Hydrologic Budgets and Conservative Ions: Potentially Important Yet Neglected Tools in the Evaluation of Passive Treatment System Effectiveness

Robert W. Nairn

Boren Distinguished Professor and Viersen Presidential Professor

CREW Director

Nicholas L. Shepherd

Graduate Research Assistant

The UNIVERSITY of OKLAHOMA

Gallogly College of Engineering

School of Civil Engineering and Environmental Science

CREW

Center for Restoration of Ecosystems and Watersheds

University of Oklahoma

Study Objectives

- Passive treatment system design advanced considerably in recent decades
- Based on contaminant mass loads and empirically-derived mass removal rates
- Performance evaluations often depend on water quality concentration changes alone
- Assume no changes in water throughput rates, ignoring portions of hydrologic budget
- Disregard any mechanisms affecting water chemical composition other than those designed to address constituents of concern


Hydrologic Budgets

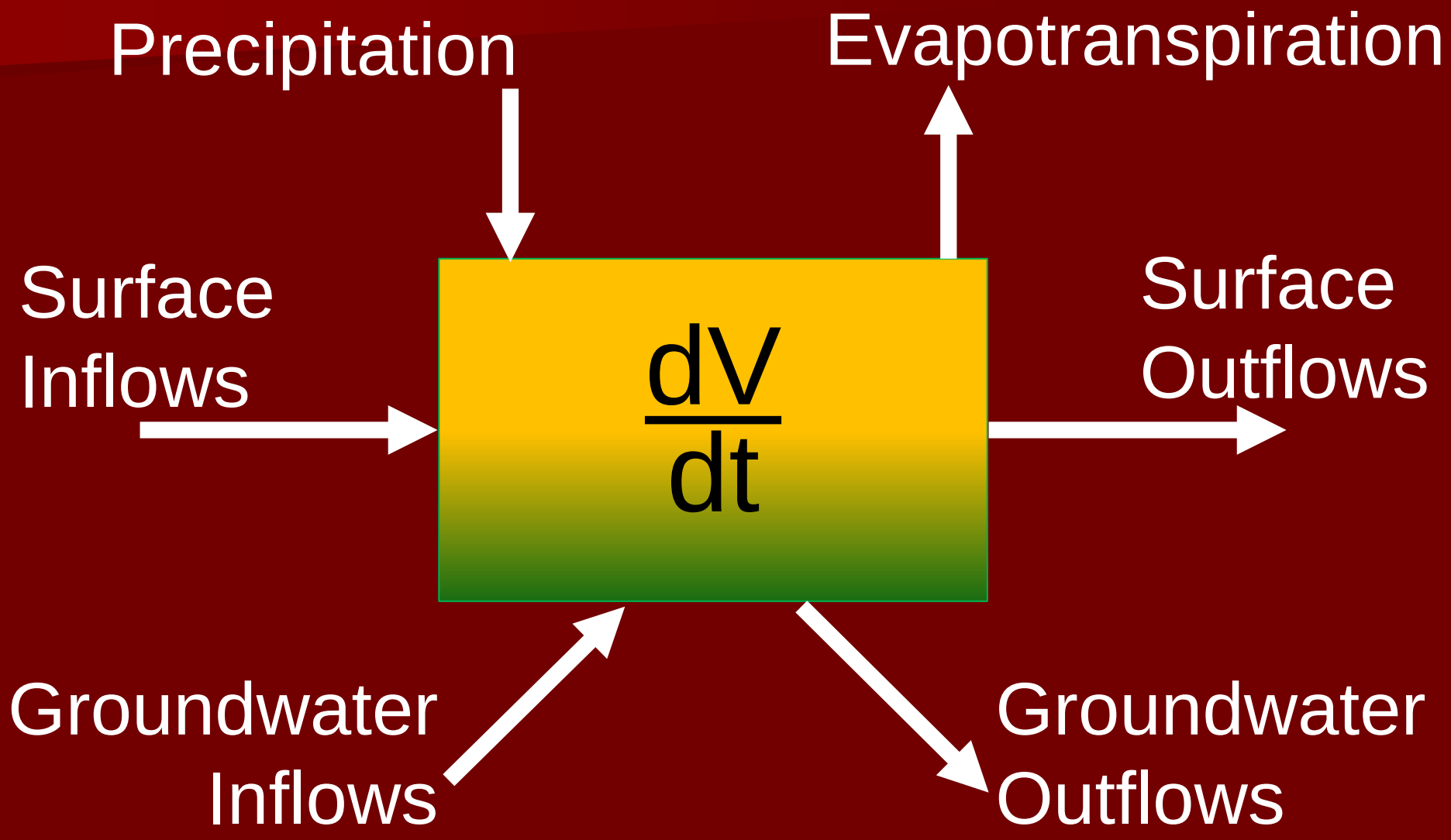

Conservative Ions


PTS Applications


Conclusions


Hydrologic Budgets

Hydrologic Budget



PTS Hydrologic Budgets

- Precipitation directly onto system surface
- Evapotranspiration directly from system surface
- Surface inflow = artesian mine water flow
  - No surface runoff
  - No channelized stream flow
  - No overbank flooding from streams
- Surface outflow from system
- Little to no groundwater influence


Conservative Ions

Conservative Ions

- Constituents present but not acted upon biogeochemically
- Concentration changes only due to dilution or evaporation
- Must be present in adequate concentration for meaningful analyses
- Used to estimate likely effects of precipitation and evapotranspiration due to temperature extremes

Conservative Ions

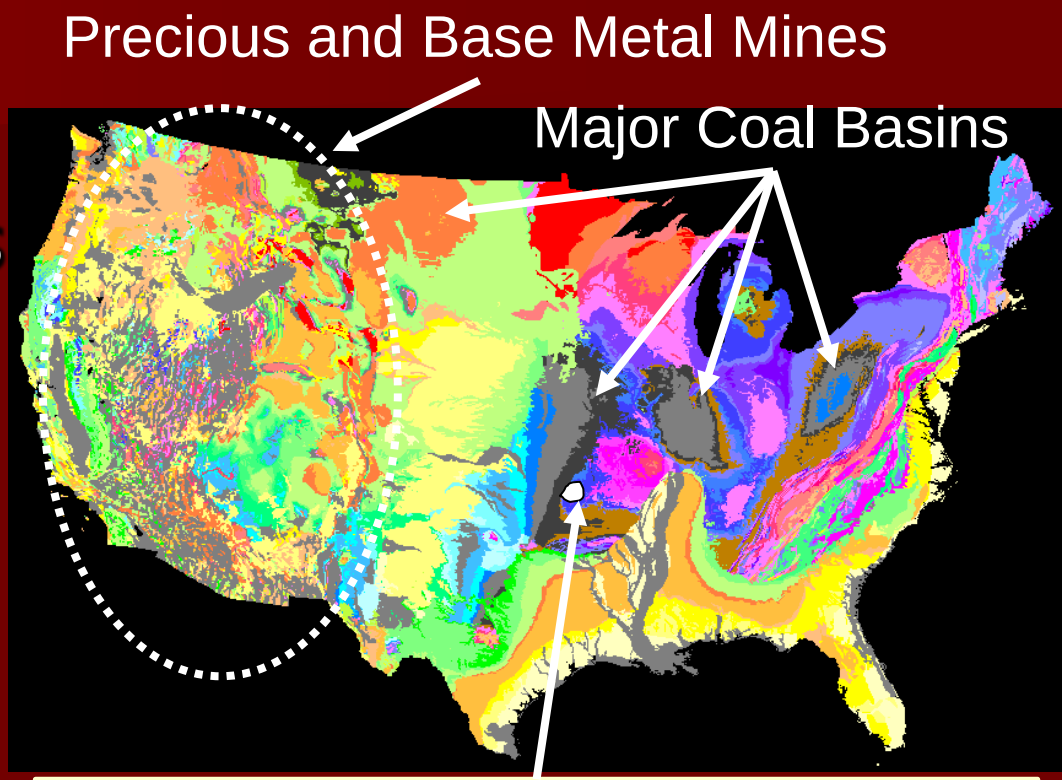
- Possible conservative ions in mining-influenced natural water systems

Cations	Anions
Li^{+}	SO_4^{2-}
K^{+}	Br^{-}
Na^{+}	Cl^{-}
Ca^{2+}	F^{-}
Mg^{2+}	NO_3^{-}
Si^{4+}	NO_2^{-}
Others?	Others?

PTS Applications

Tri-State Lead-Zinc Mining District

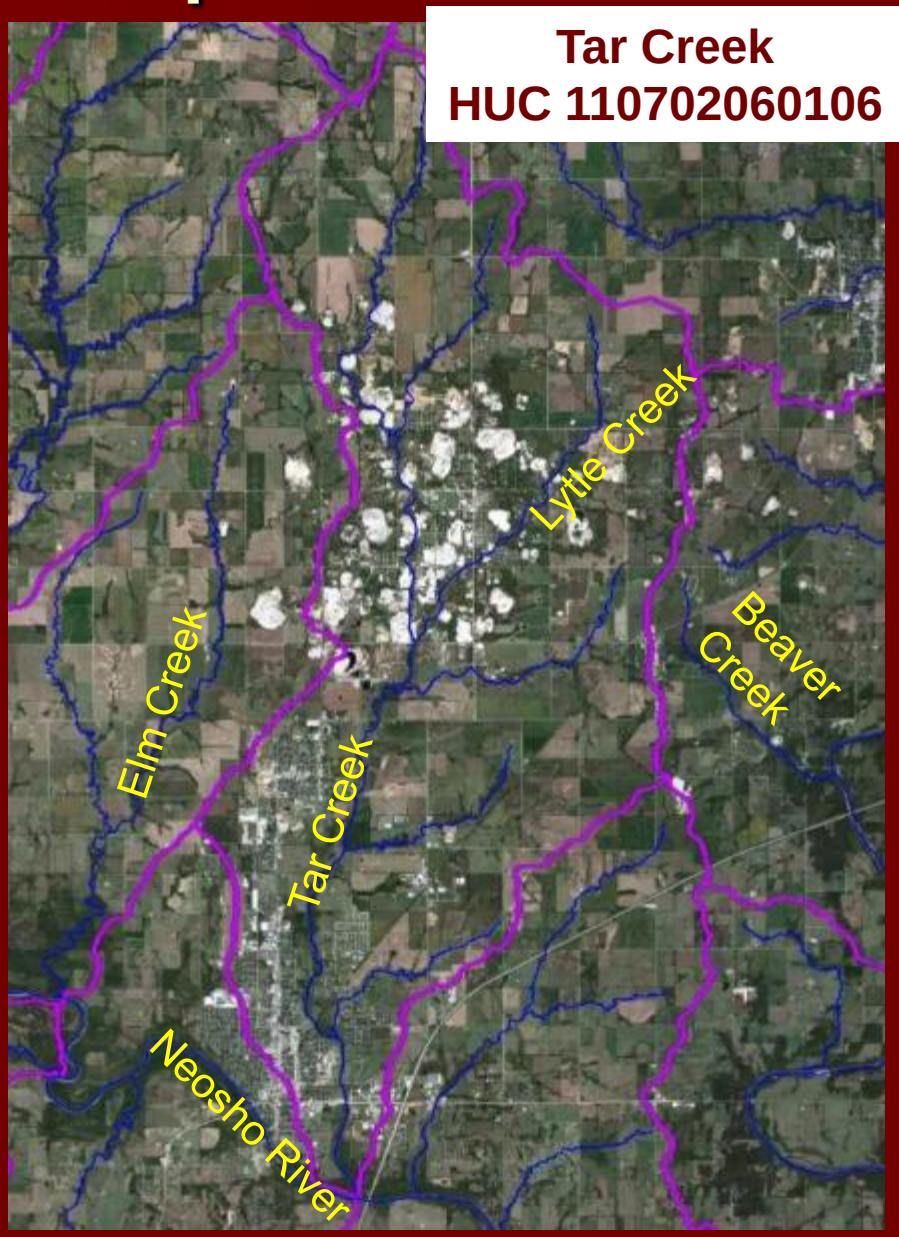
- >3000 km^2 mined ~1838-1971
- Mississippian sulfides
  - Galena (PbS)
  - Sphalerite (ZnS)
- Extensive underground workings
- Massive surface processing operations



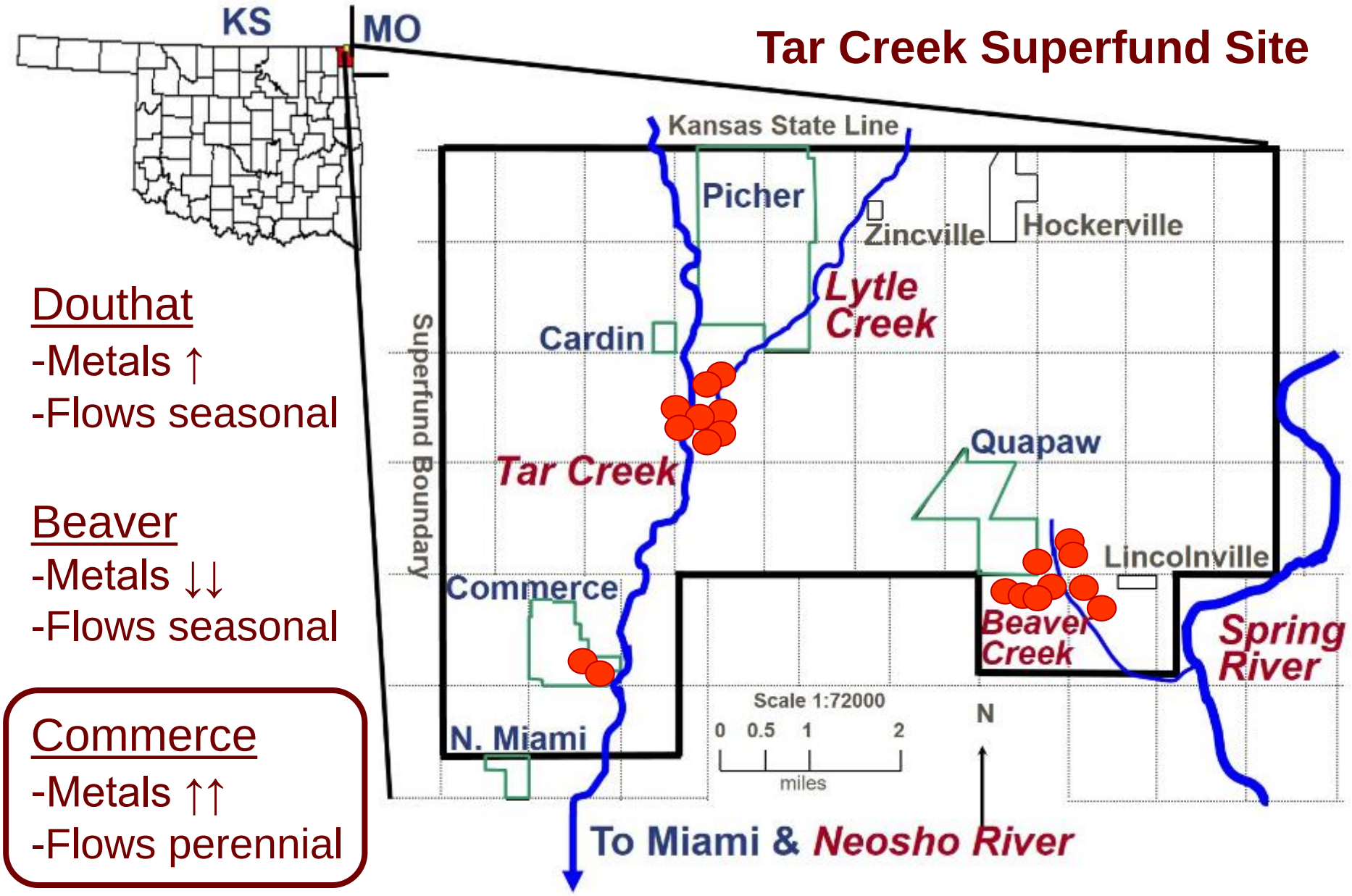
Tri-State Lead-Zinc Mining District
- Joplin Field, Missouri
- Galena Field, Kansas
- Picher Field, Oklahoma

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”



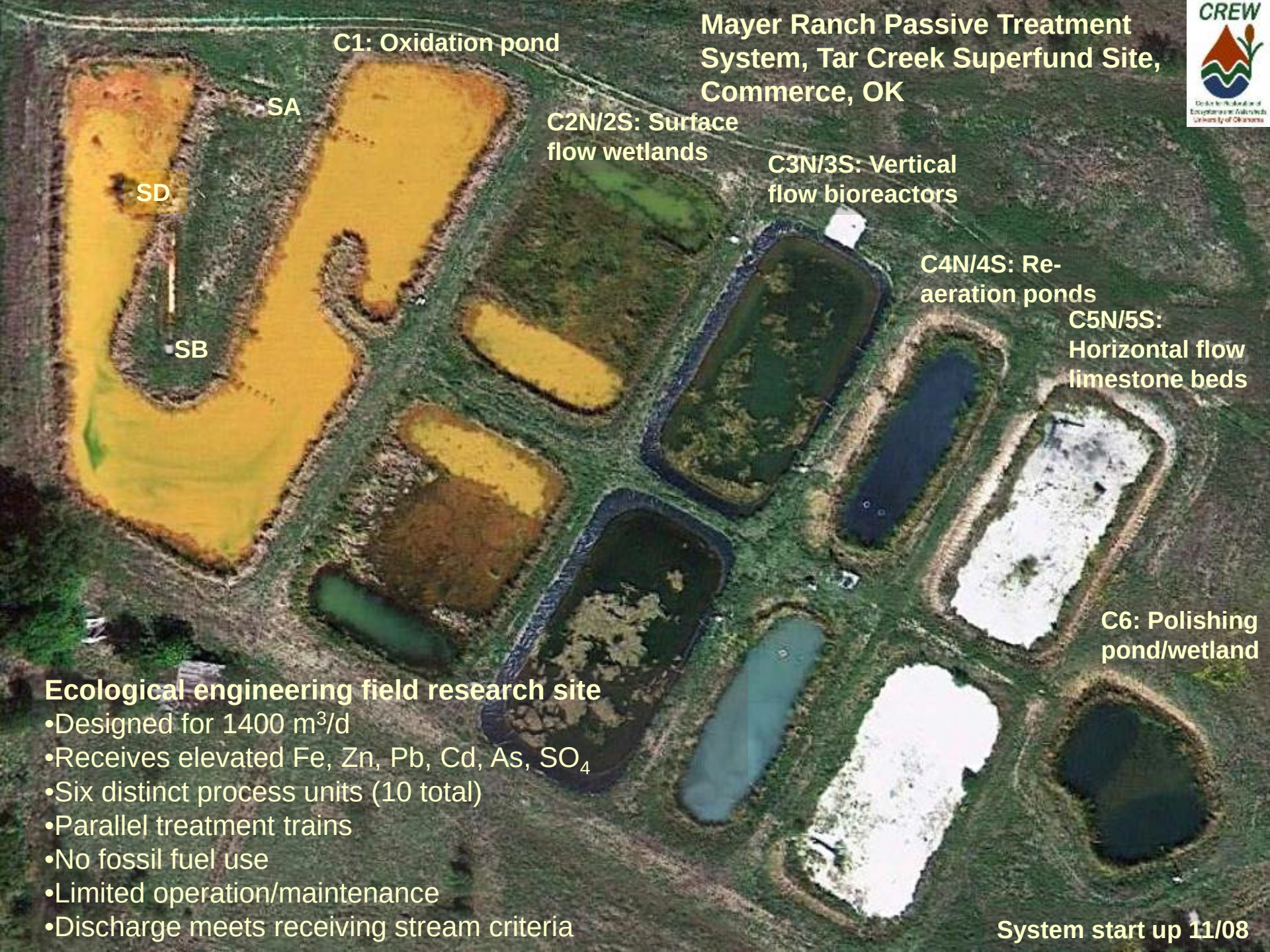
Artesian Mine Water Discharges



Douthat
-Metals ↑
-Flows seasonal

Beaver
-Metals ↓↓
-Flows seasonal

Commerce
-Metals ↑↑
-Flows perennial


Mayer Ranch Passive Treatment System, Tar Creek Superfund Site, Commerce, OK
CREW
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

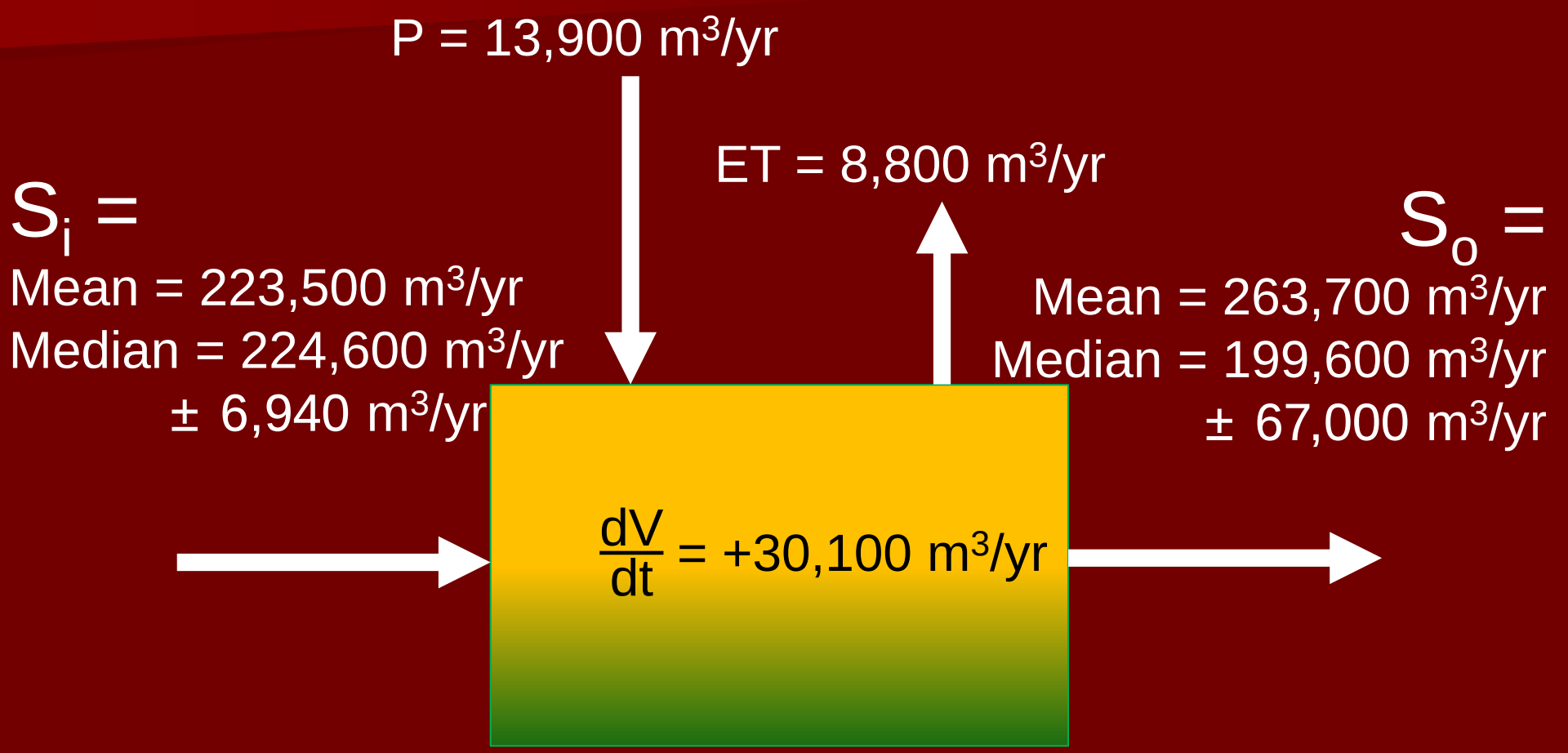
MRPTS Hydrologic Budgets

$$\frac{\Delta V}{\Delta t} = \frac{\Delta(dxA)}{\Delta t} = S_{in} - S_{out} + P - ET$$

- Presented as changes in volume or depth
- S_{in} discrete data obtained monthly
- S_{out} continuous monitoring
- P obtained from Oklahoma Mesonet
- ET calculated using Thornthwaite Equation


$K_{clay} \equiv 10^{-8}$ cm/s

Annual MRPTS Hydrologic Budget



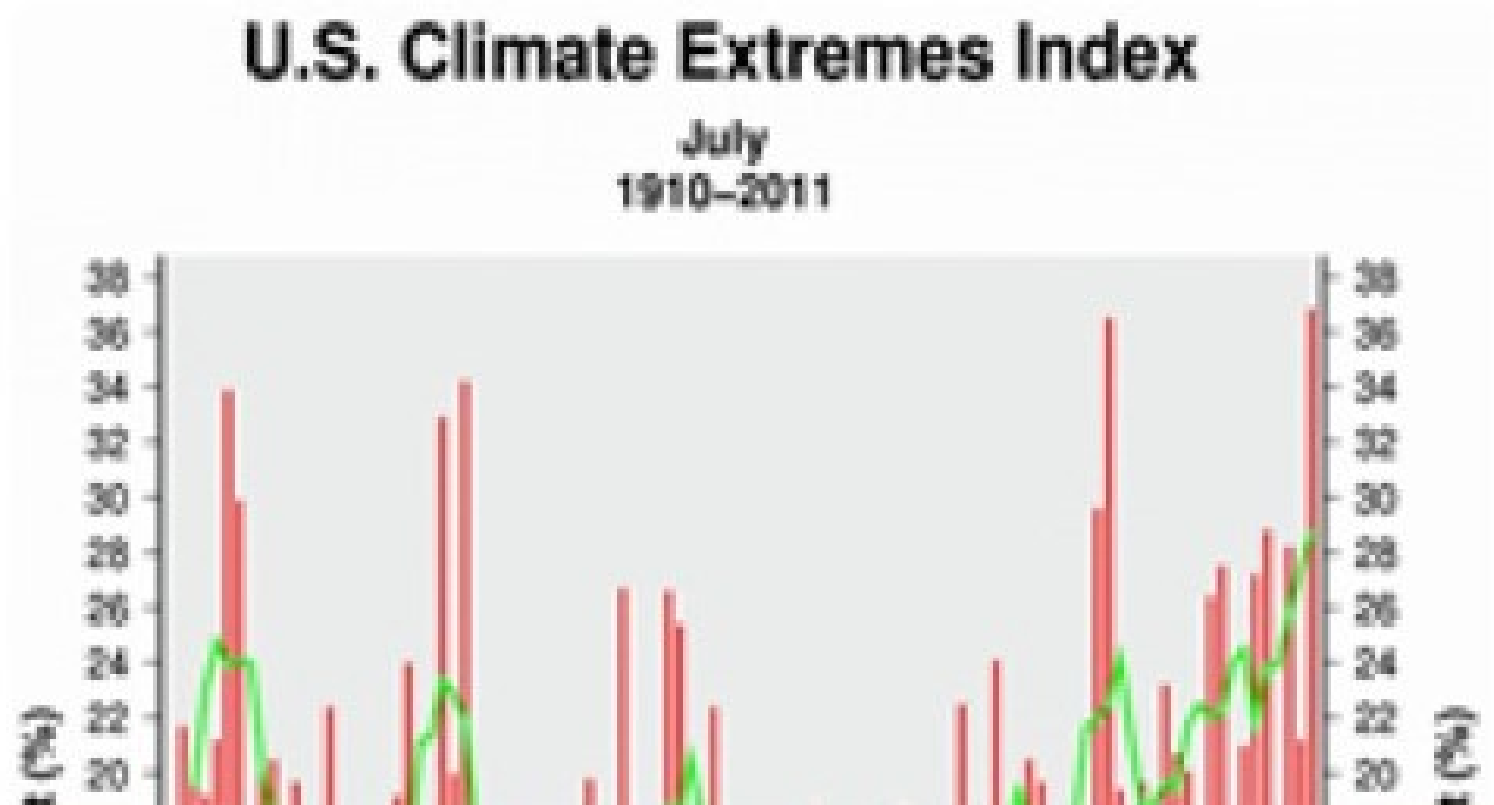
The Washington Post
Democracy Dies in Darkness

Local

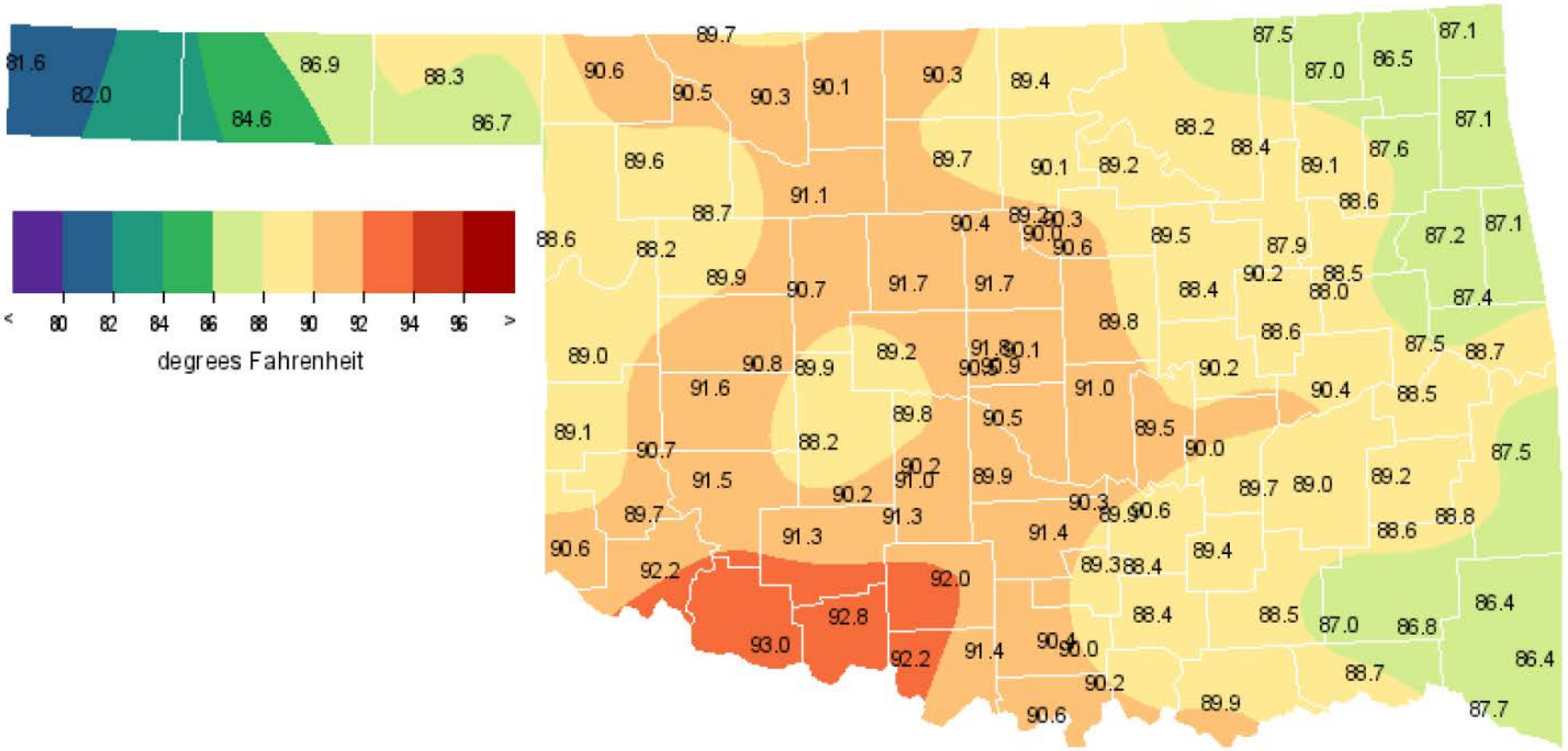
July: most extreme and 4th warmest in US; Oklahoma hottest ever state average temperature

July 2011

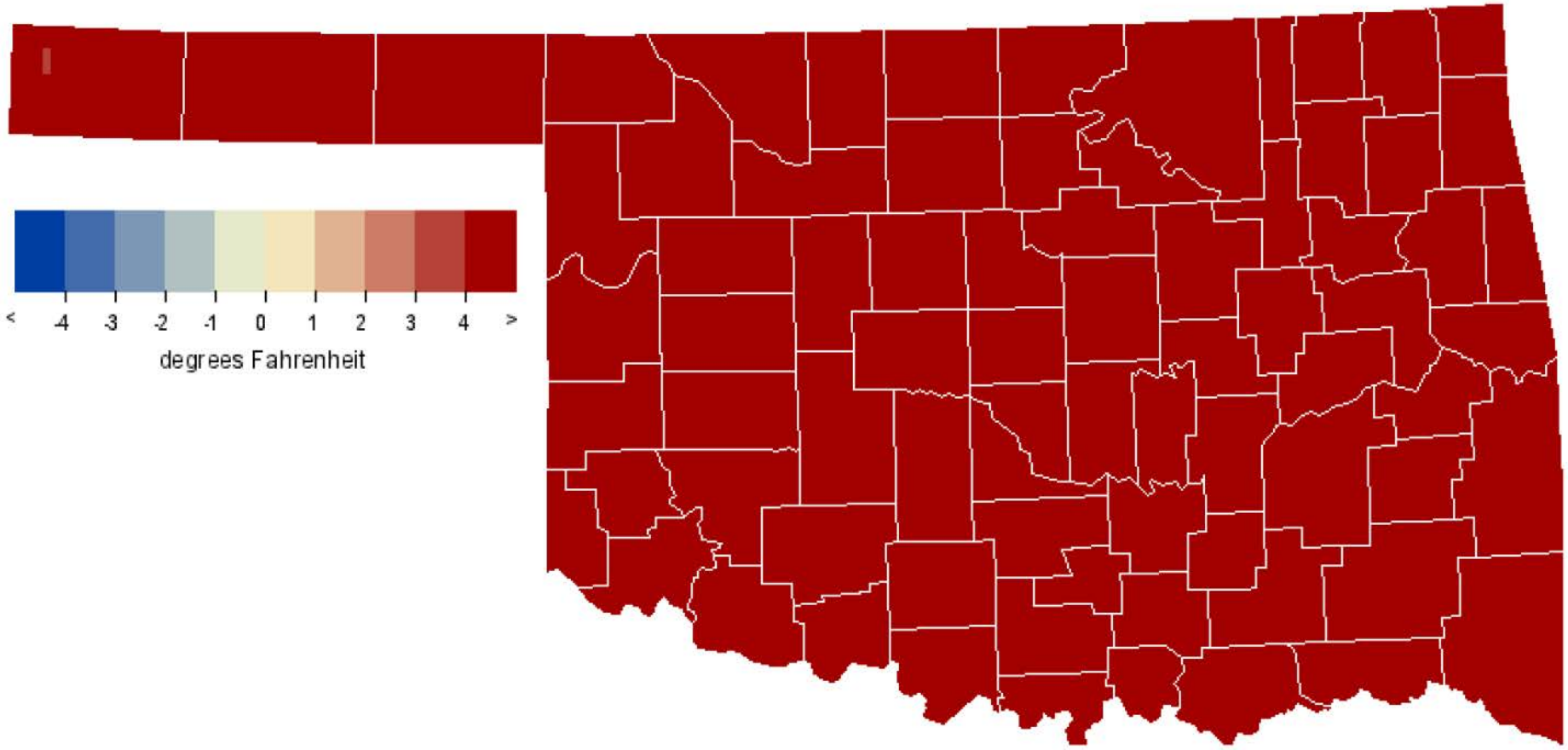
By Jason Samenow August 9, 2011 Email the author



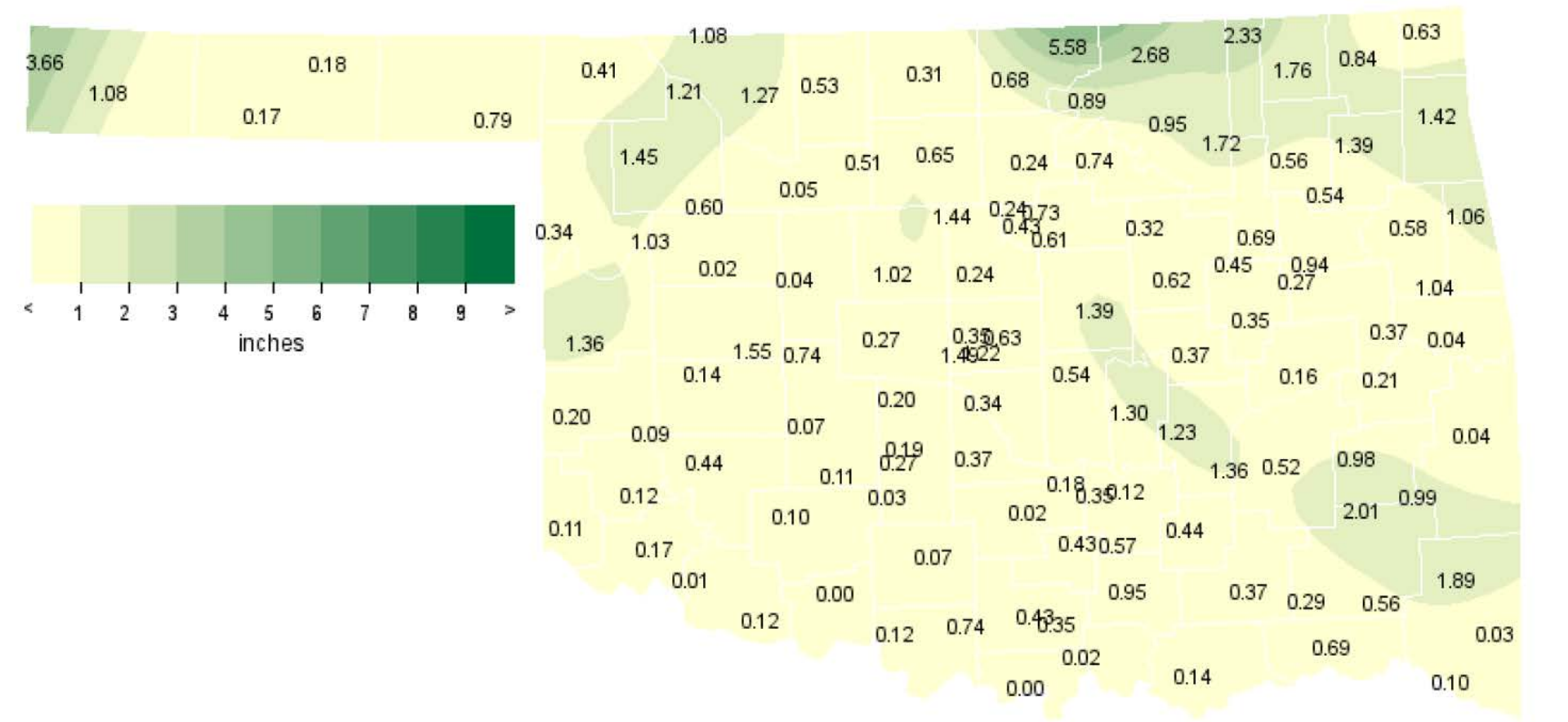
JULY 2011 AVERAGE TEMPERATURE



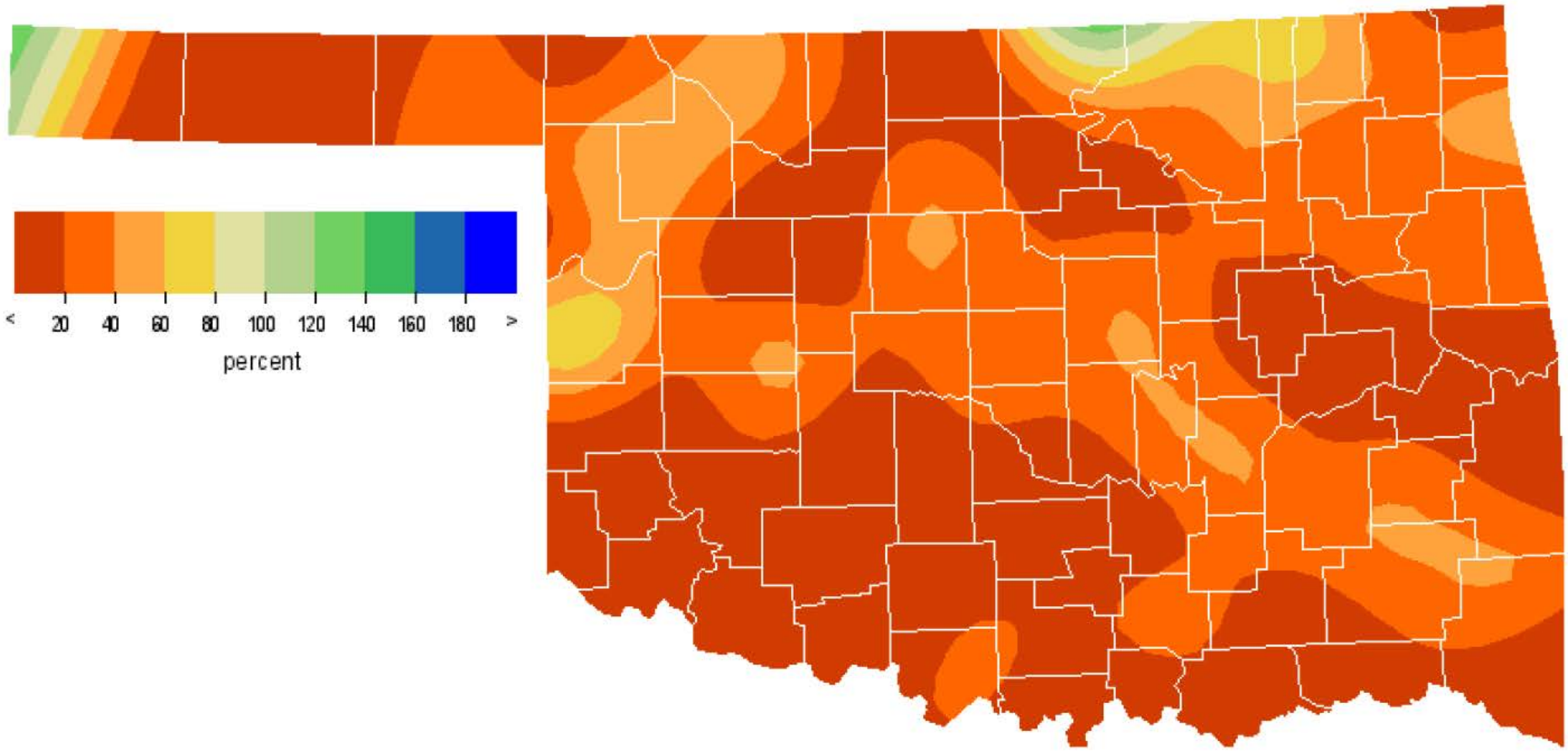
JULY 2011 DEPARTURE FROM NORMAL TEMPERATURE



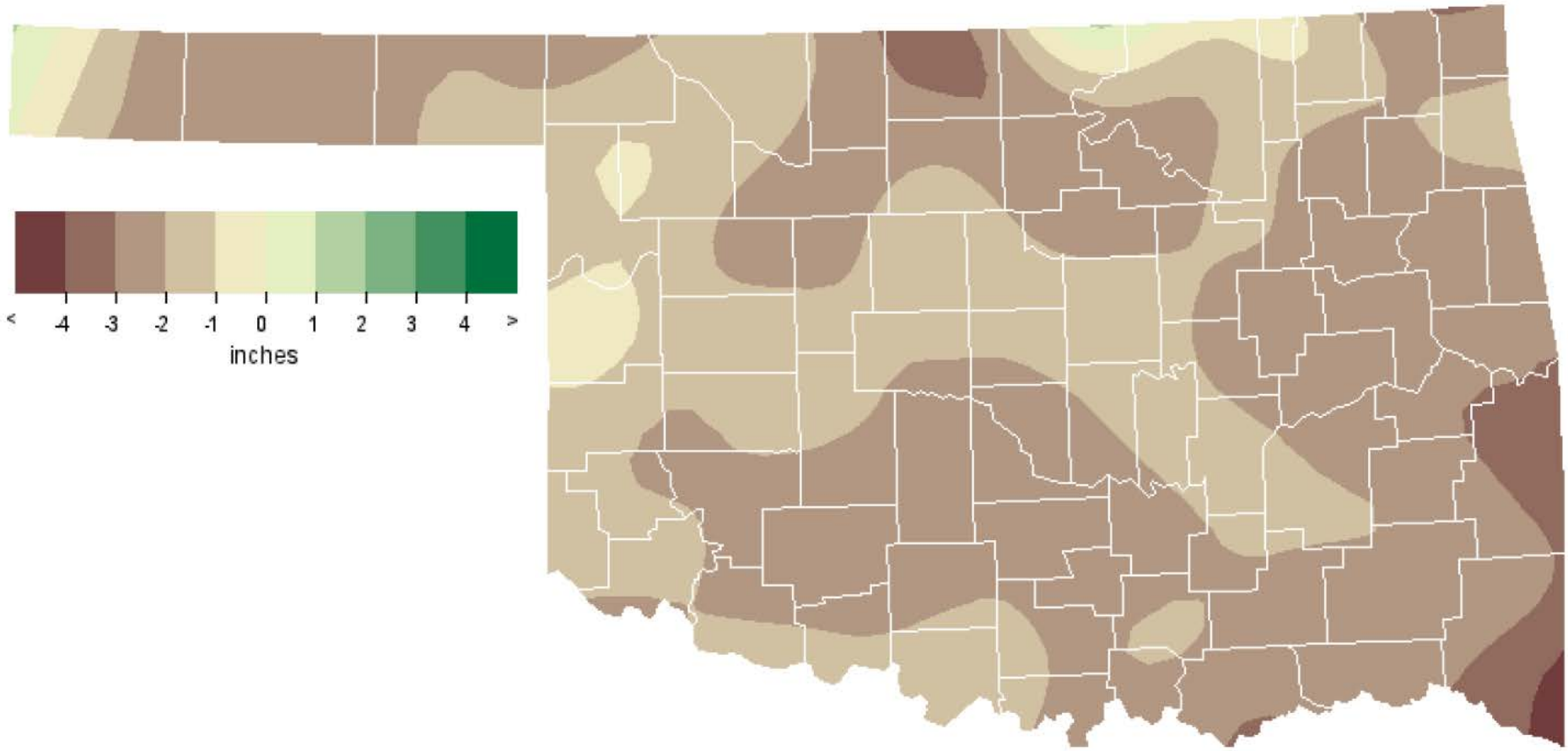
JULY 2011 OBSERVED PRECIPITATION

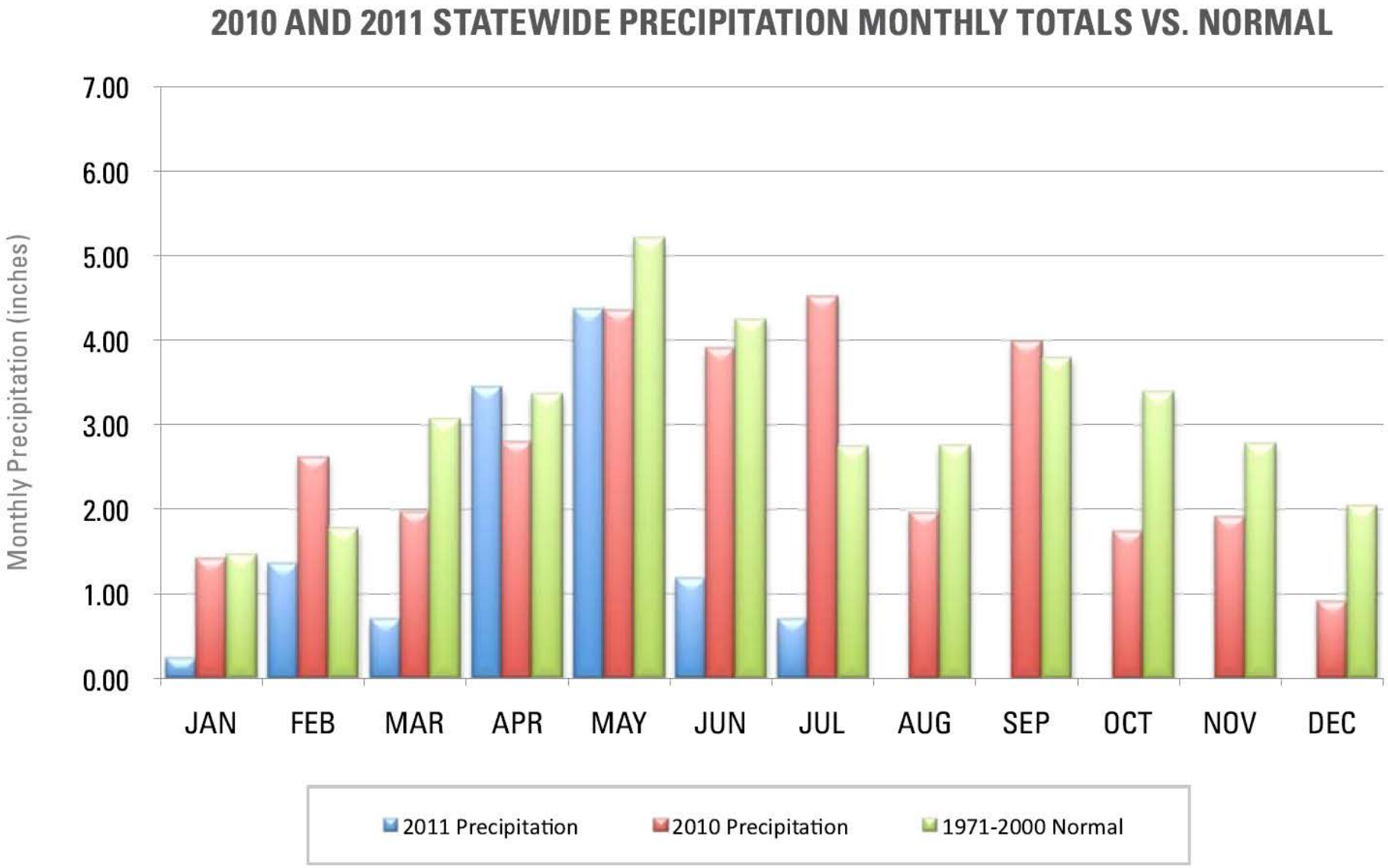


JULY 2011 PERCENT OF NORMAL PRECIPITATION

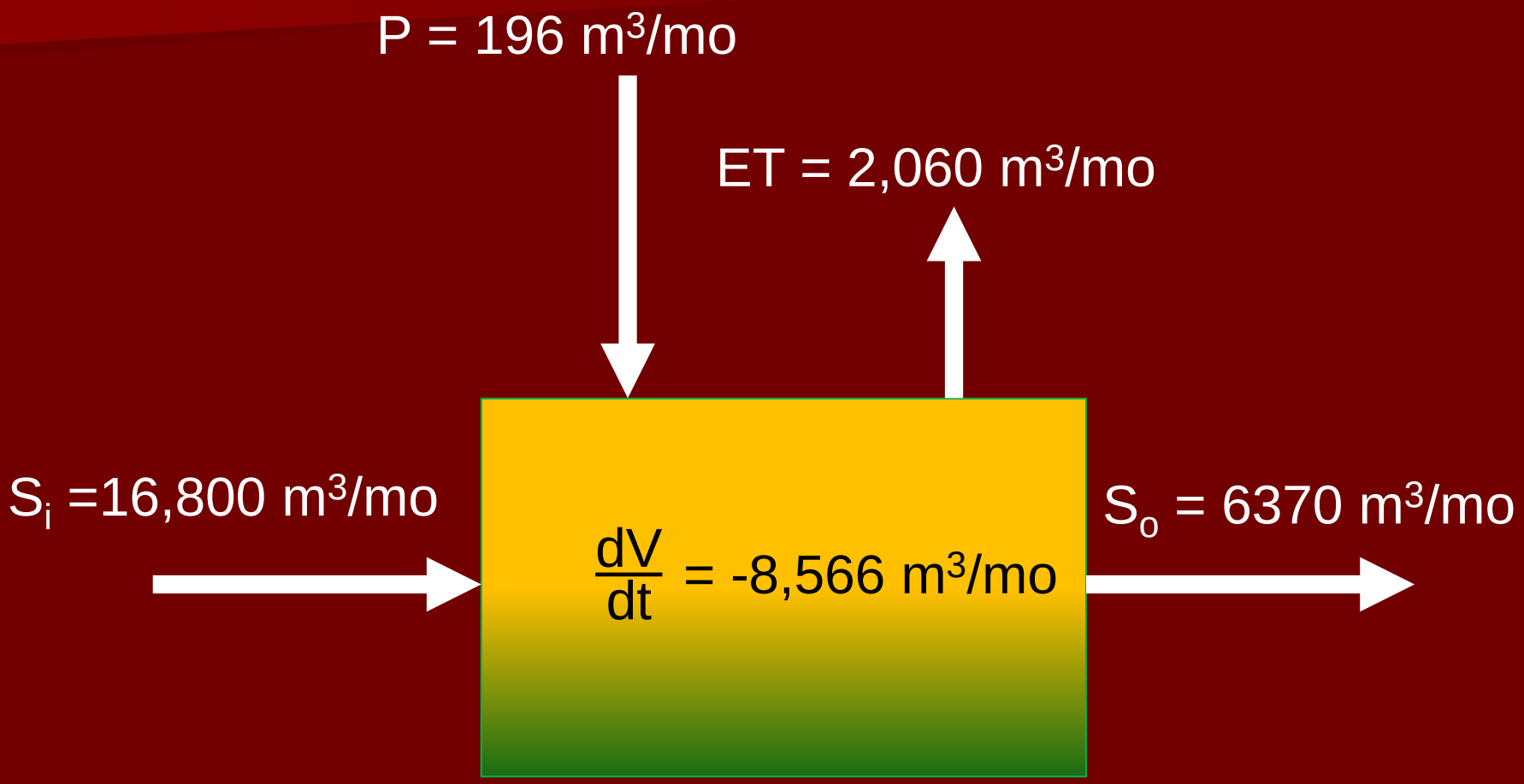


JULY 2011 DEPARTURE FROM NORMAL PRECIPITATION




2010 AND 2011 STATEWIDE PRECIPITATION MONTHLY TOTALS VS. NORMAL
Monthly Precipitation (inches)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2011 Precipitation
2010 Precipitation
1971-2000 Normal

July 2011 MRPTS Hydrologic Budget



Deluge inundates Oklahoma City with third-wettest day in its history

May 2015

Author: Tom DiLiberto

May 20, 2015

Print

Even though the severe weather season started off slow for much of the Midwest, May has been quite active for severe thunderstorms, tornadoes, and torrential rains. On May 6, severe thunderstorms formed across the heart of Tornado Alley from southern Nebraska, south through Kansas, Oklahoma, and into northern Texas. According to the AP, twelve people were injured in the resulting tornadoes across the Plains (preliminary reports were of 65 tornadoes), with officers twice having to evacuate the airport in Oklahoma City.

On May 6, 2015, heavy rain swept across Oklahoma City. These radar images show light rain in pale blue, moderate rain in medium blue, and very heavy rain in purple. Climate.gov animation by Hunter Allen, based on National

Current Event Location

Rating:

★★★★★

Your rating: None Average: 5 (6 votes)

Share This:

Reviewer:

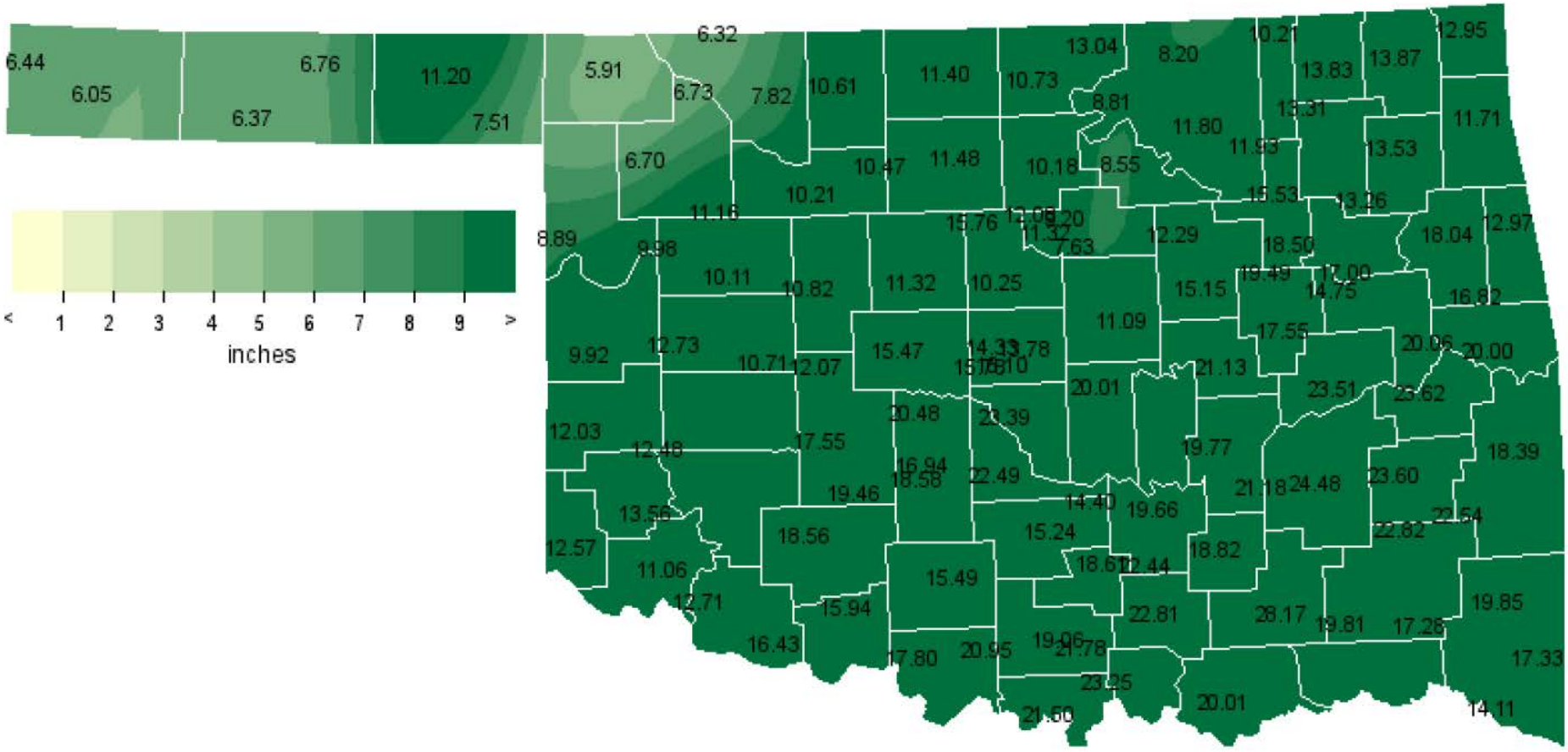
Emily Becker

May 2015 floods in Oklahoma and Texas

More in this event

Flood disaster in Texas and Oklahoma
June 2, 2015

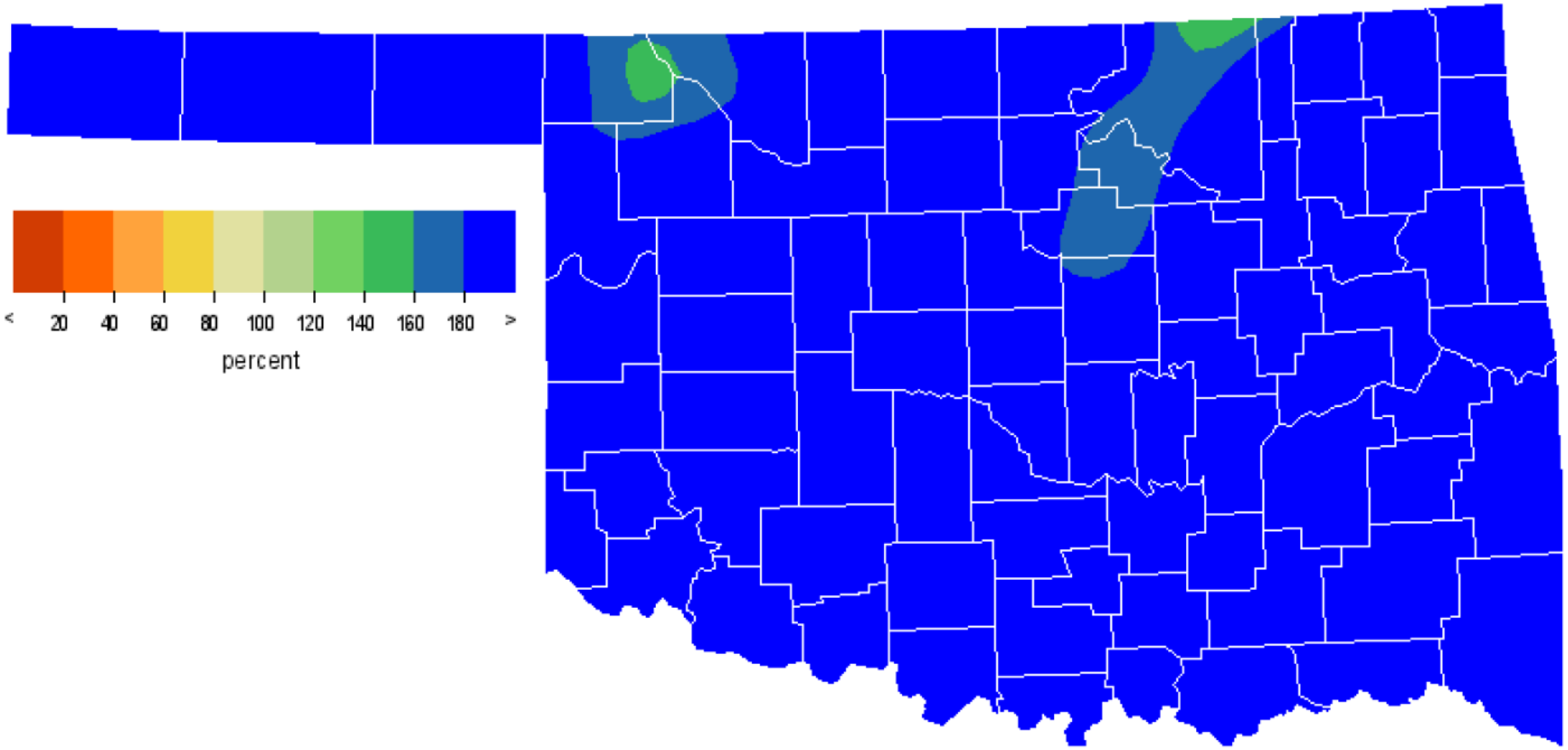
MAY 2015 OBSERVED PRECIPITATION



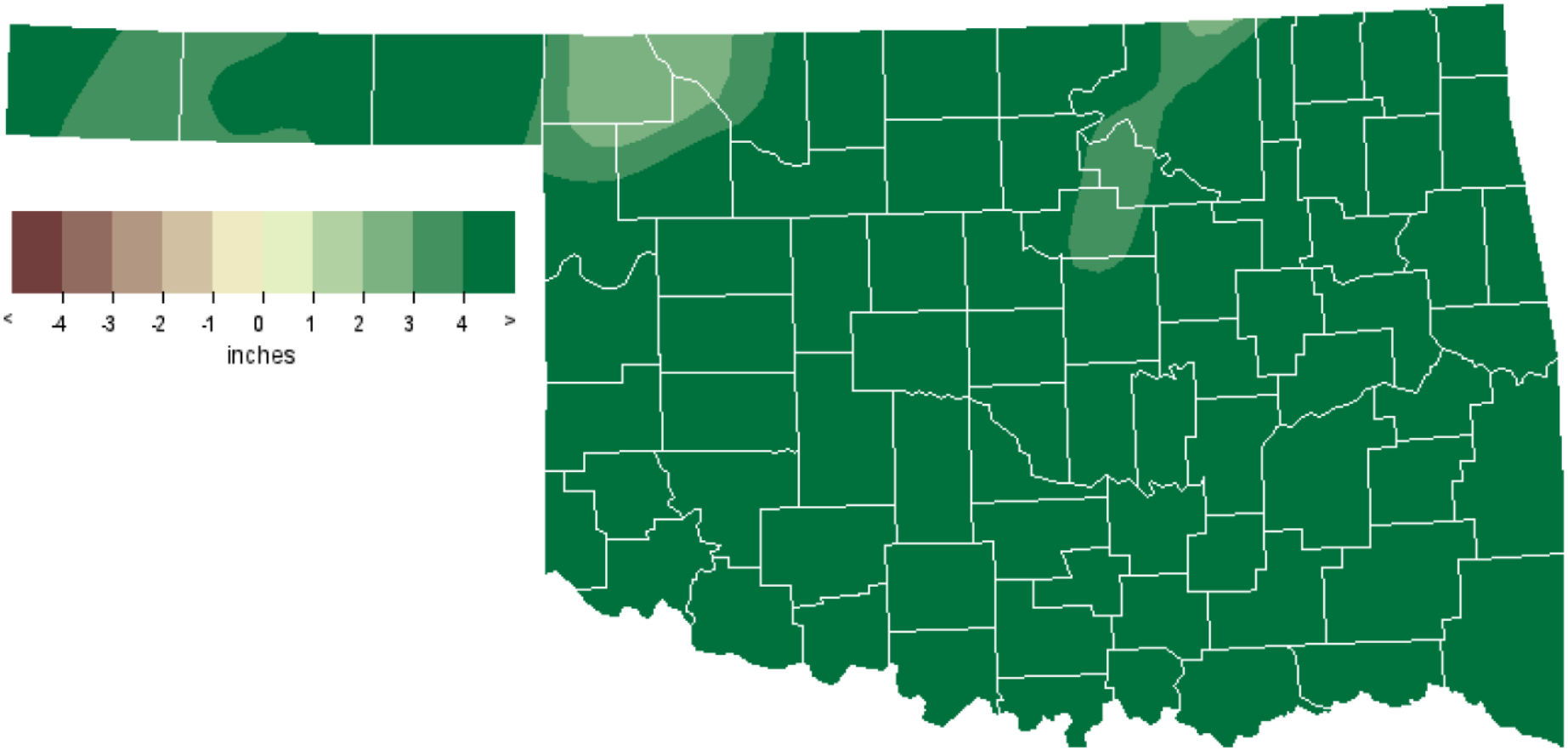
< 1 2 3 4 5 6 7 8 9 >

inches

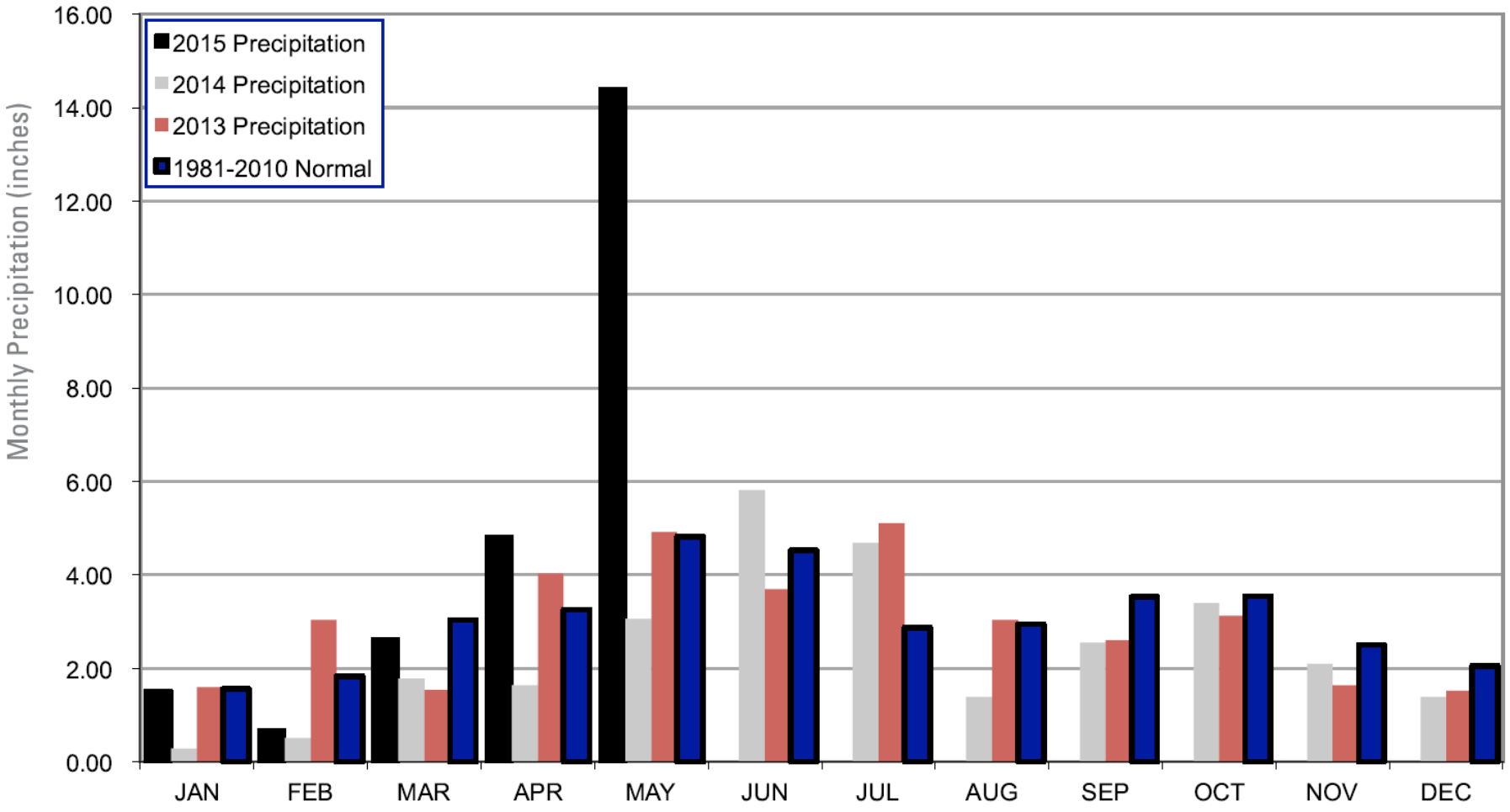
MAY 2015 PERCENT OF NORMAL PRECIPITATION



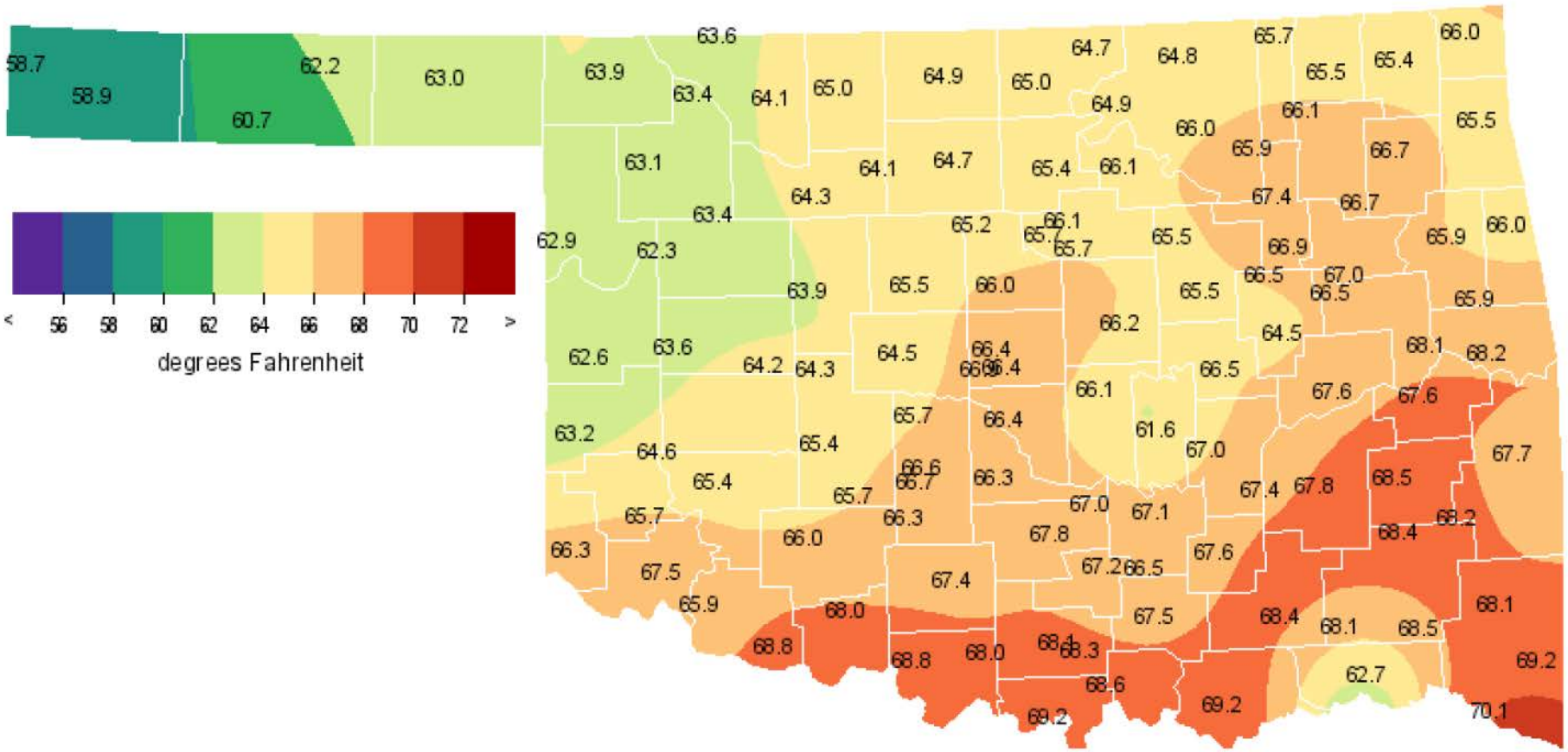
MAY 2015 DEPARTURE FROM NORMAL PRECIPITATION



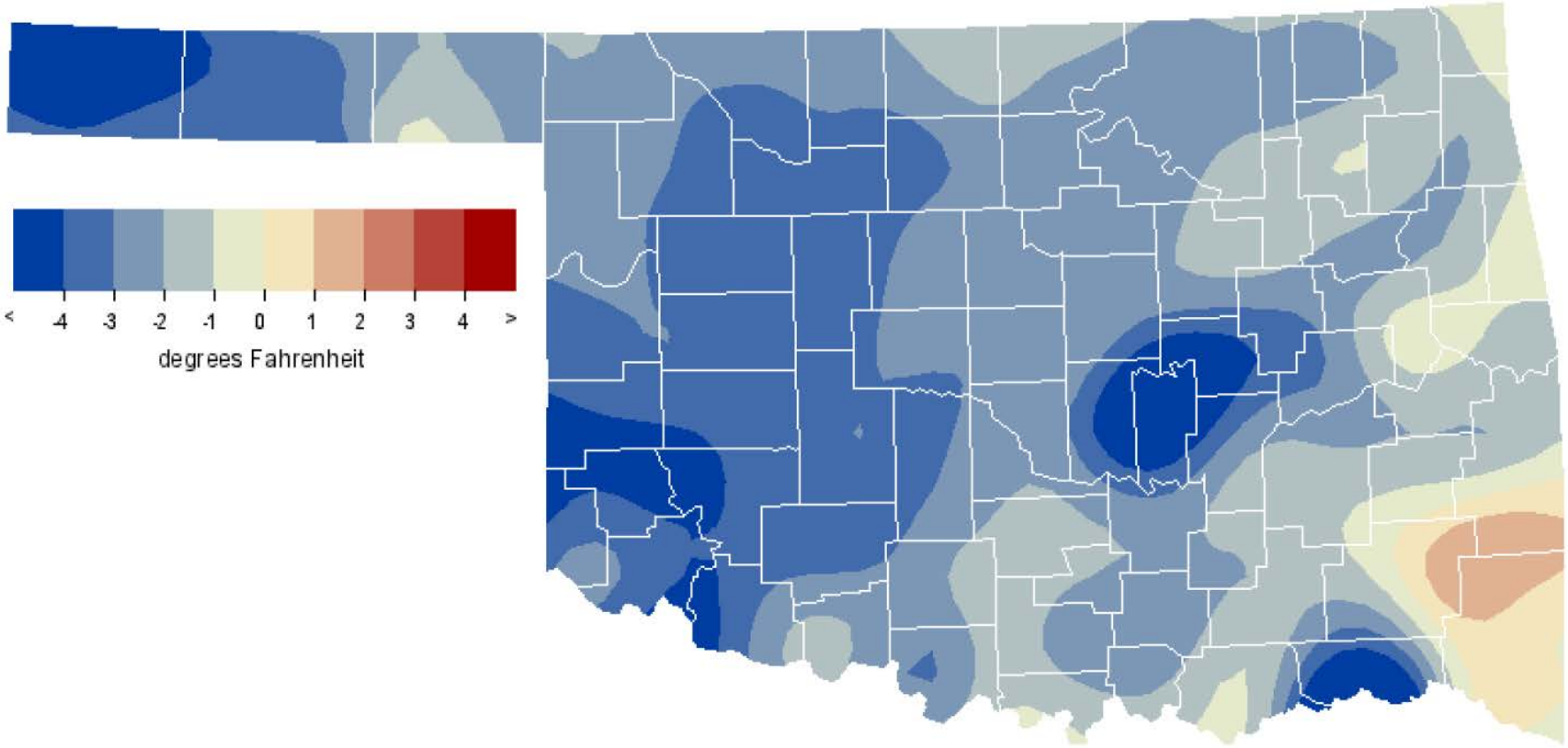
2013, 2014 AND 2015 STATEWIDE PRECIPITATION MONTHLY TOTALS VS. NORMAL



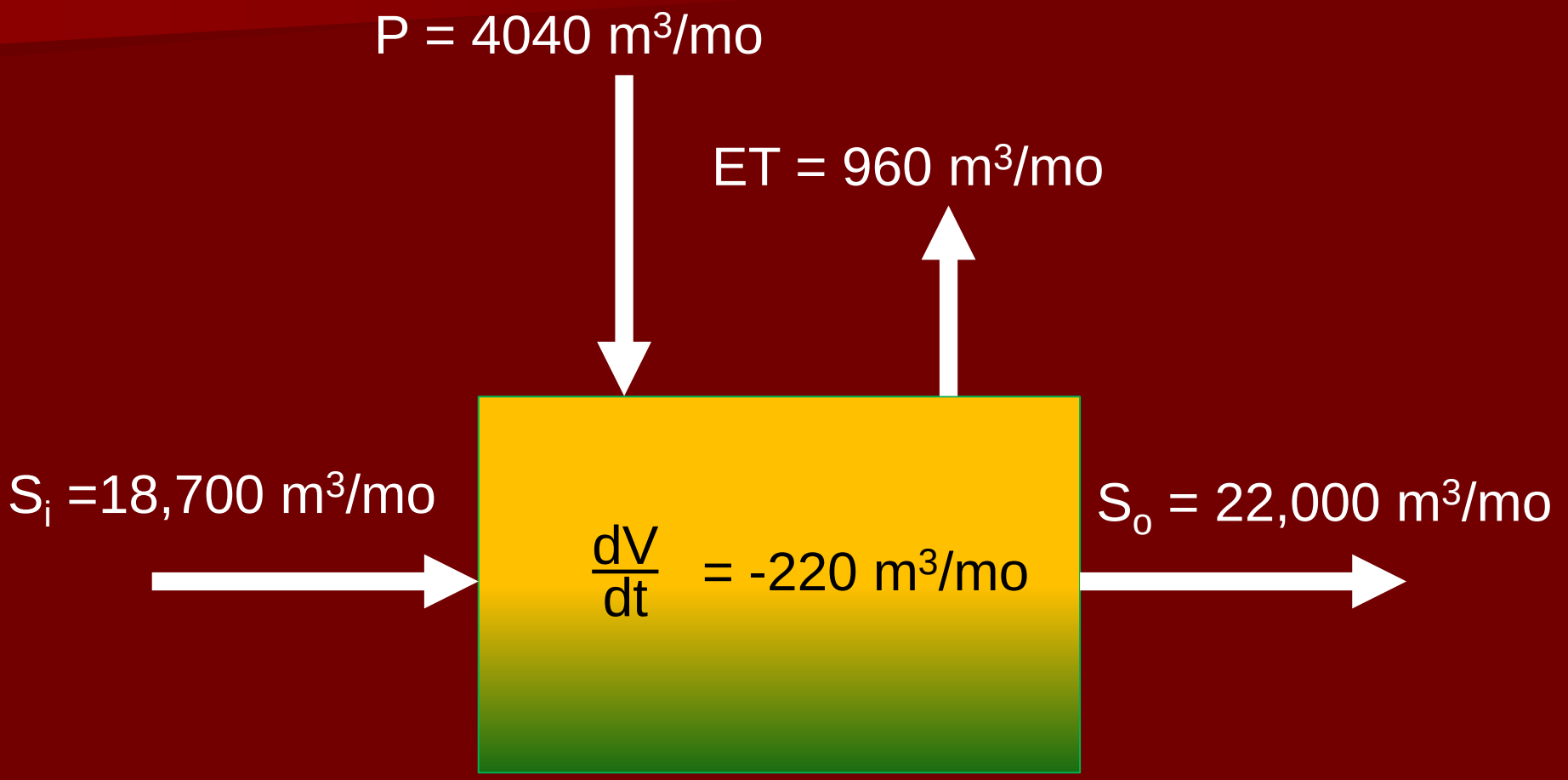
MAY 2015 AVERAGE TEMPERATURE



MAY 2015 DEPARTURE FROM NORMAL TEMPERATURE



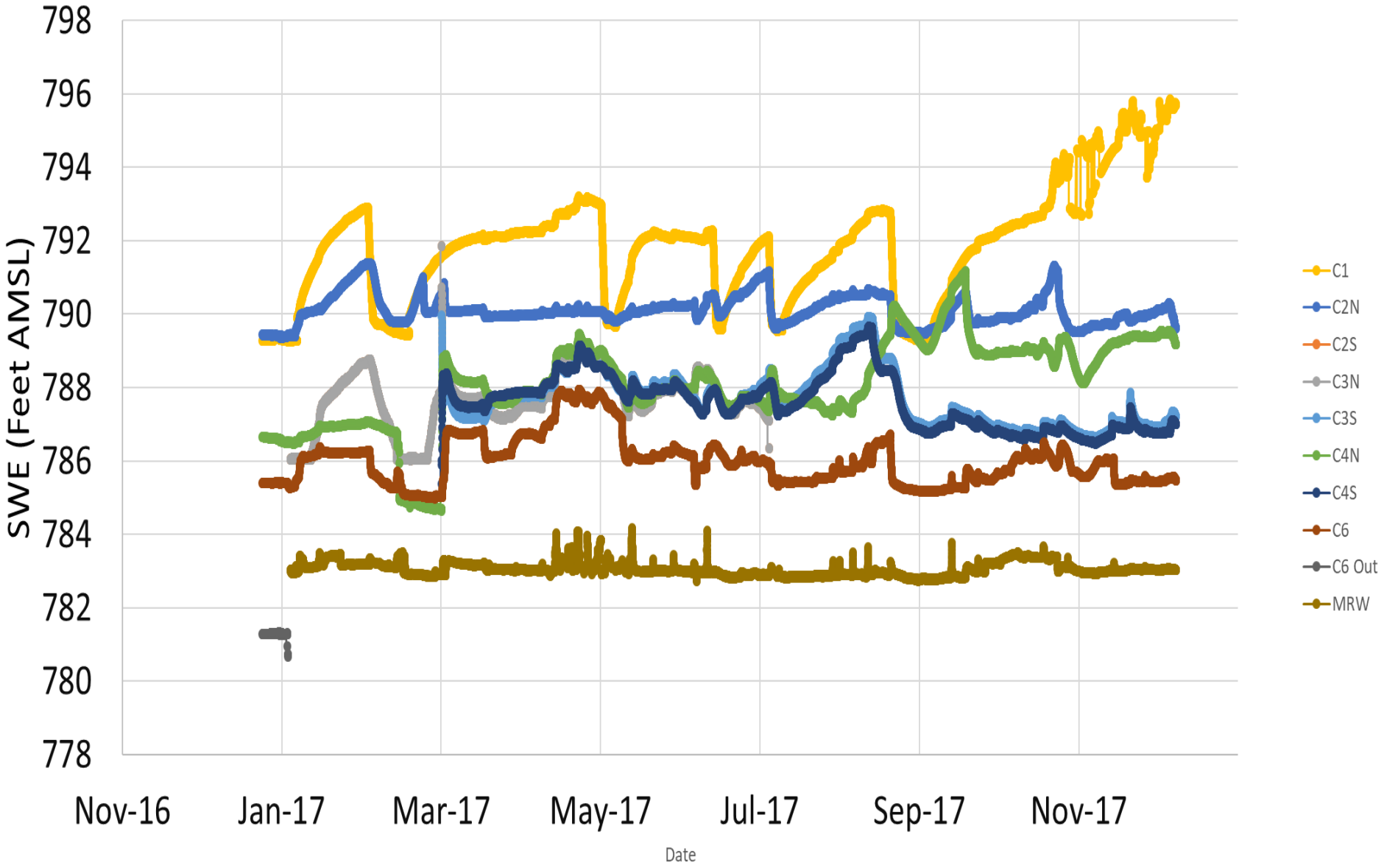
May 2015 MRPTS Hydrologic Budget

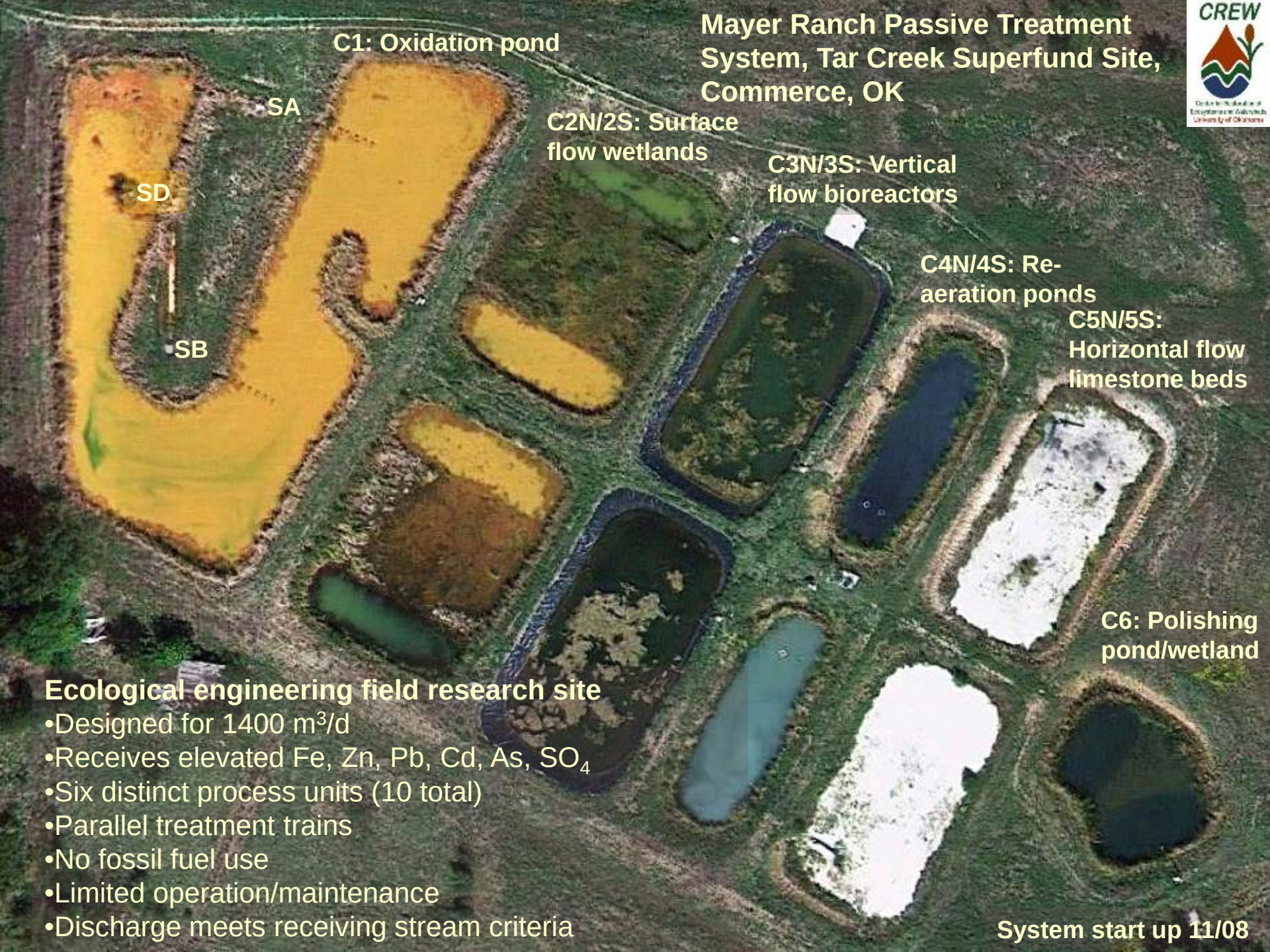


Hydrologic Budgets

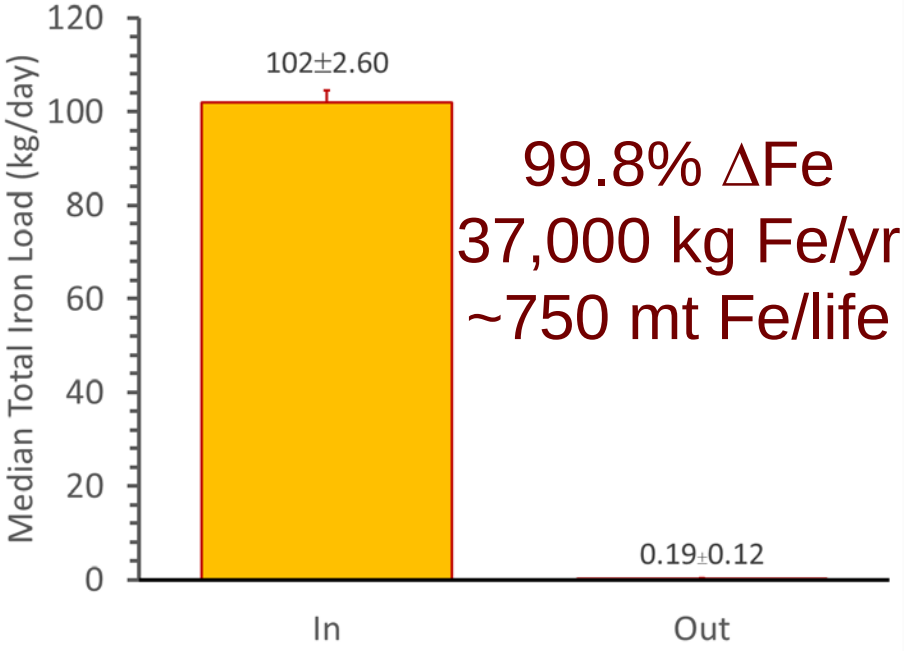
- Continuous monitoring needed to evaluate variability
- Calculation of continuous surface volumetric inflows and outflows
- Evaluation of surface water elevation variability
- May help in understanding of passive treatment system performance

Continuous SWE Monitoring

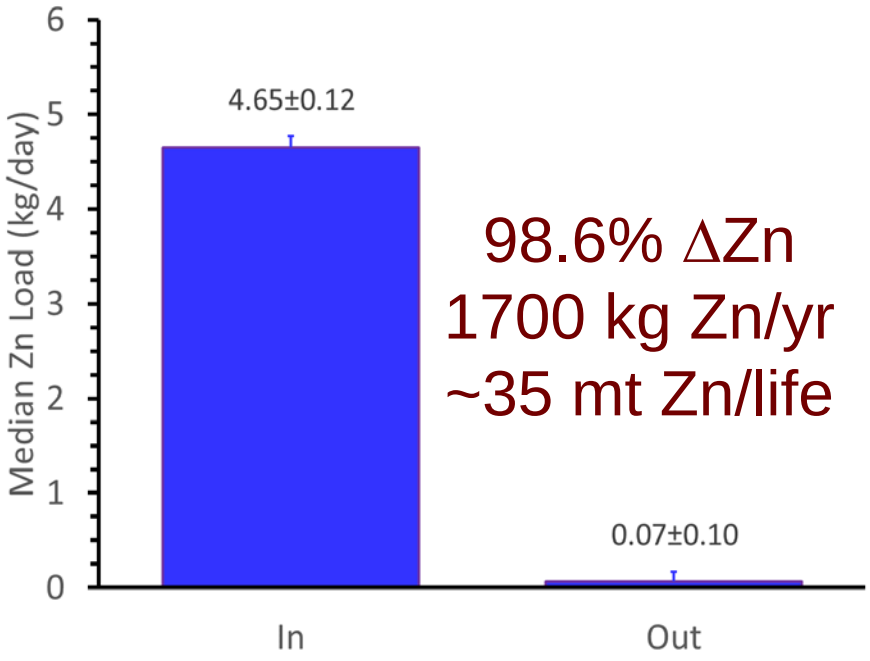



Mayer Ranch Passive Treatment System, Tar Creek Superfund Site, Commerce, OK
CREW
C1: Oxidation pond
SA
SD
SB
C2N/2S: Surface flow wetlands
C3N/3S: Vertical flow bioreactors
C4N/4S: Re-aeration ponds
C5N/5S: Horizontal flow limestone beds
C6: Polishing pond/wetland
Ecological engineering field research 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

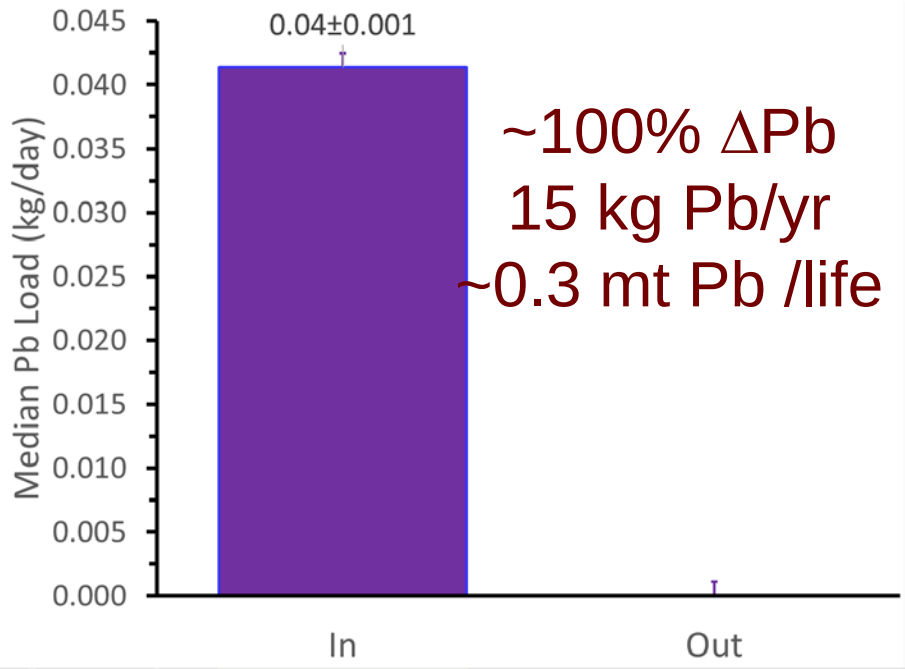
Mayer Ranch PTS - COCs



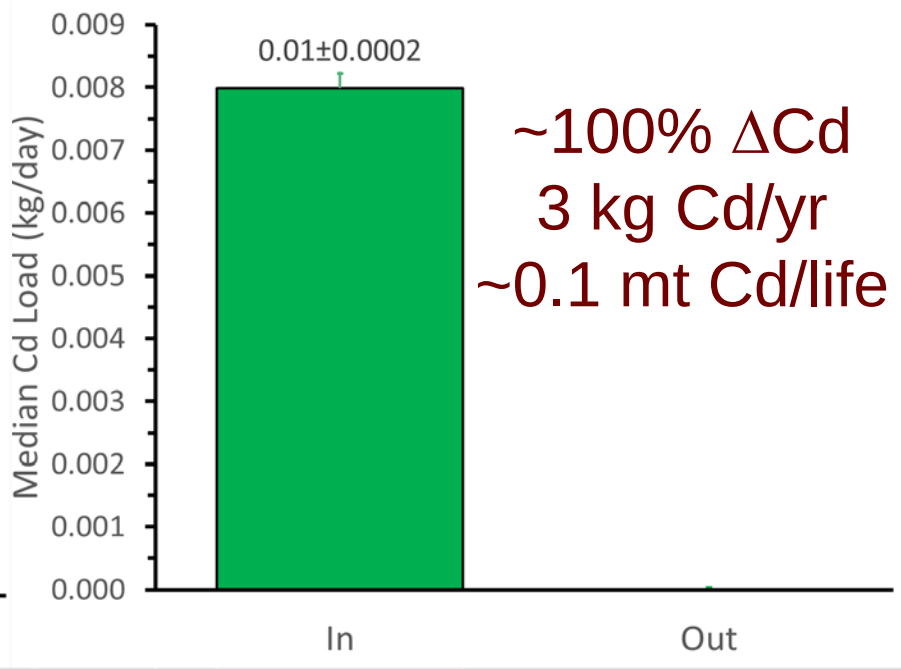
99.8% ΔFe
37,000 kg Fe/yr
~750 mt Fe/life



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

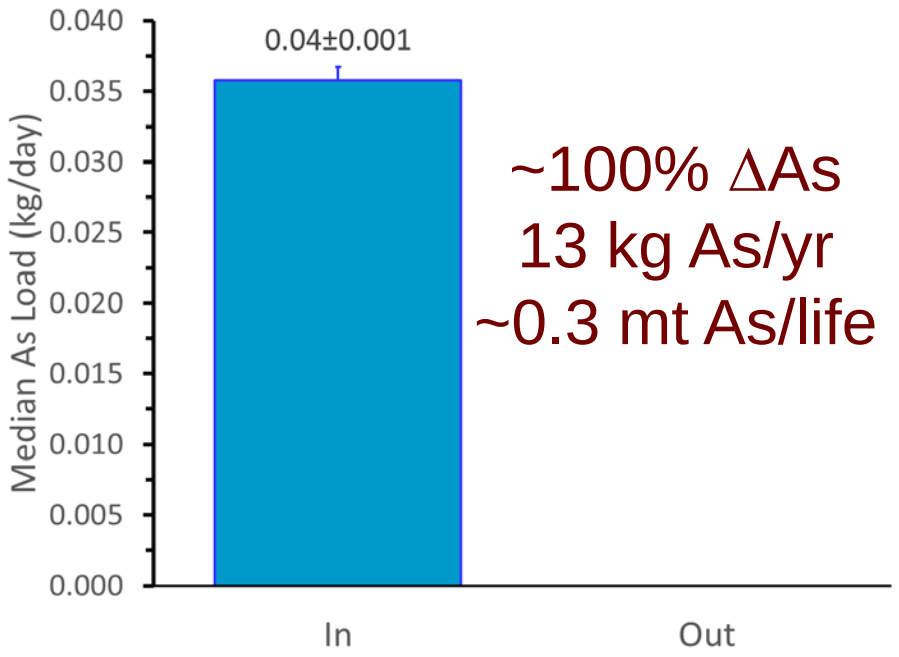


~100% ΔPb
15 kg Pb/yr
~0.3 mt Pb /life

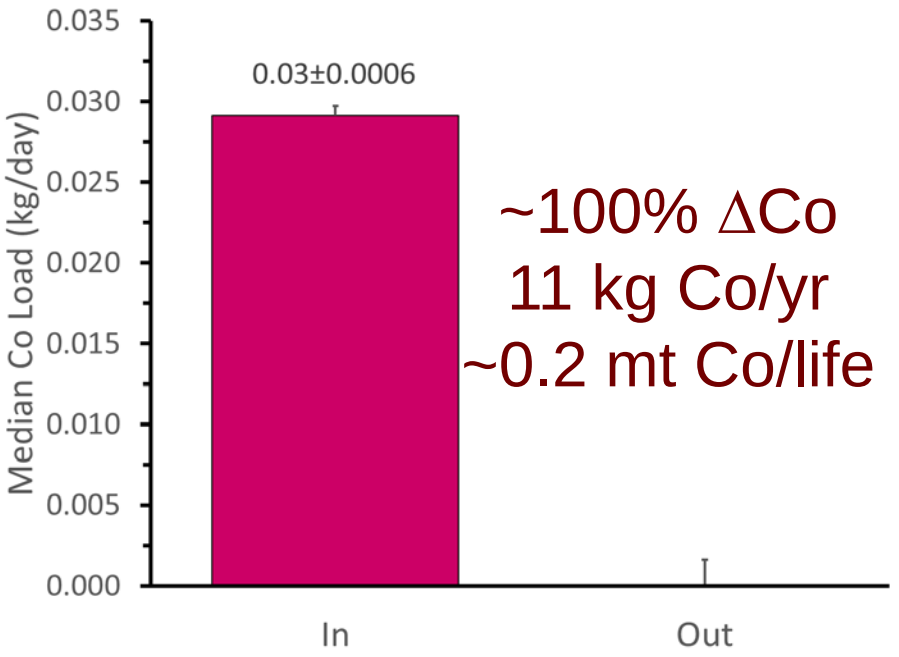


~100% ΔCd
3 kg Cd/yr
~0.1 mt Cd/life

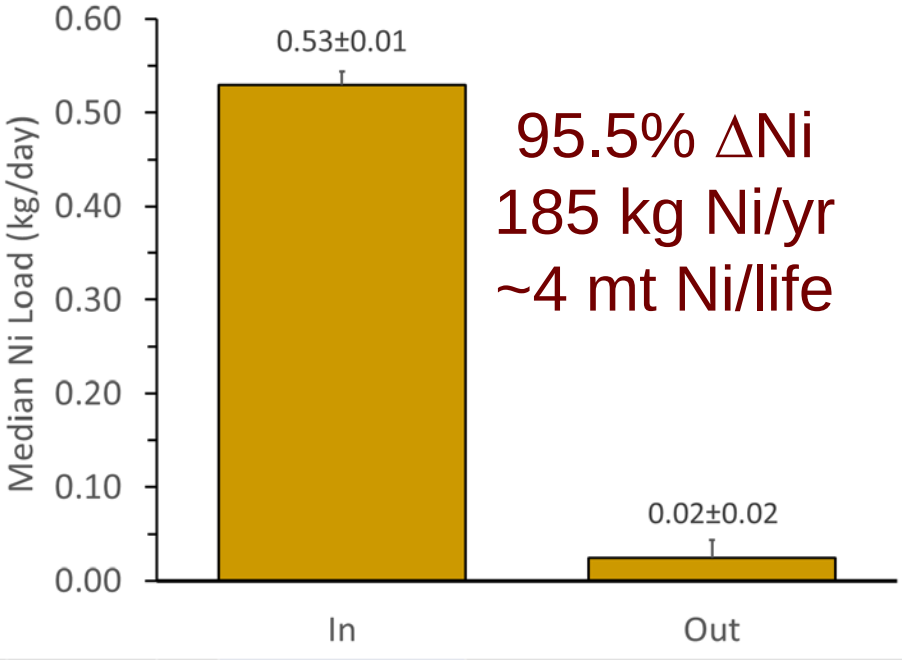
Mayer Ranch PTS – Other Metals



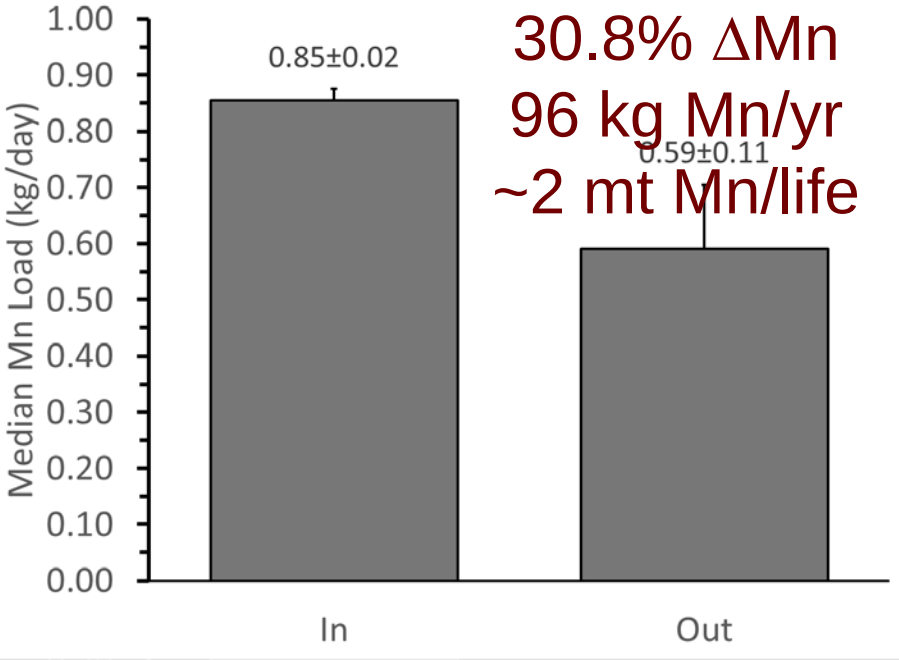
~100% ΔAs
13 kg As/yr
~0.3 mt As/life



~100% ΔCo
11 kg Co/yr
~0.2 mt Co/life

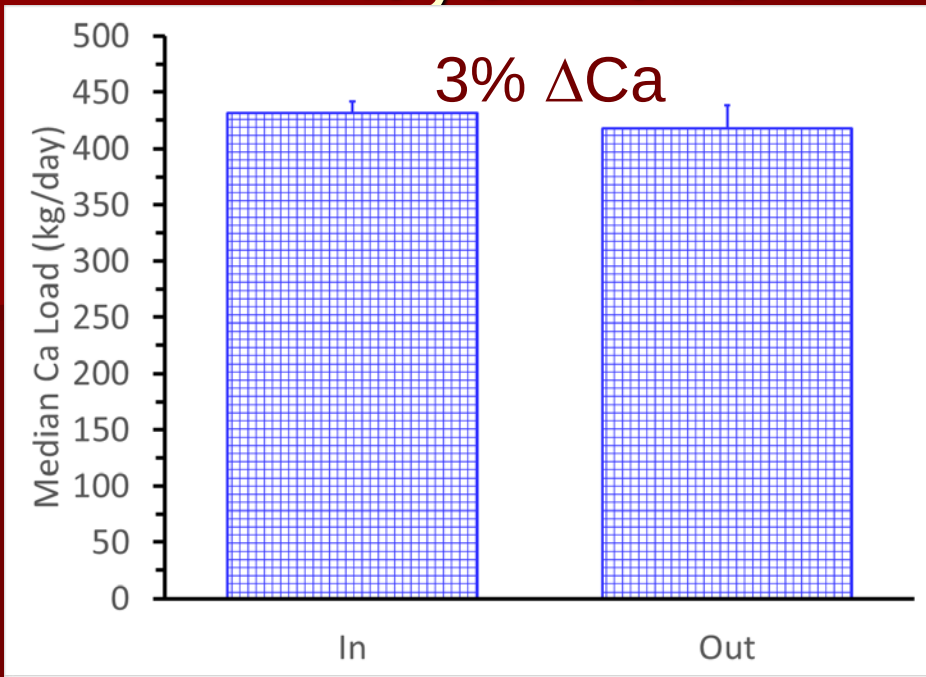


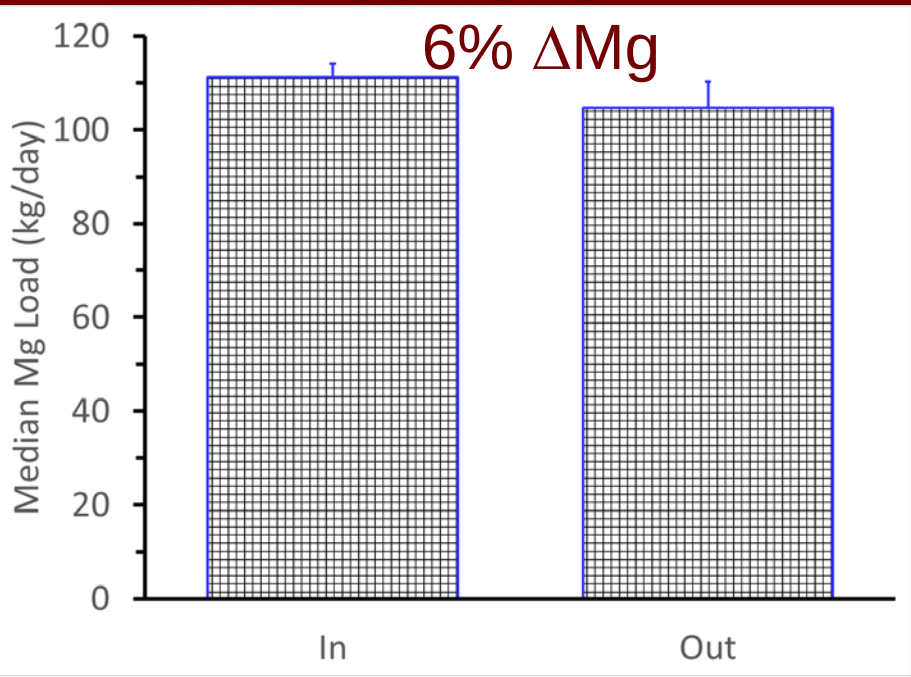
95.5% ΔNi
185 kg Ni/yr
~4 mt Ni/life

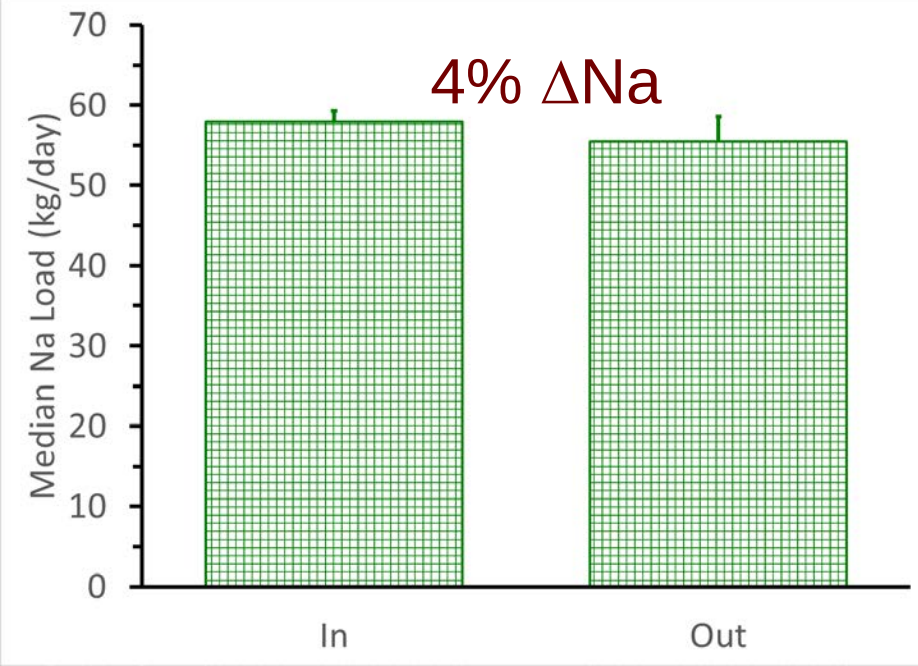


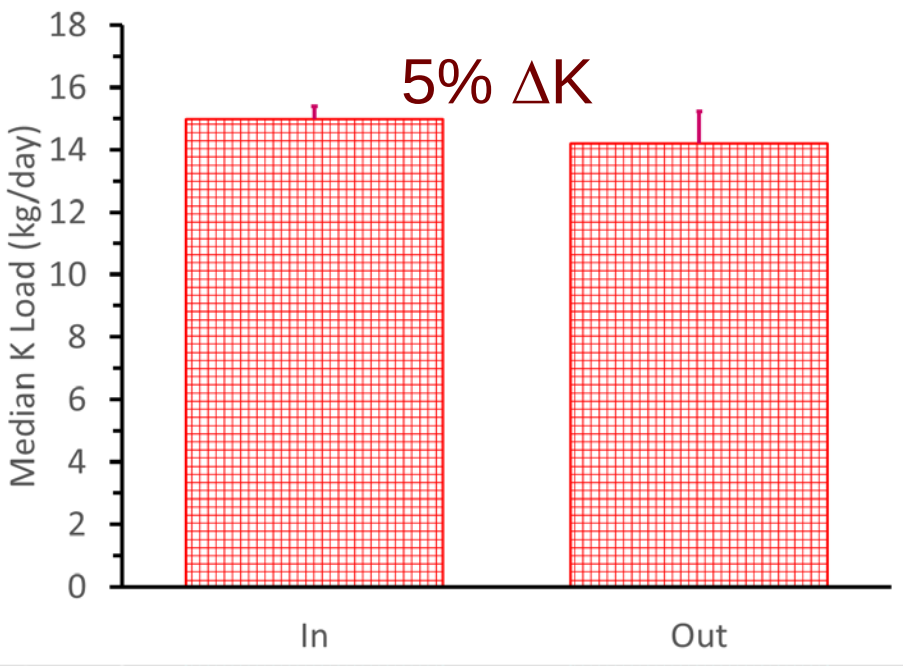
30.8% ΔMn
96 kg Mn/yr
~2 mt Mn/life

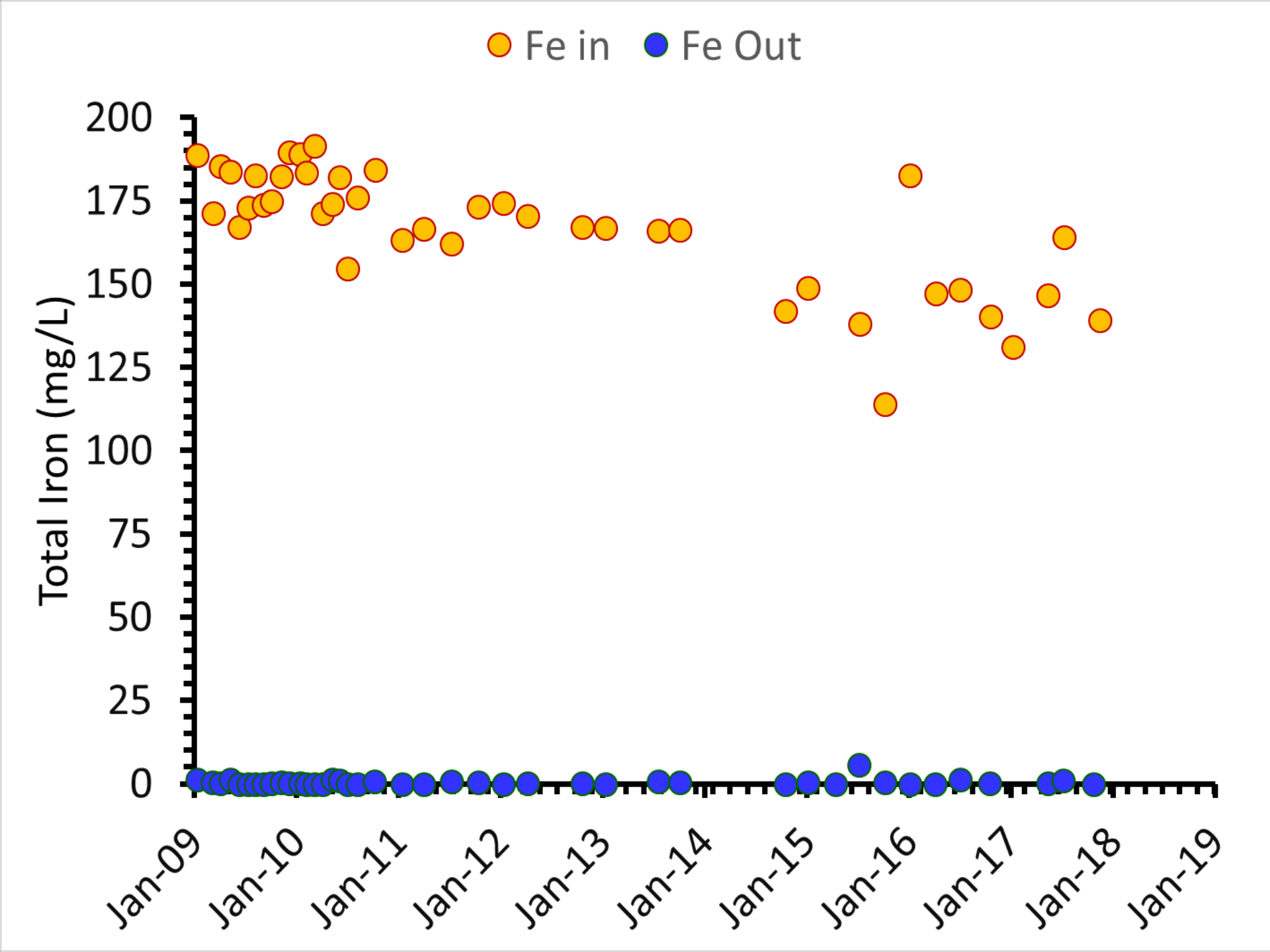
Mayer Ranch PTS – Base Cations

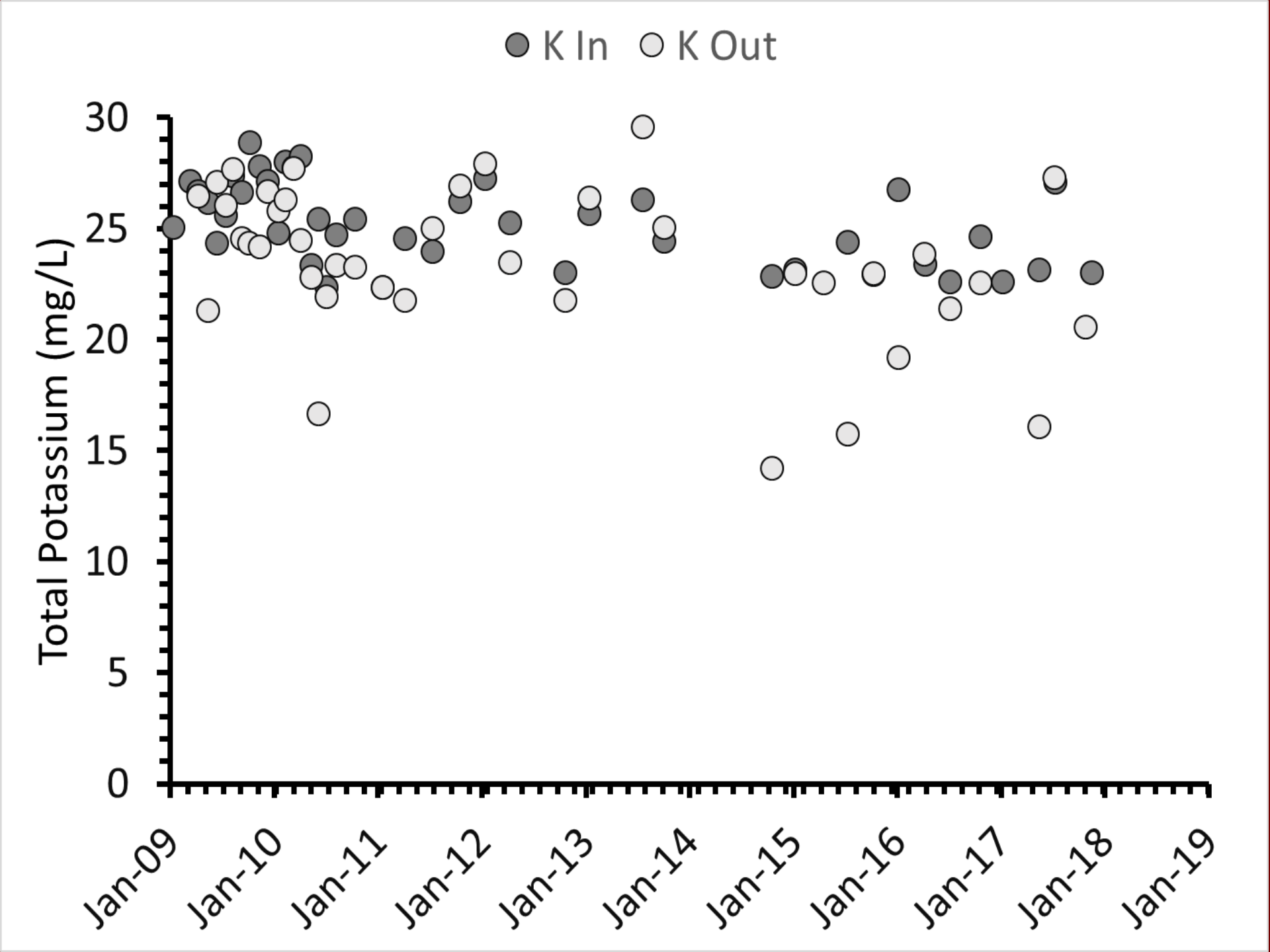




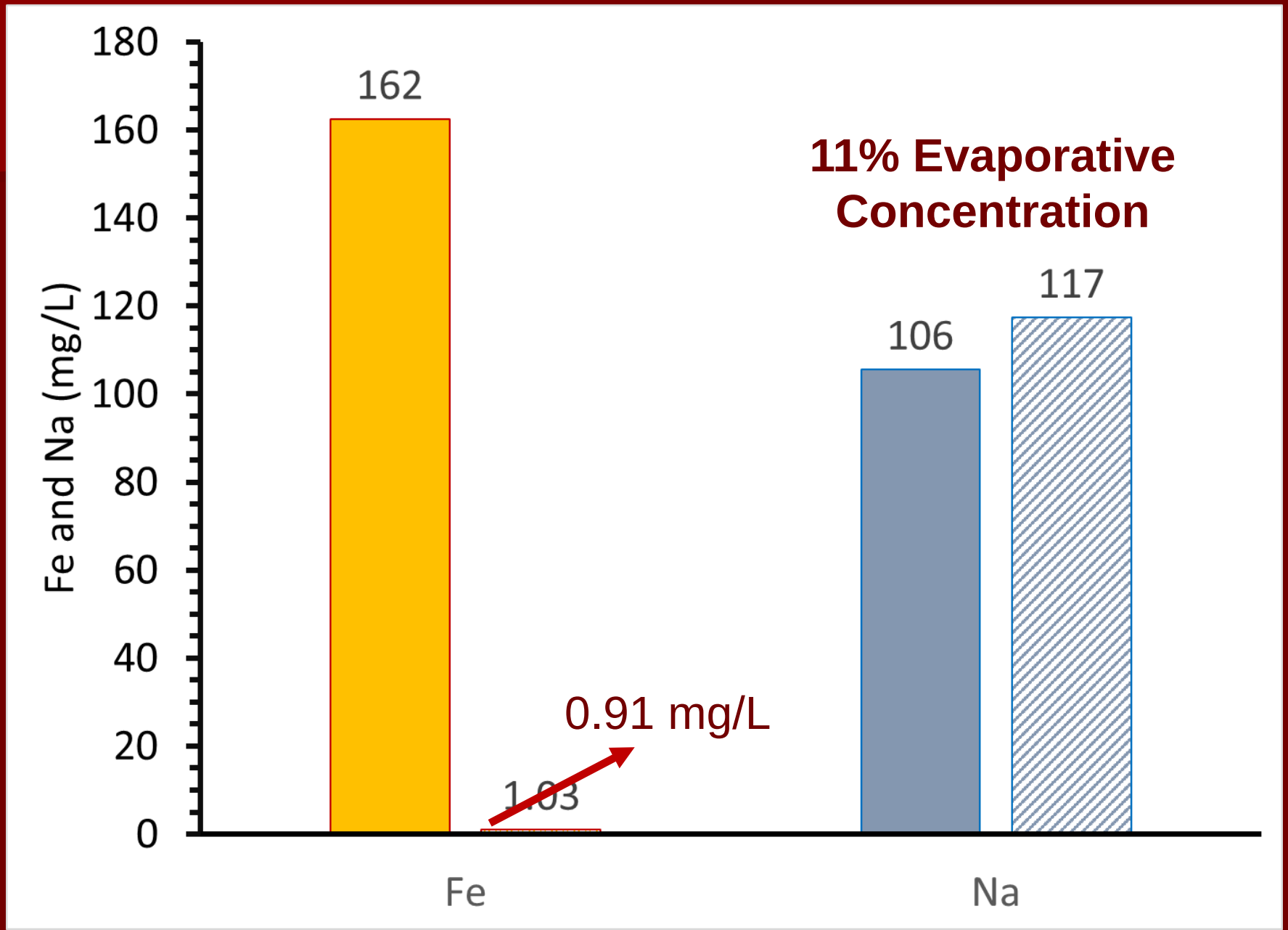




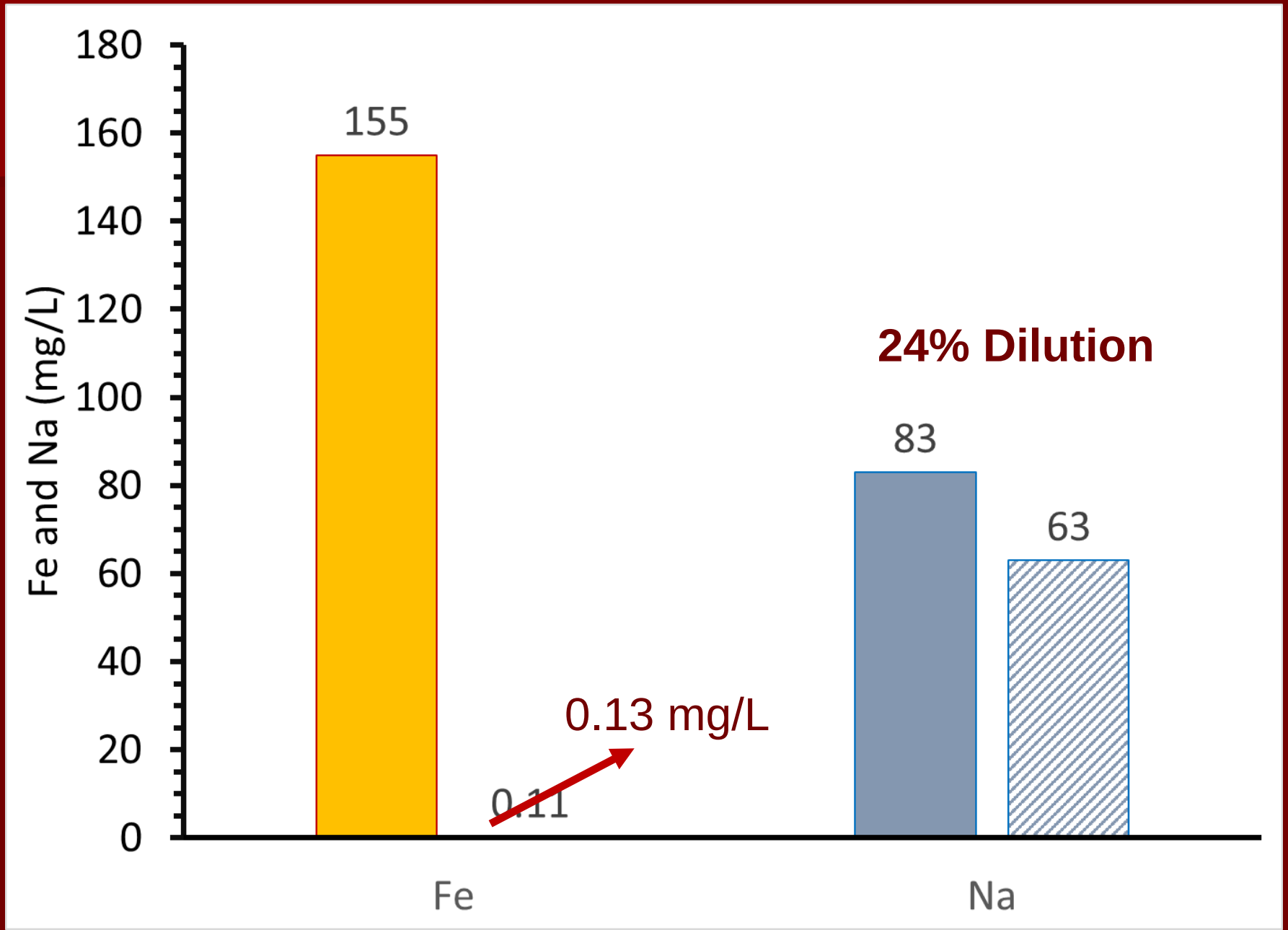

Fe in
Fe Out
Total Iron (mg/L)
200
175
150
125
100
75
50
25
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15
Jan-16
Jan-17
Jan-18
Jan-19


K In
K Out
Total Potassium (mg/L)
30
25
20
15
10
5
0
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15
Jan-16
Jan-17
Jan-18
Jan-19

July 2011 (0.63” precipitation)



July 2015 (5.71” precipitation)



Conclusions

Conclusions

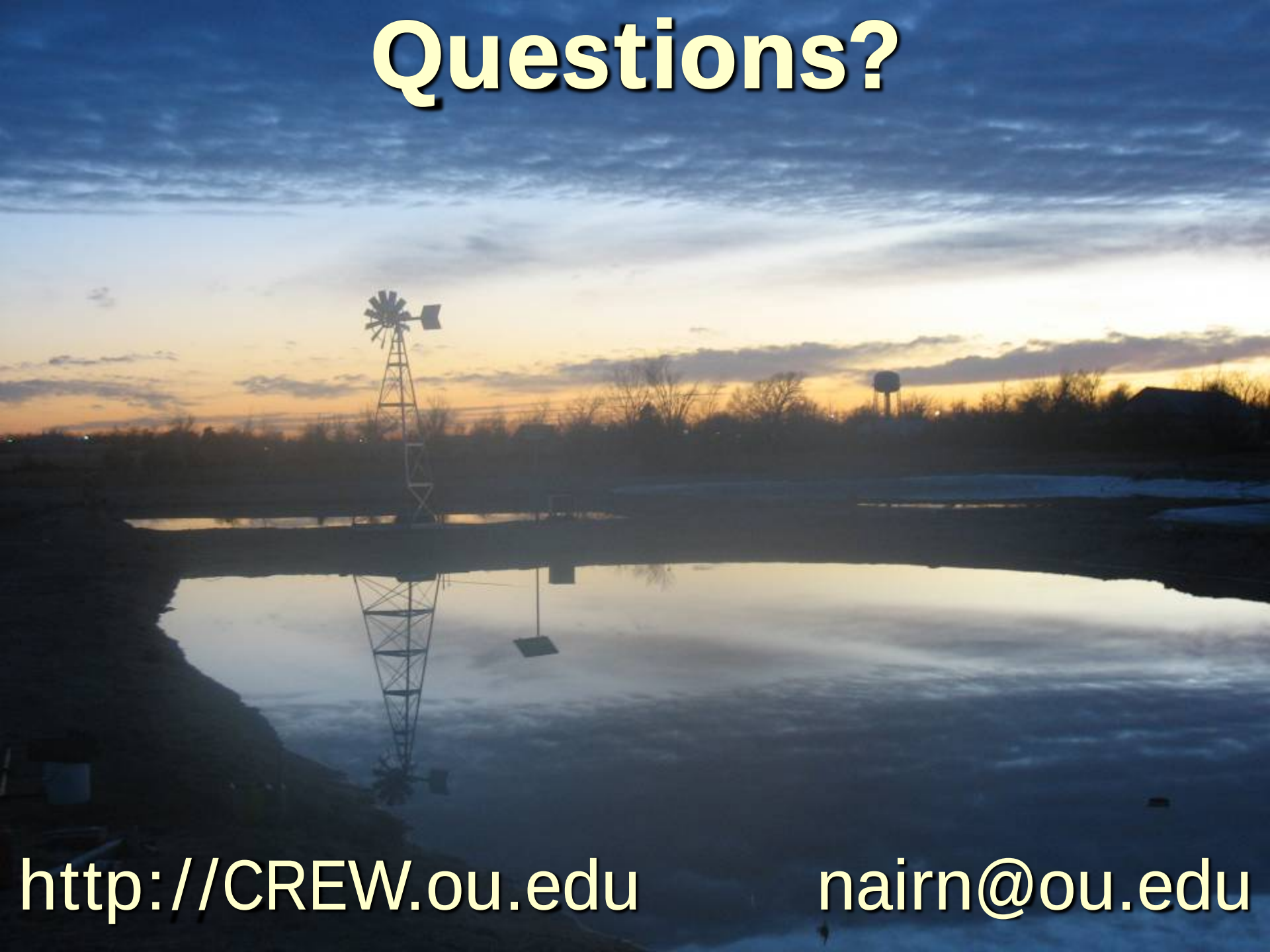
- With continuous monitoring, realistic hydrologic budgets may be developed to help understand passive treatment system biogeochemical function
- Conservative ions may provide a tool to further evaluate biogeochemical function, and help evaluate the role of evaporative concentration and dilution in passive treatment systems

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

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