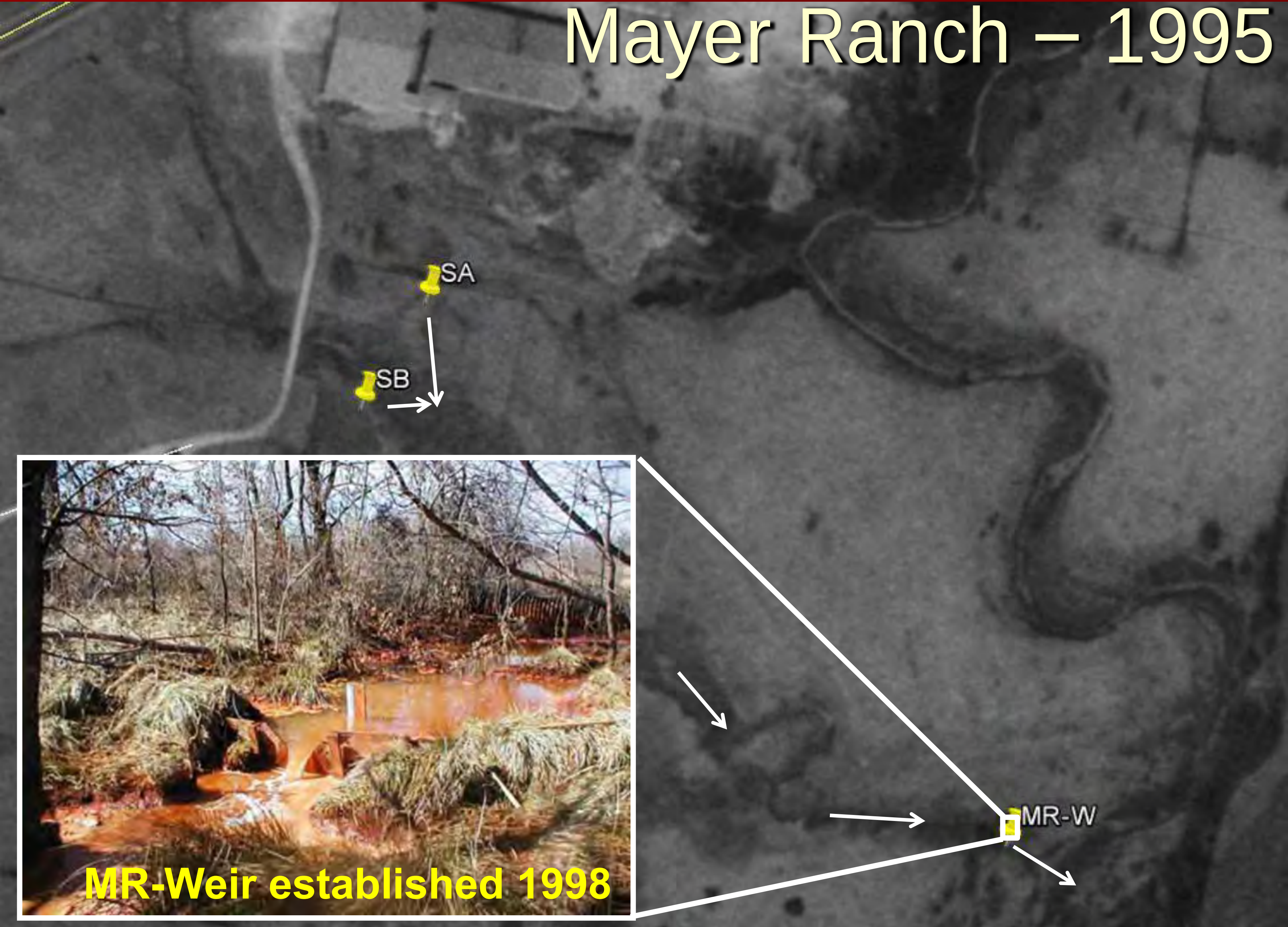
Mayer Ranch Study Site

- Artesian discharges from abandoned boreholes
- 150 – 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

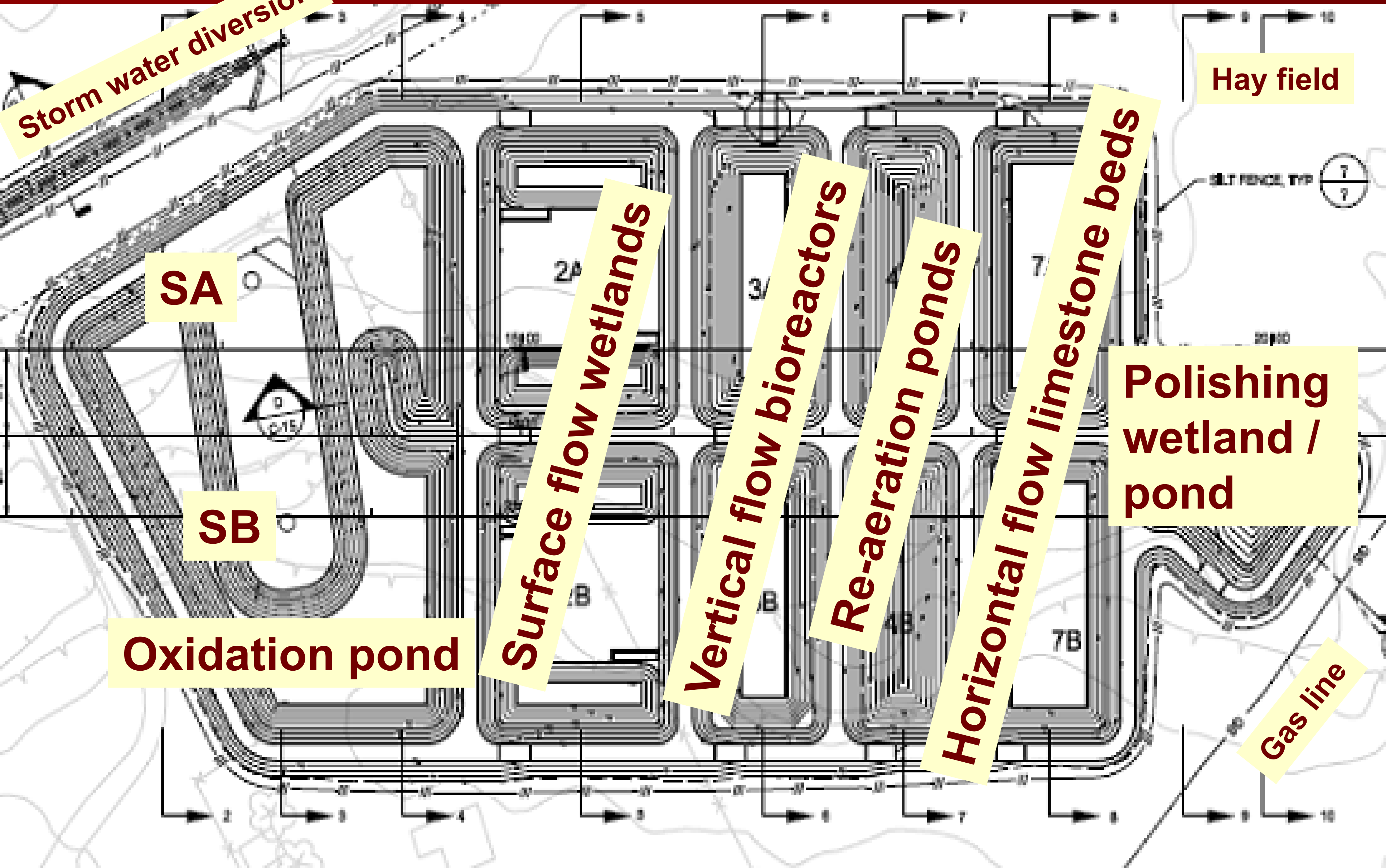
Mayer Ranch – 1995



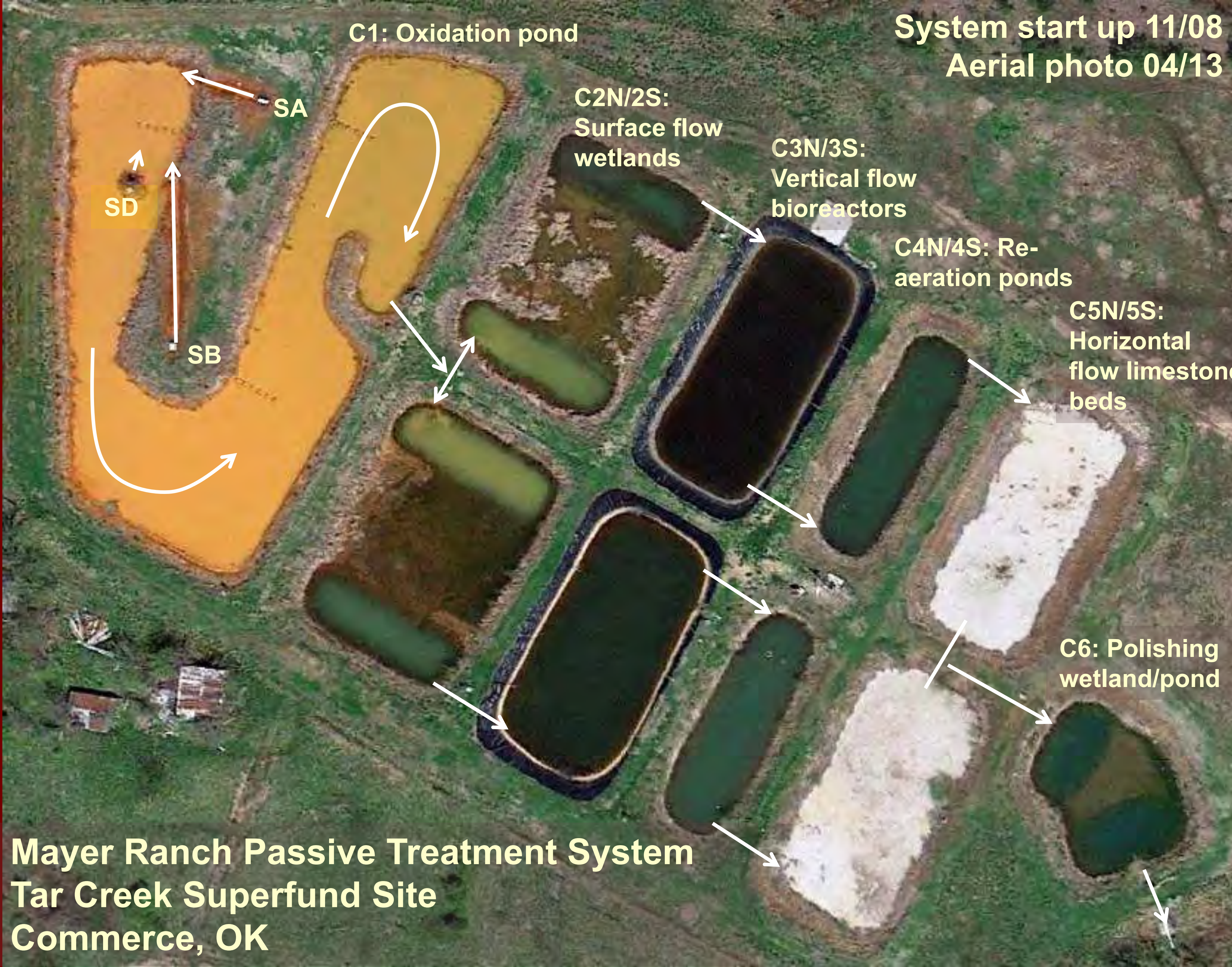
Conceptual Design

- Based on decade of research
- Targeted contaminant removal
  - Oxidation reactions
  - Reduction reactions
  - Sorption
  - Precipitation
- Sequential process units

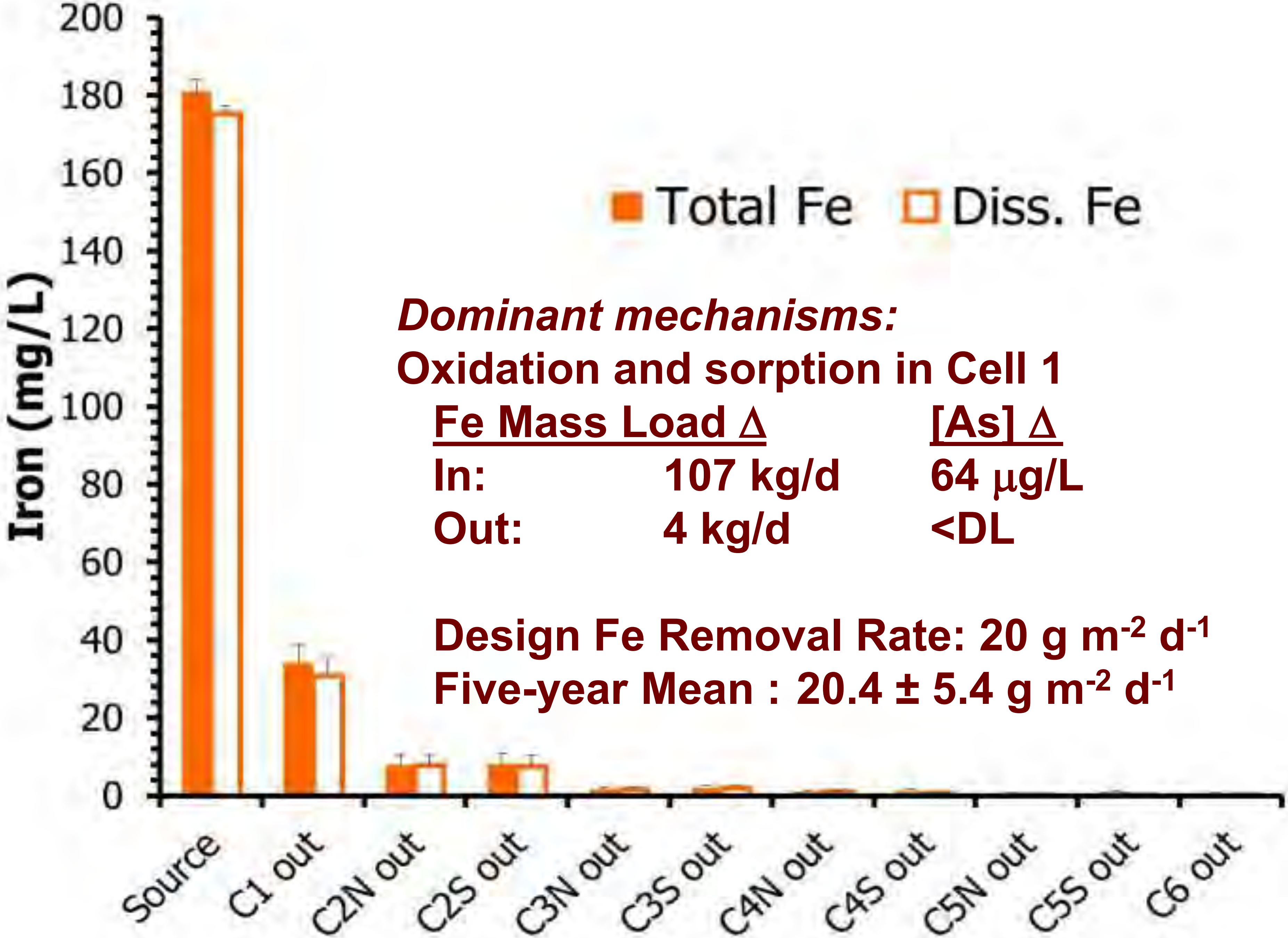
Engineering Design




System start up 11/08
Aerial photo 02/09
1
2S
2N
3S
3N
4S
4N
5S
5N
6
Mayer Ranch Passive Treatment System
Tar Creek Superfund Site
Commerce, OK


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


Passive Treatment
Performance



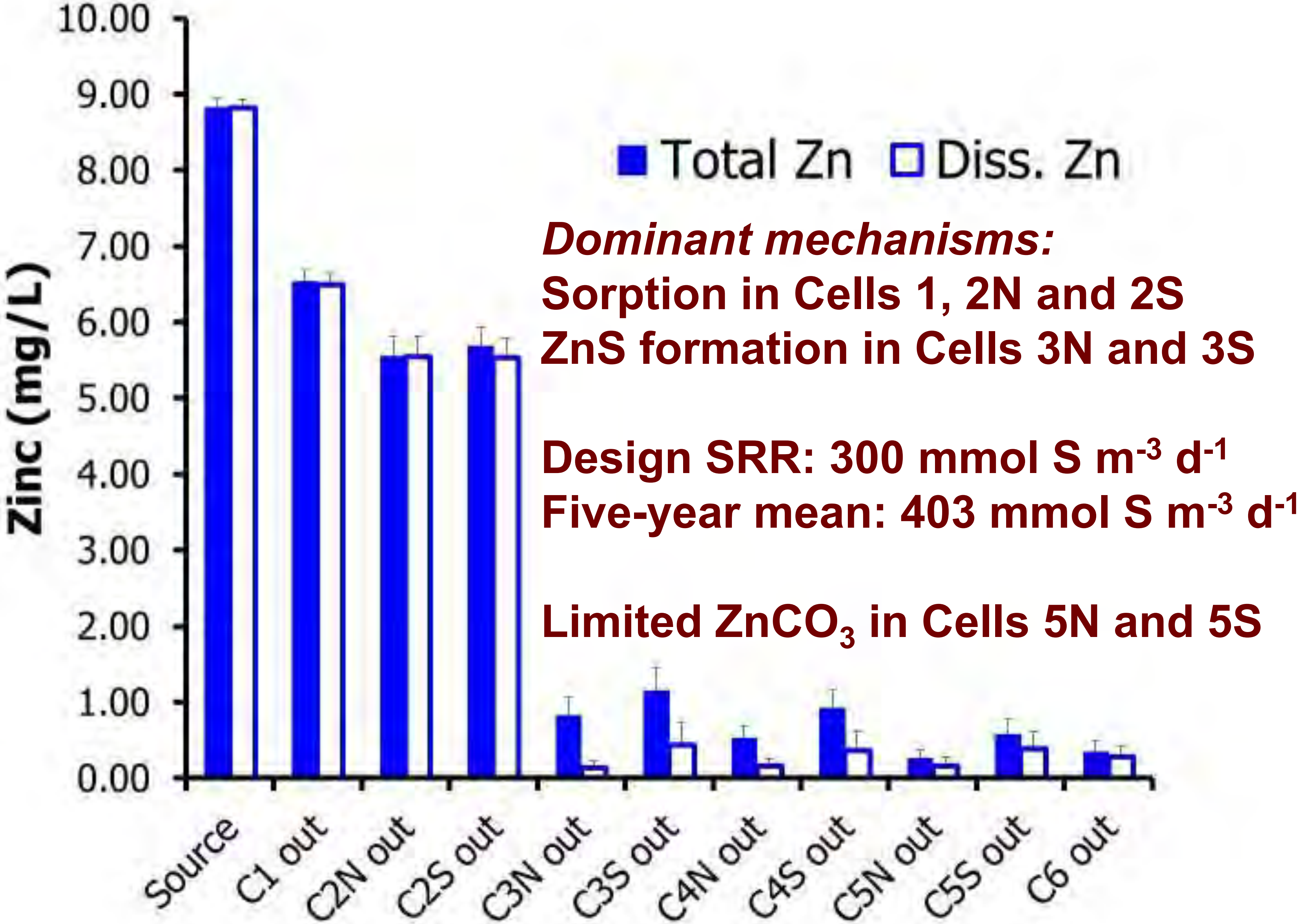
Dominant mechanisms:

Oxidation and sorption in Cell 1

Fe Mass Load Δ		**[As] Δ**
In:	**107 kg/d**	**64 μg/L**
Out:	**4 kg/d**	**<DL**

Design Fe Removal Rate: 20 g m^{-2} d^{-1}

Five-year Mean : 20.4 ± 5.4 g m^{-2} d^{-1}

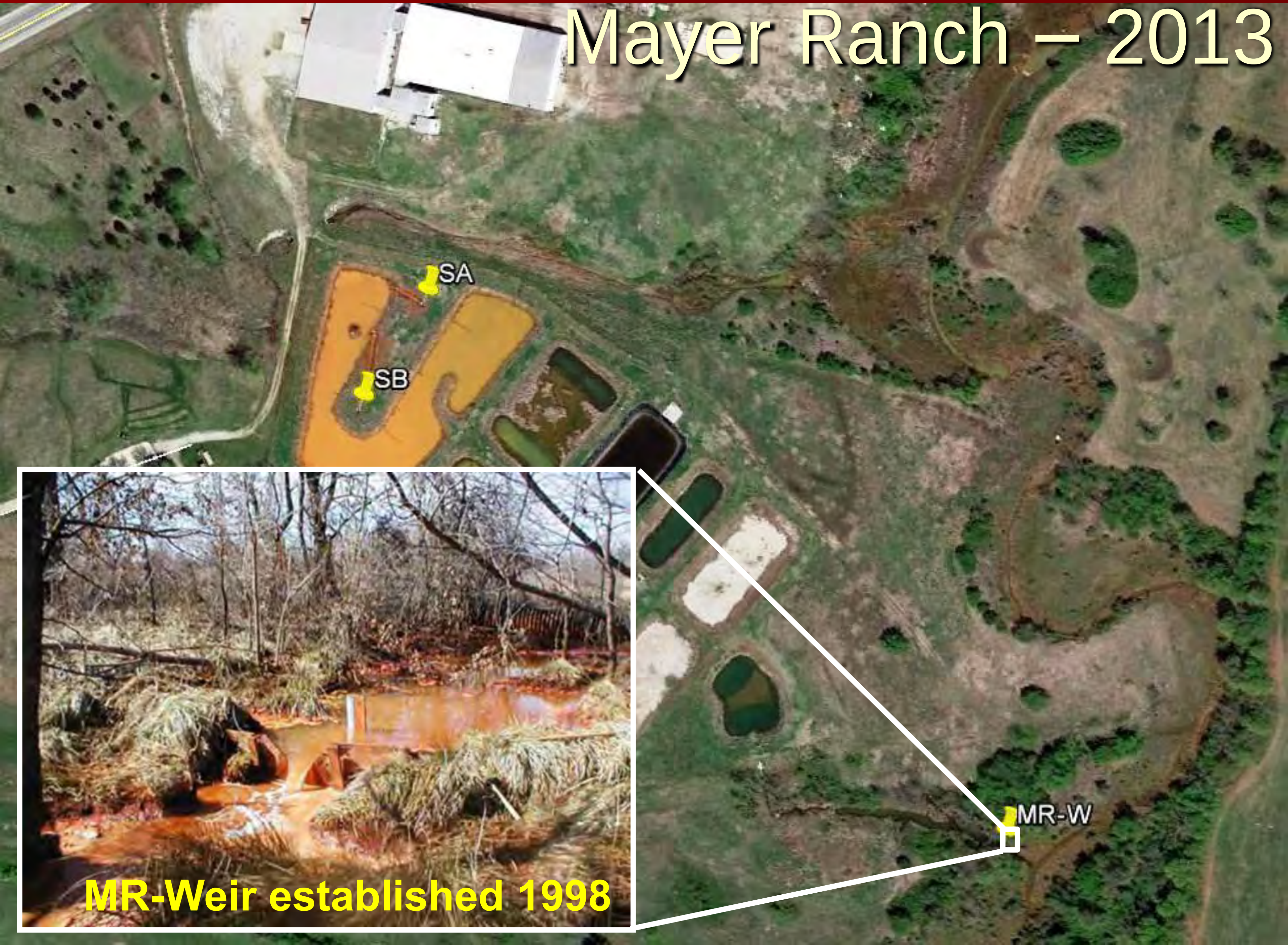


Zinc (mg/L)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Total Zn
Diss. Zn
Source
C1 out
C2N out
C2S out
C3N out
C3S out
C4N out
C4S out
C5N out
C5S out
C6 out
Dominant mechanisms:
Sorption in Cells 1, 2N and 2S
ZnS formation in Cells 3N and 3S
Design SRR: 300 mmol S m^{-3} d^{-1}
Five-year mean: 403 mmol S m^{-3} d^{-1}
Limited $ZnCO_3$ in Cells 5N and 5S

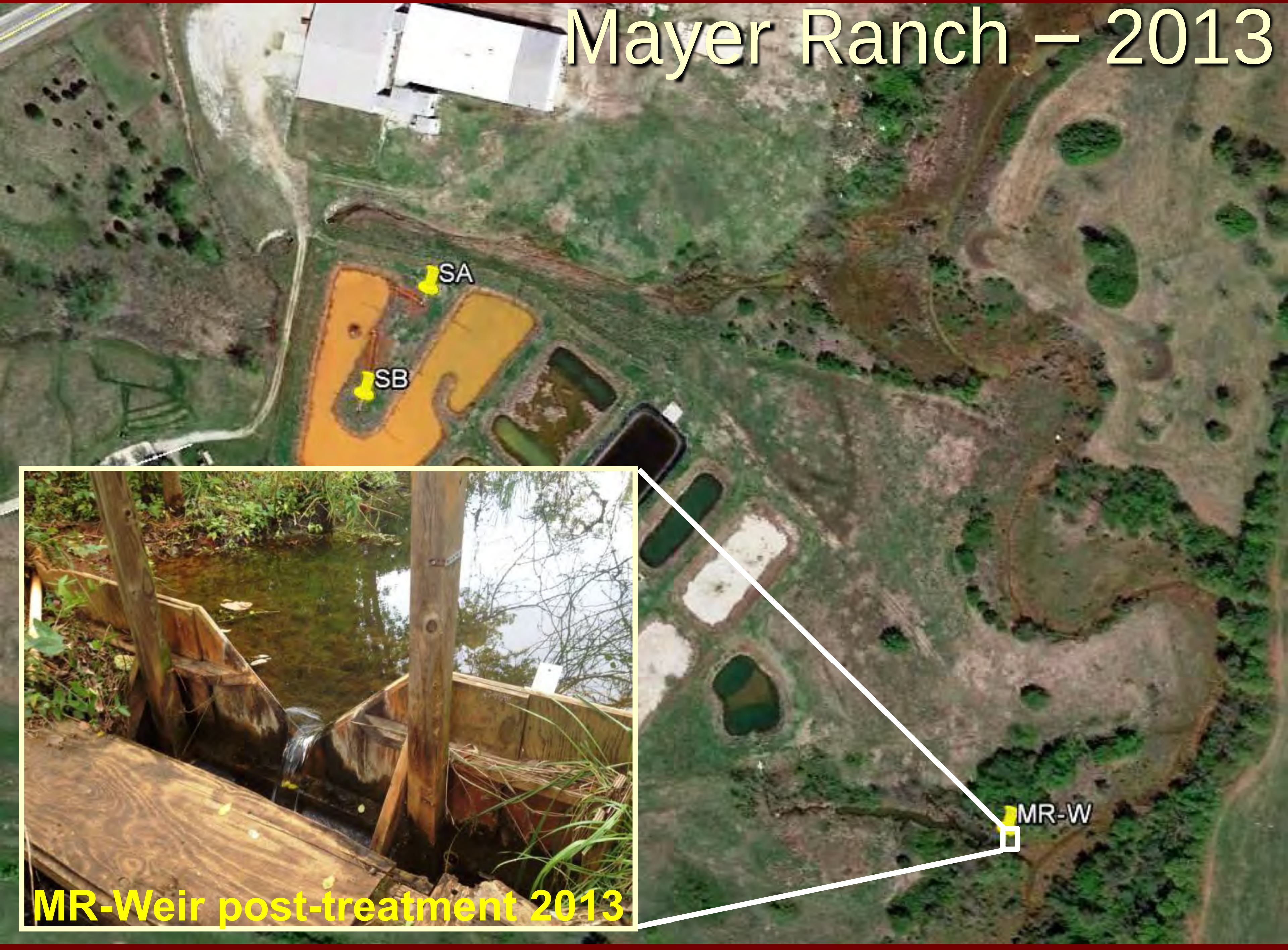
Mean Water Quality Changes

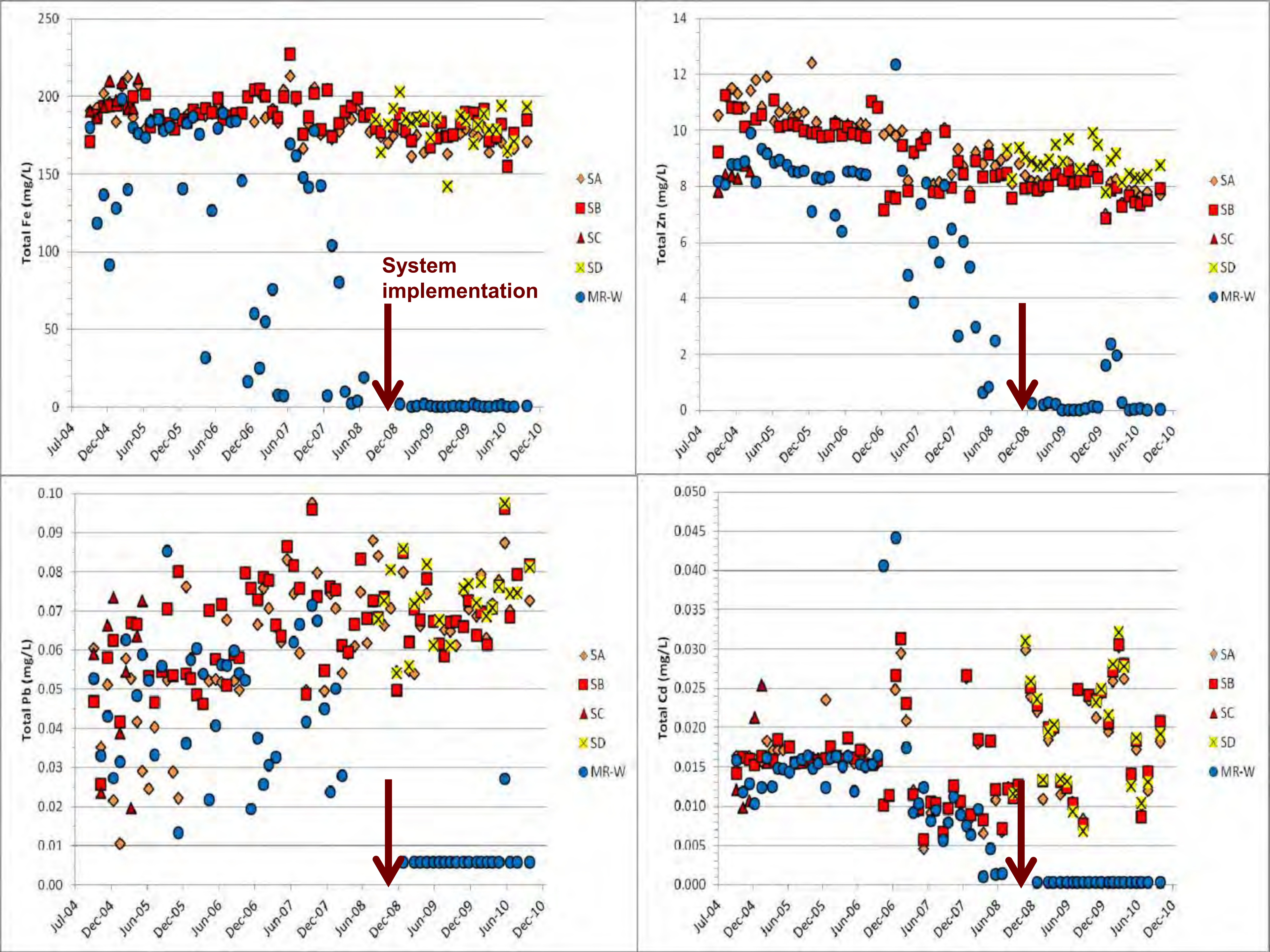
	In	Out
pH	5.95	7.02
Tot. Alk. (mg/L)	393	224
Net Alk. (mg/L)	29	224
Fe (mg/L)	192	0.13
Zn (mg/L)	11	0.25
Ni (mg/L)	0.97	0.15
Cd (μg/L)	17	<DL
Pb (μg/L)	60	<DL
As (μg/L)	64	<DL
SO_4^{-2} (mg/L)	2239	2057

Mayer Ranch – 2013



Mayer Ranch – 2013

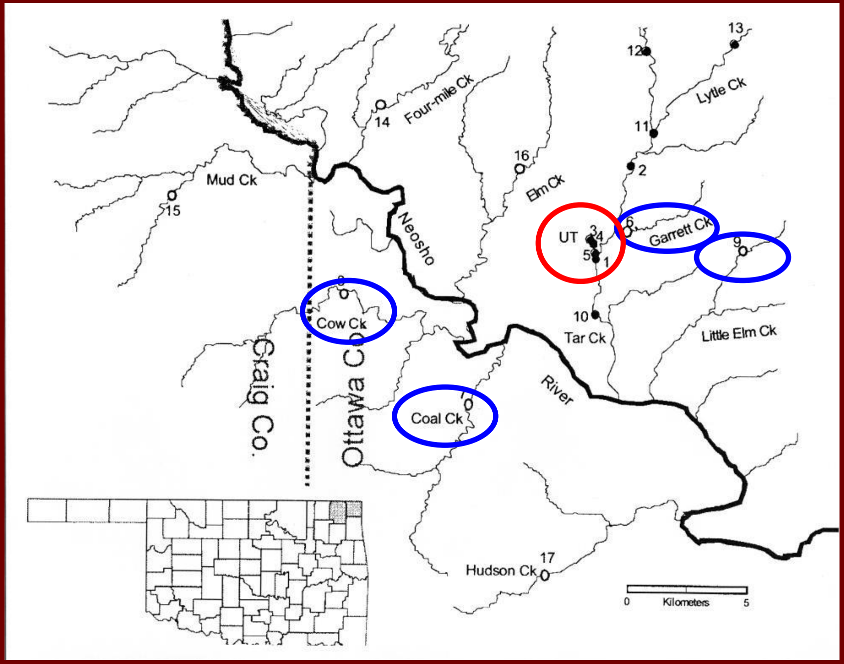



Total Fe (mg/L)
Total Zn (mg/L)
Total Pb (mg/L)
Total Cd (mg/L)
System implementation
SA
SB
SC
SD
MR-W
Jul-04
Dec-04
Jun-05
Dec-05
Jun-06
Dec-06
Jun-07
Dec-07
Jun-08
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10


Receiving stream downstream of
system effluent

Receiving Stream Ecological Recovery

- Marked improvement in water quality (metals loads decreased)
- Early indications of return of fish community



Receiving Stream

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

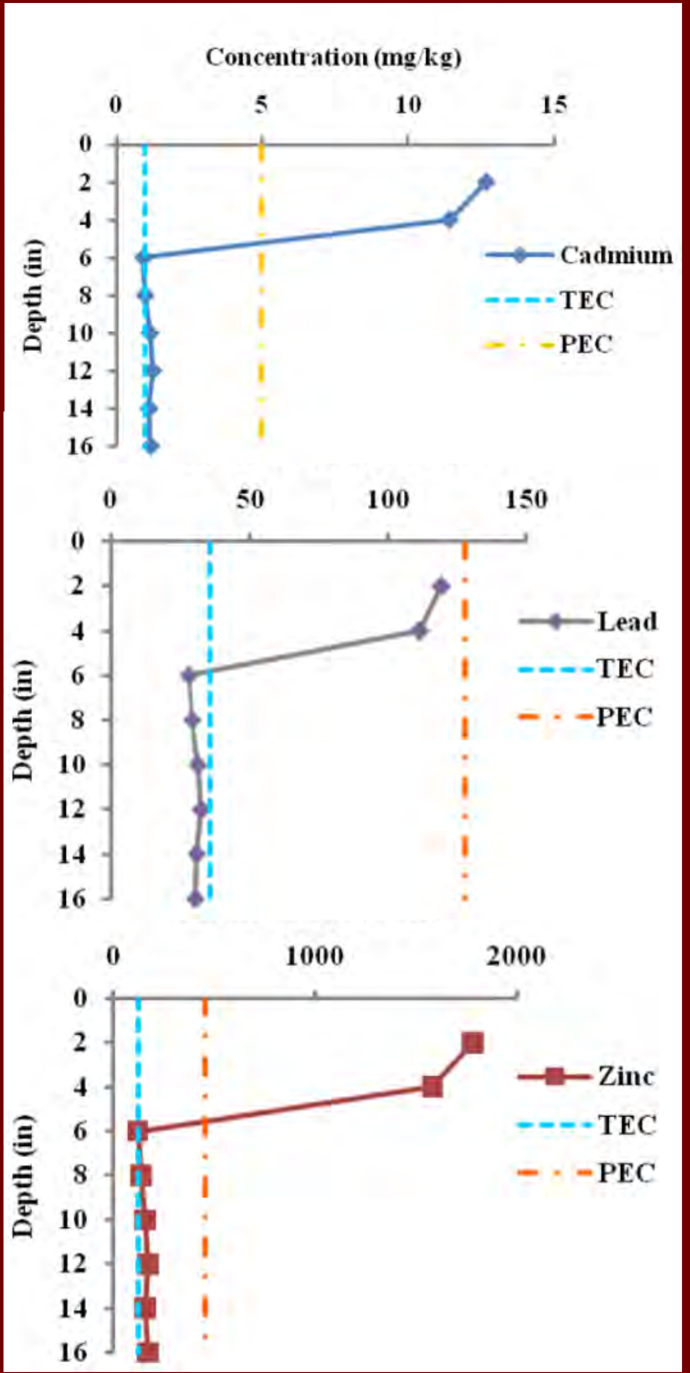
		Catch per unit effort (CPUE)	
Scientific name	Common name	2005-07	2009-12
Gambusia affinis	Western mosquitofish	39.24	187.60
Lepomis cyanellus	Green sunfish	0.81	16.80
Lepomis macrochirus	Bluegill	1.00	3.00
Lepomis megalotis	Longear sunfish	0.02	6.80
Notemigonus crysoleucas	Golden shiner	0.17	0.60
Lepomis 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

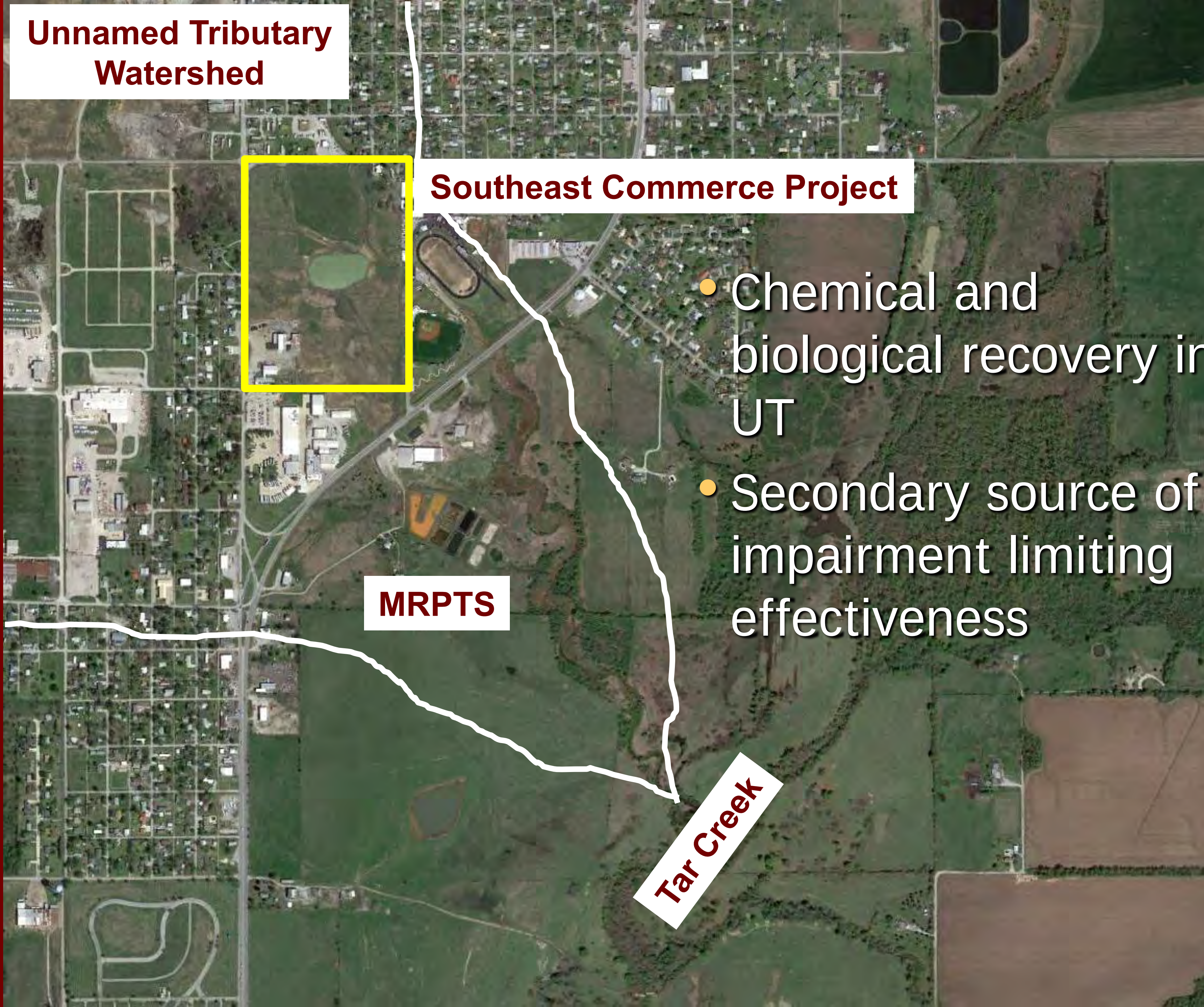
	Mass retained (kg/year)
Fe	57000
Zn	3300
Ni	300
Cd	5
Pb	17
As	18

Grand Lake O' the Cherokees Sediments

- Premier recreational reservoir
- Surficial sediments show elevated metals



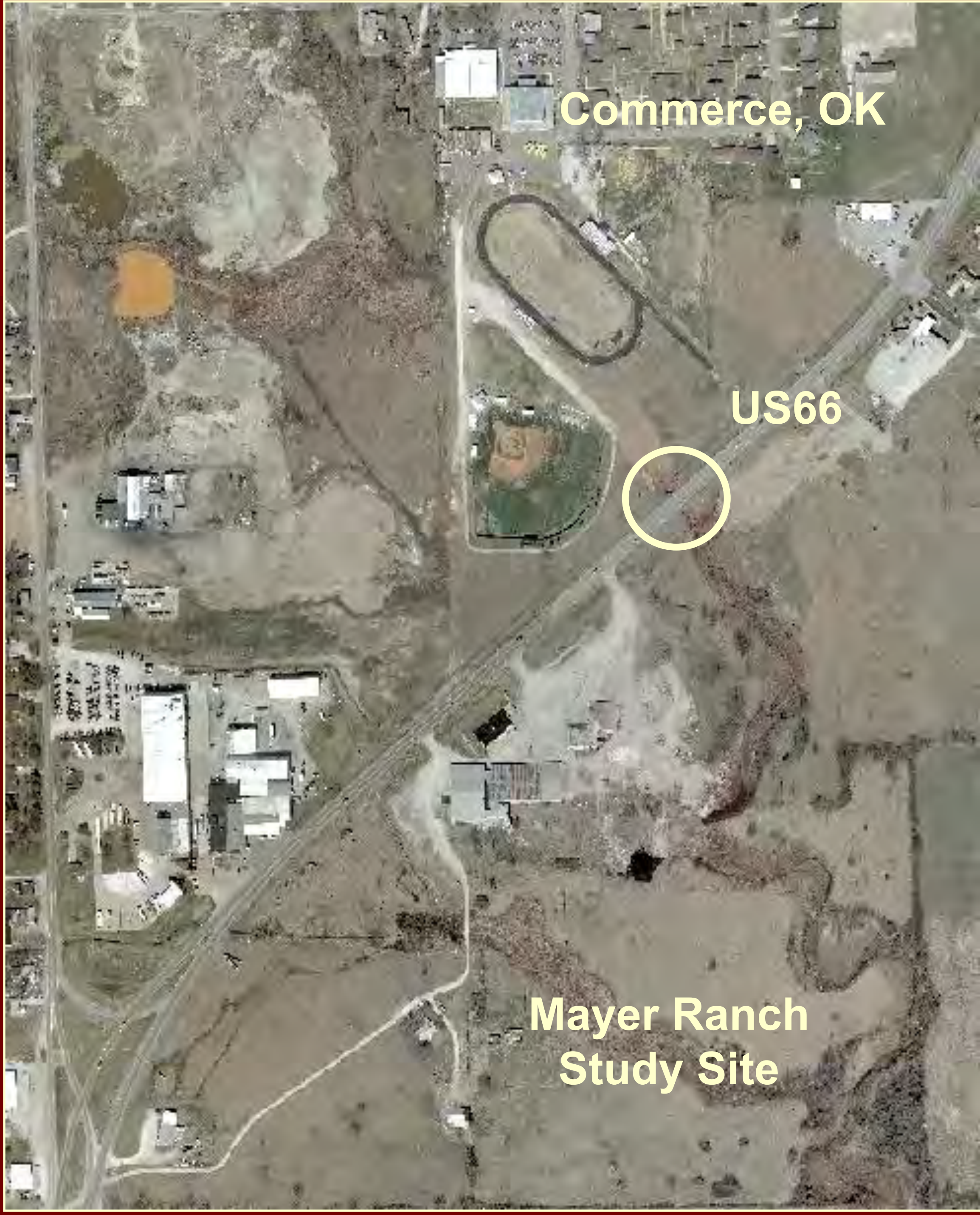

What comes next?



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

SE Commerce

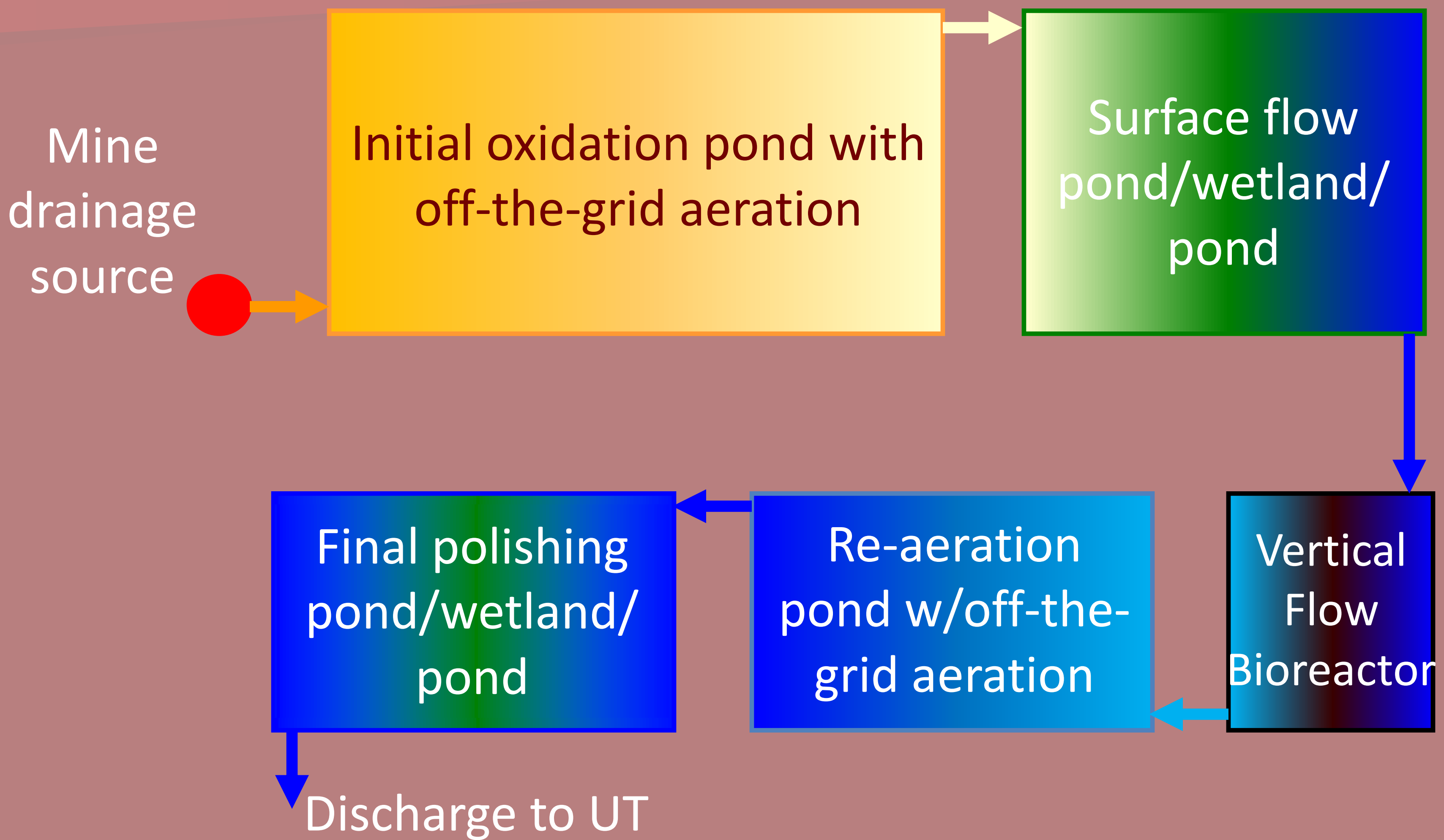
- "Red Hole" and "Green Hole" collapses
- Surface reclaimed ~ 2006
- Water currently discharges into conduit under US66



SE Commerce

- Flow: 100 gpm
  - Fe: 140 mg/L
  - Zn: 11 mg/L
  - Pb: 62 μg/L
  - Cd: 37 μg/L

SE Commerce Conceptual Design



Beaver Creek

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

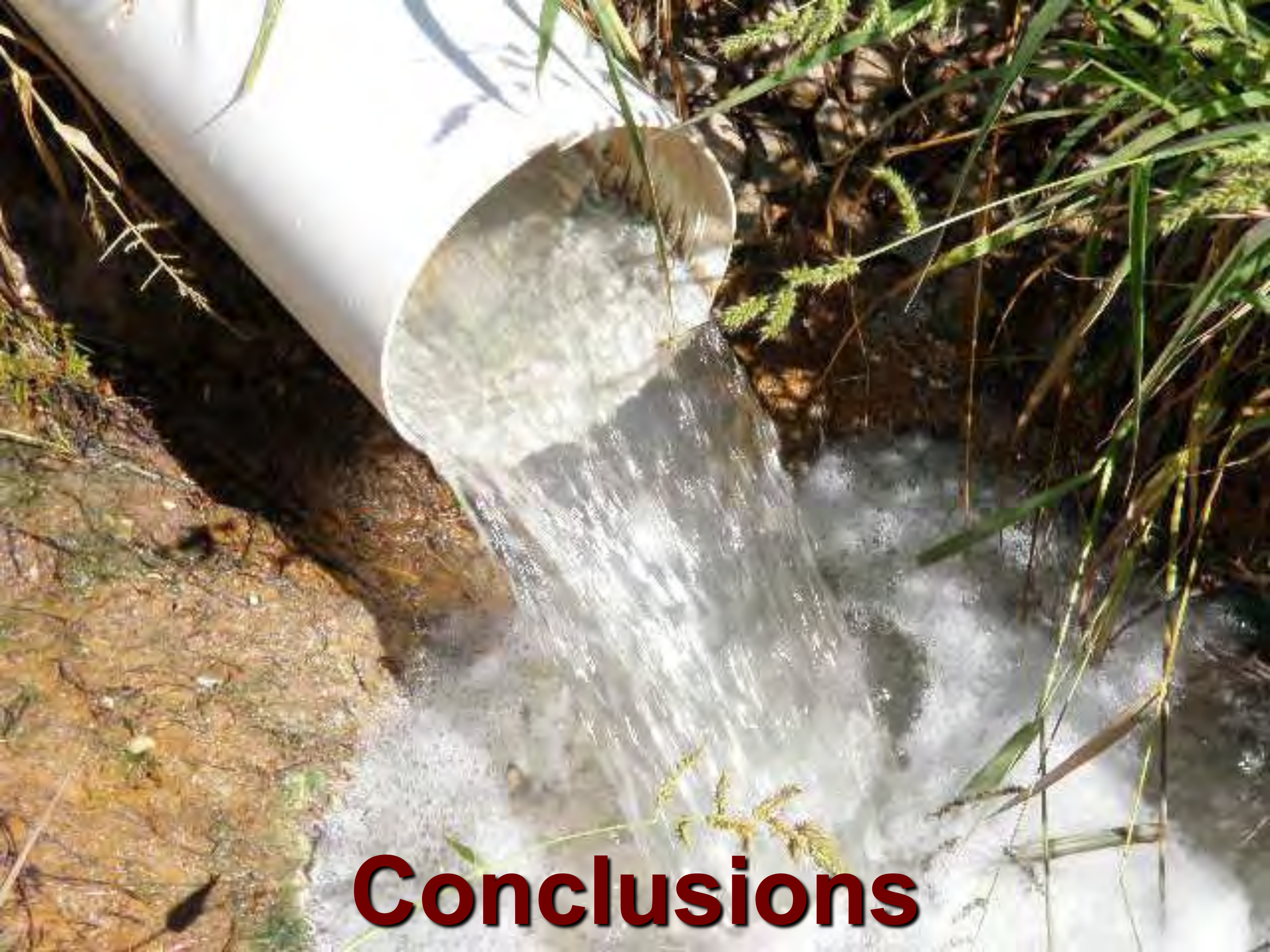
	BC MD8
pH	6.62
Fe (mg/L)	9.28
Zn (mg/L)	1.60
Pb (µg/L)	15
Cd (µg/L)	1

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

- Passive treatment represents effective mechanism for mine water quality improvement
- Technology transferable to other mine water discharges
- Reconsideration of previous administrative decisions warranted

Reversing the Irreversible?

- As of 2010, EPA noted that **passive treatment**

"...*could be an economically feasible engineered remedy for surface water at the site. For these reasons, in this fourth five-year review, the fund balancing ... waiver ... may no longer be appropriate and* ***should be reevaluated.***"

- What will be said in 2015?

Acknowledgements

- George and Maxine Mayer and family
- Red Pritchard and family
- 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

The CREW

K.A. Strevett, R.C. Knox, W.J. Matthews, E. Bergey, J. Basara, J.A. LaBar, C.H. Kellogg, A.D. O'Sullivan, S.A. Yepez, A.D. Smith, J.M. McAllister, W.J. Andrews, A.J. Brewer, B.E. Santamaria, C.A. Neely, A.E. Garrido, W. J. Strosnider, D.L. Lutes, M.M. Roberts, D.M. Hensley, R.L. White, C.F. Gause, T.L. Traw, J. Coffey, C.M. Porter, D. Athay, B. Winter, N.J. Iverson, V.B. Arvidson, R.A. Garrett, C.R. DuBois, E.E. Breetzke, M.N Mercer, J. Arango Calderon, N. Berg-Mattson, J.D. Brumley, B.R. Furneaux, M.J. Rice, R.C. Dutnell, L.R. 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, E. 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, et al.


Questions?
http://CREW.ou.edu
nairn@ou.edu