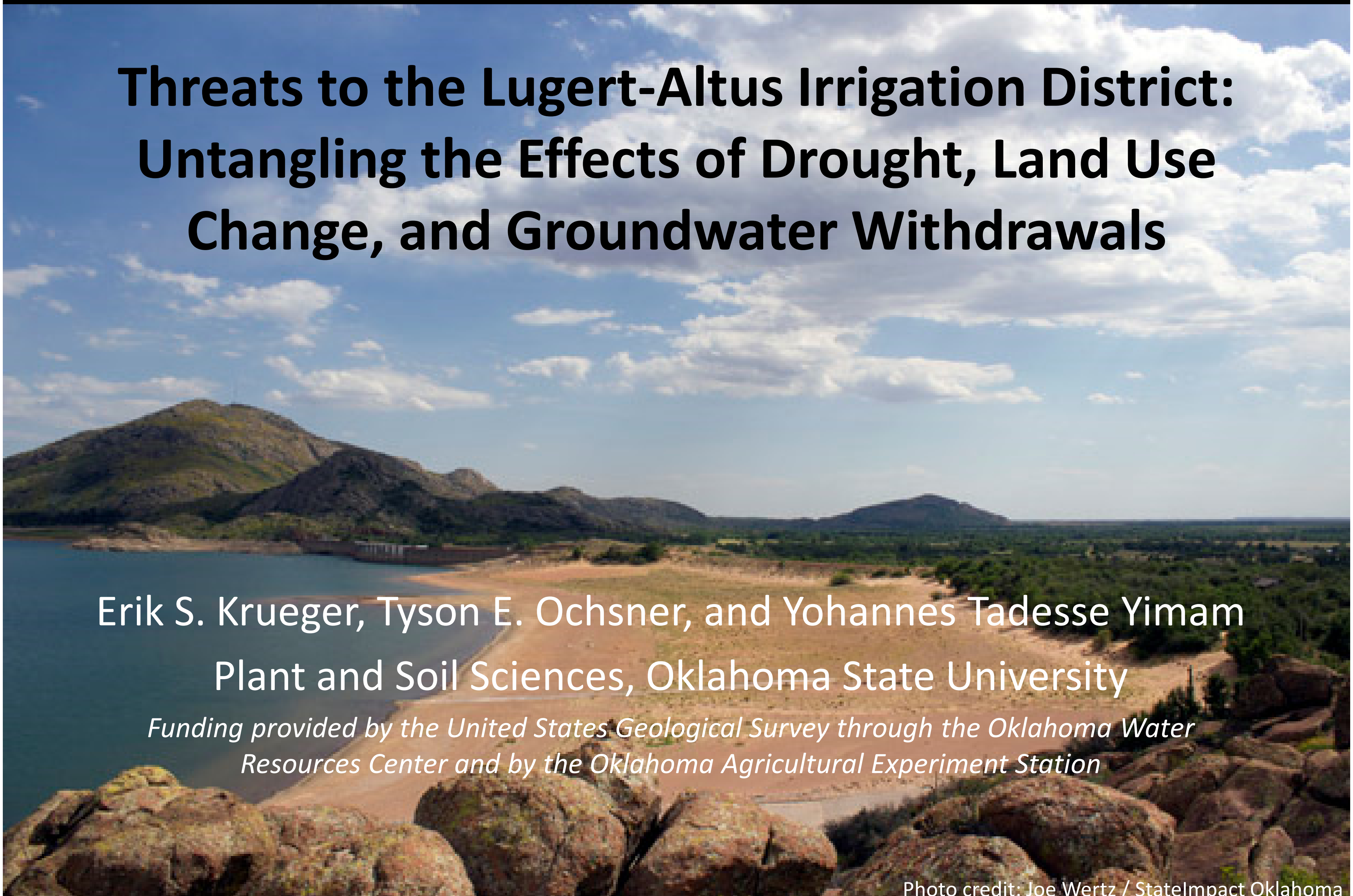

Threats to the Lugert-Altus Irrigation District: Untangling the Effects of Drought, Land Use Change, and Groundwater Withdrawals

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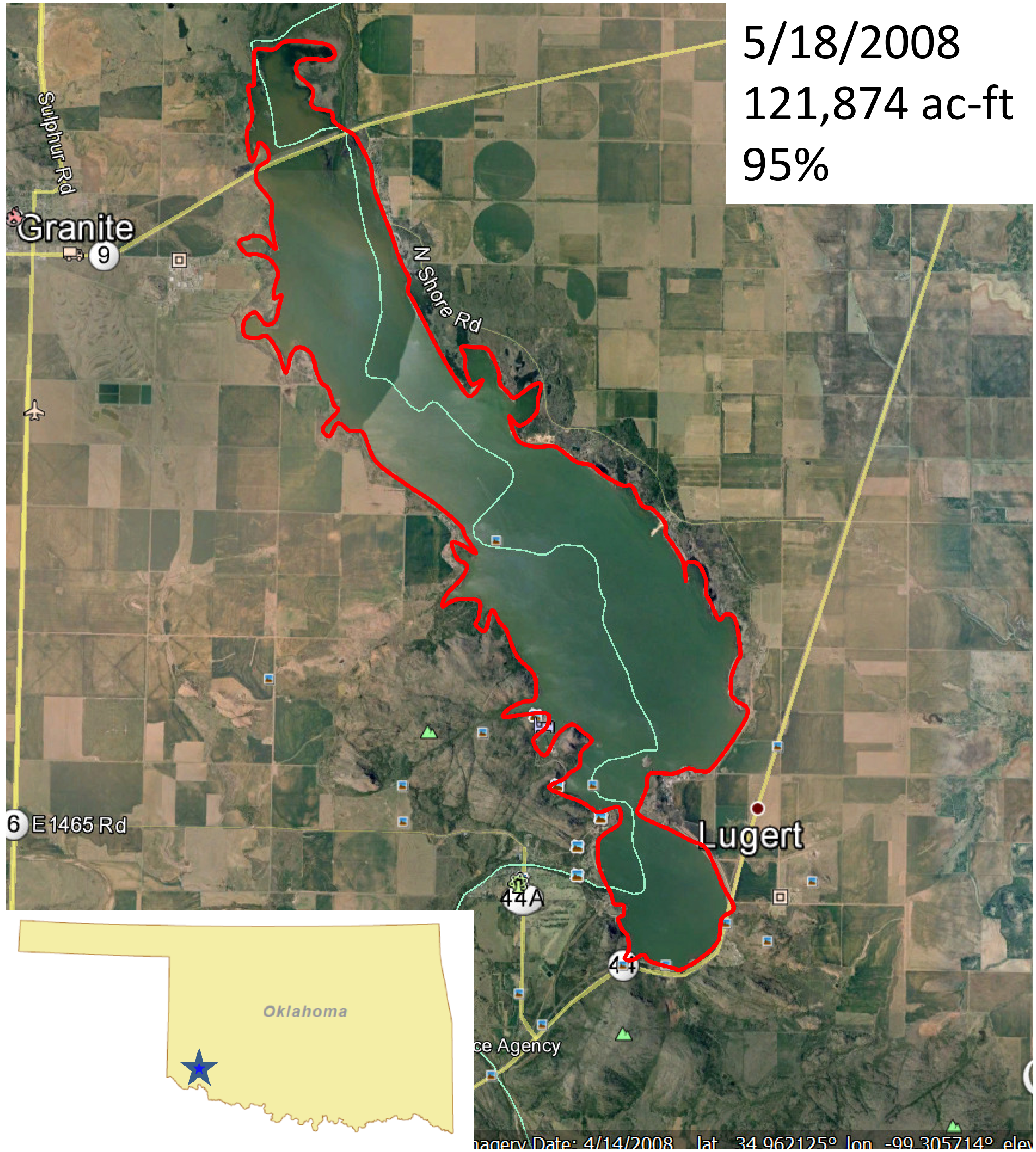
Funding provided by the United States Geological Survey through the Oklahoma Water Resources Center and by the Oklahoma Agricultural Experiment Station

Photo credit: Joe Wertz / StateImpact Oklahoma

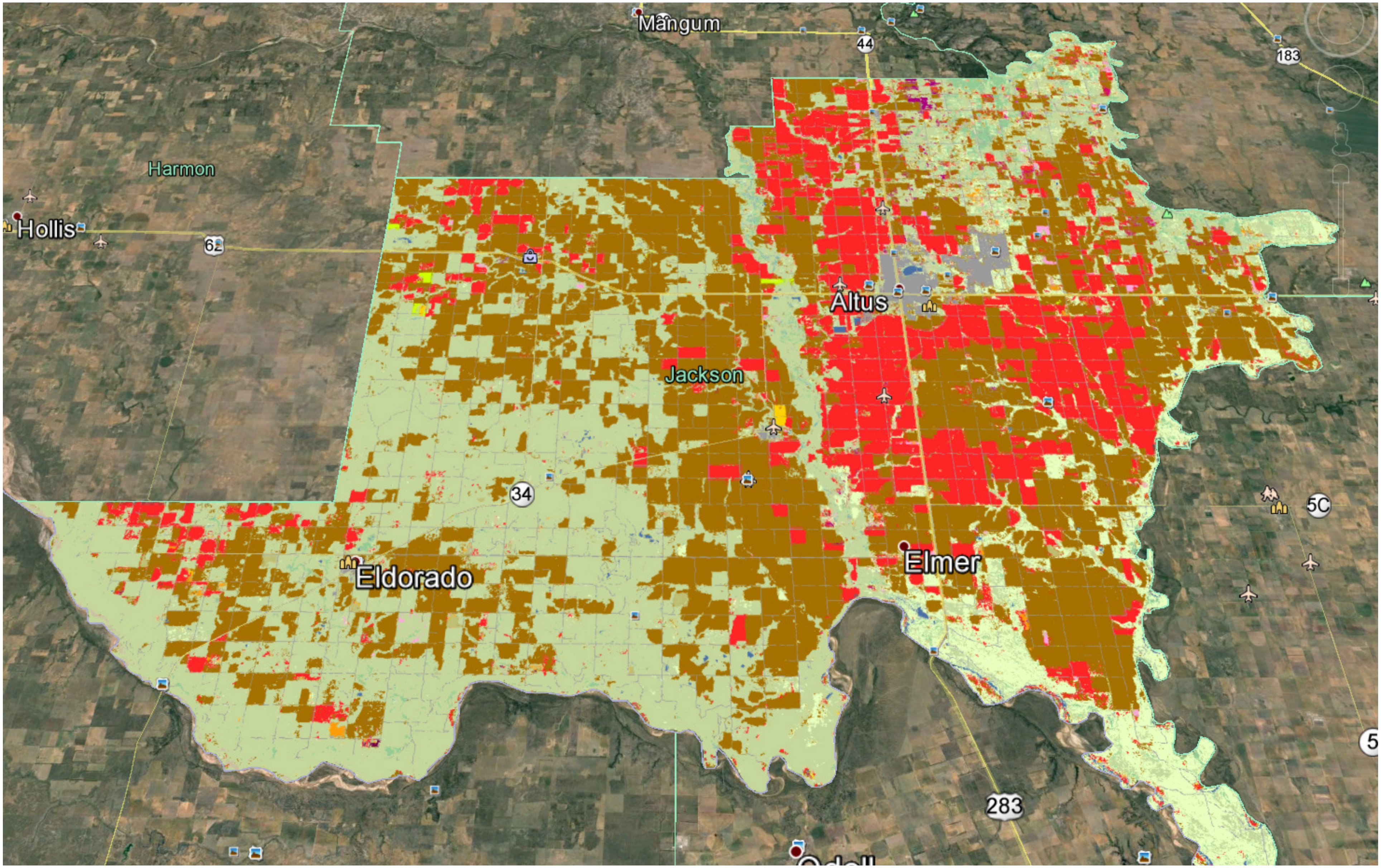
Lake Altus-Lugert

- Altus Dam completed in 1947
- Irrigation, recreation, municipal, flood control, fish and wildlife
- 128,286 ac-ft conservation pool
- 46,000 ac irrigated in LAID

5/18/2008
121,874 ac-ft
95%



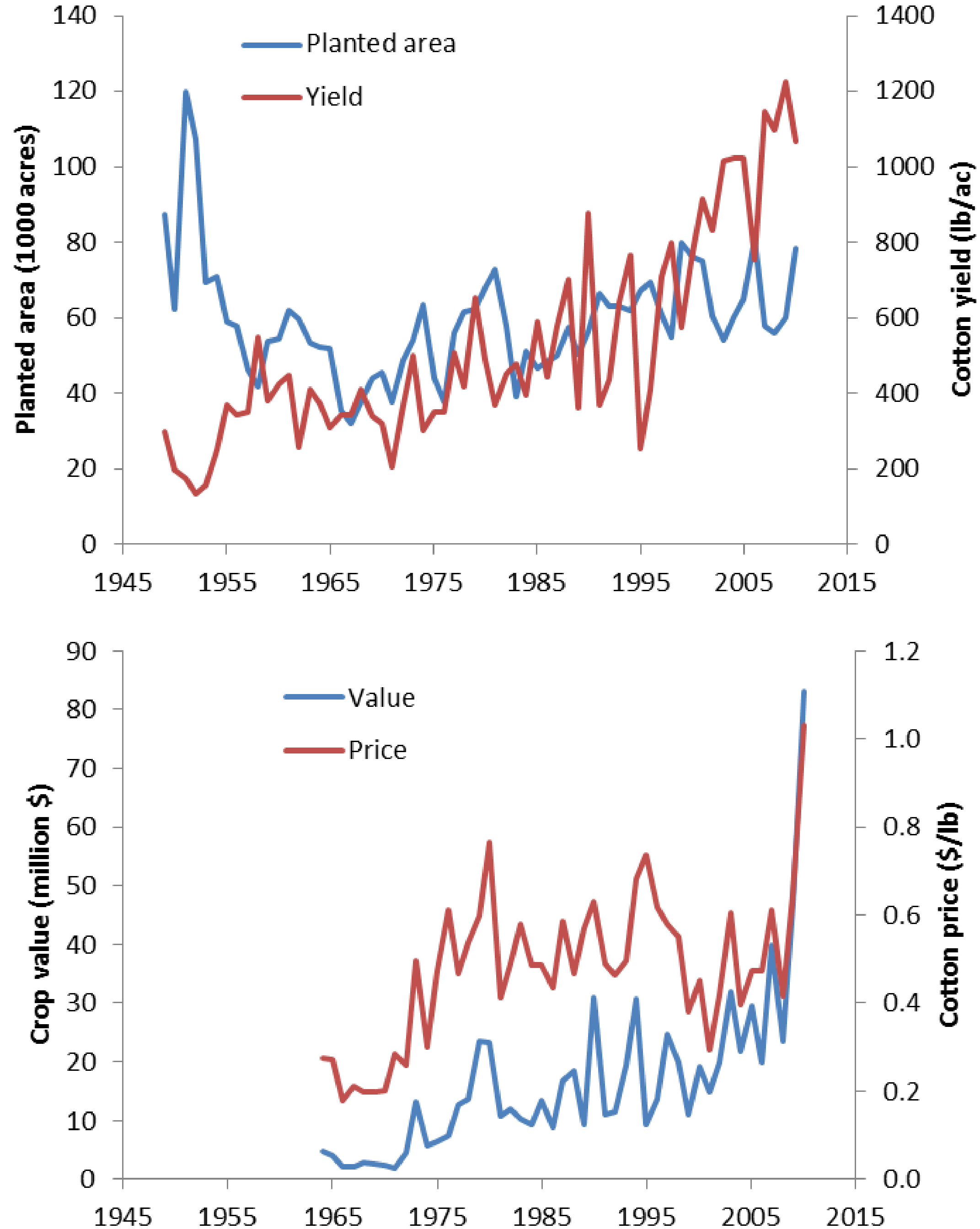
2010 Jackson County Cropland Data Layer



Red areas indicate cotton fields, the majority in the LAID.

Jackson Co. Cotton

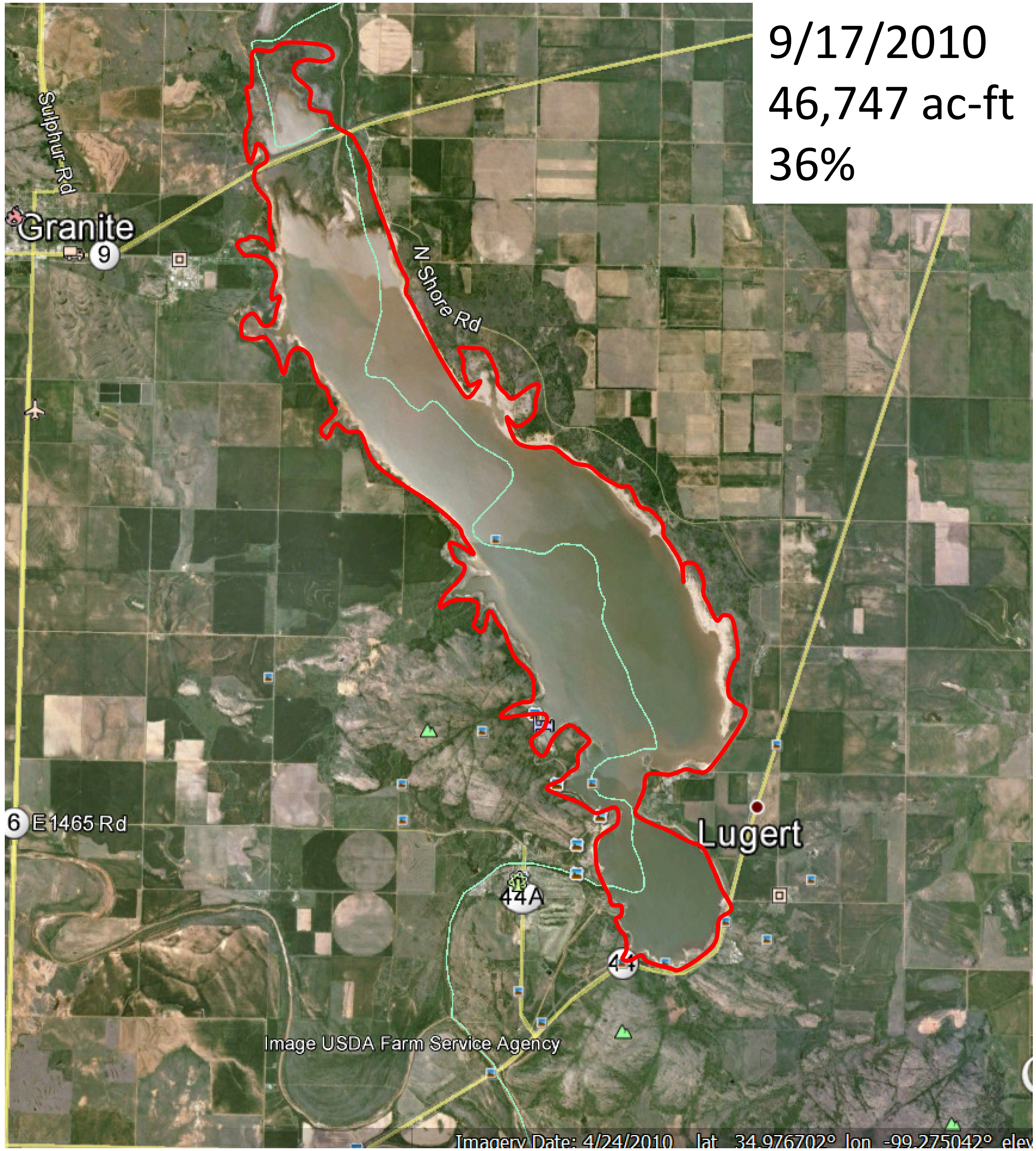
- Record high yields 2007-2010
- Record high price in 2010
- County cotton crop value reached $83 million in 2010



Turning point

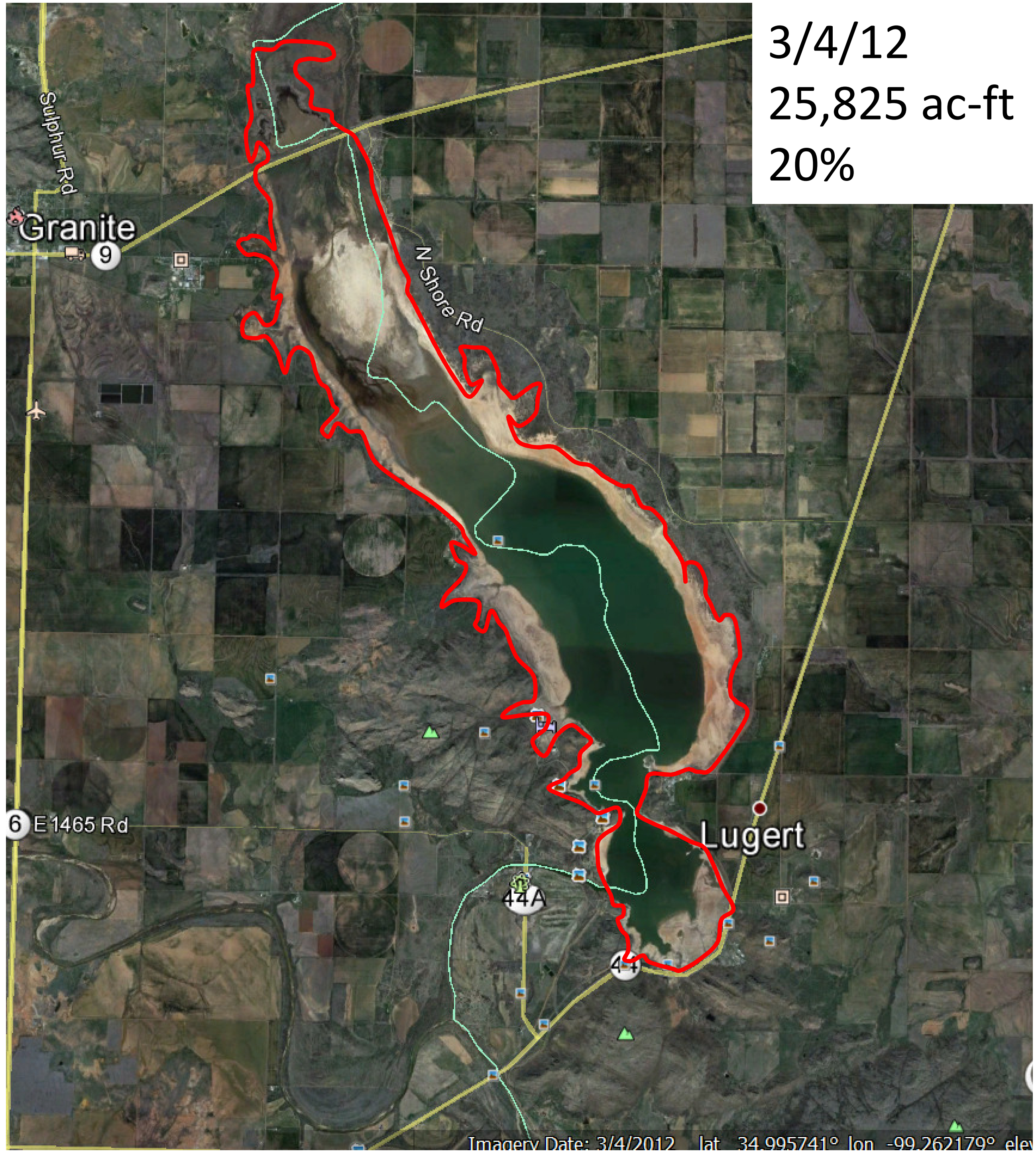
- 2010 irrigation releases lowered lake level
- Drought conditions began to develop

9/17/2010
46,747 ac-ft
36%



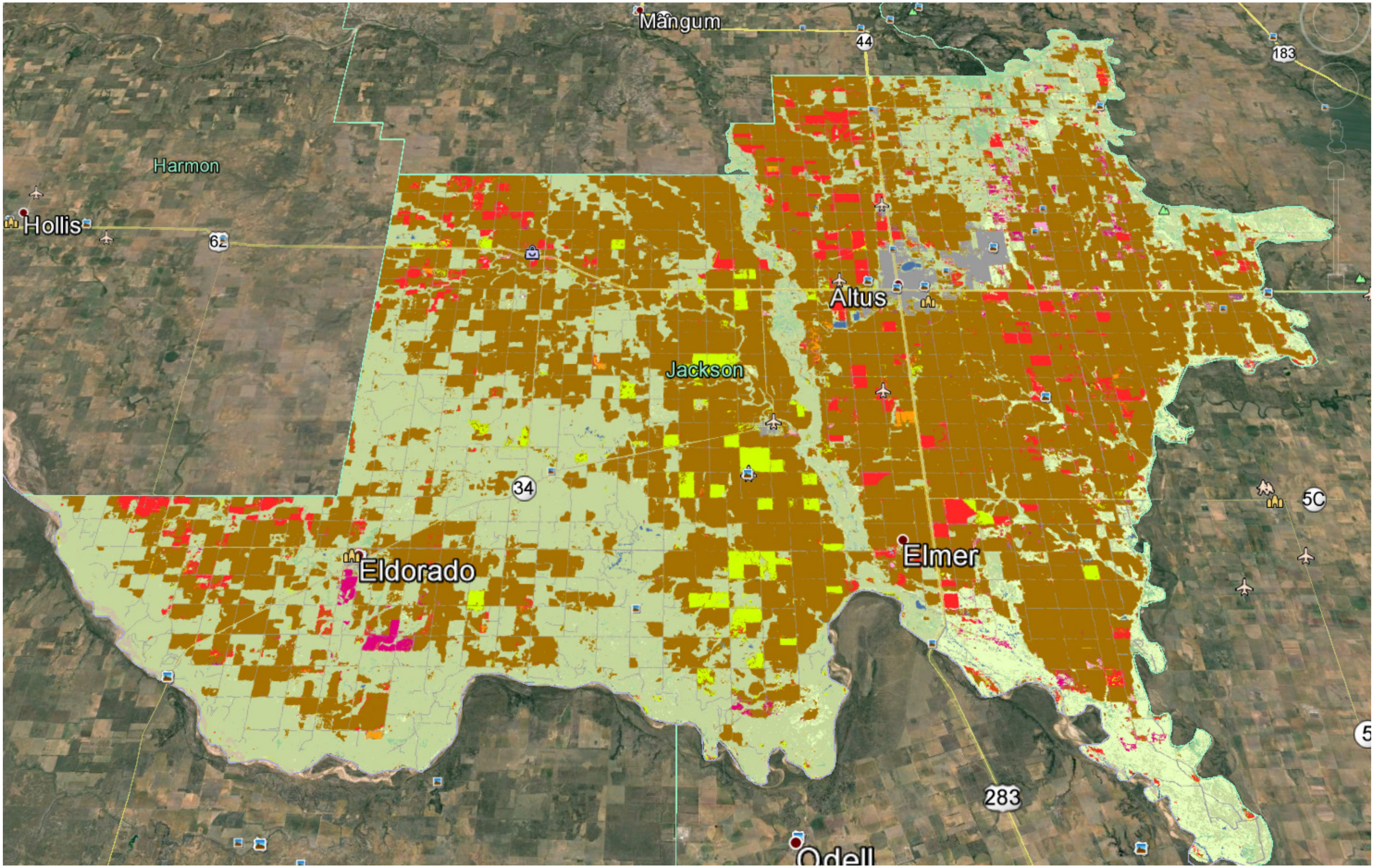
Trouble

- 1947-2010 average inflow: **103,441** ac-ft
- 2011 inflow: **26,492** ac-ft
- 2012 inflow: **16,010** ac-ft
- 2013 inflow: **3,879** ac-ft (record low)



Golden algae bloom in early 2013 results in total fish kill.

2013 Jackson County Cropland Data Layer

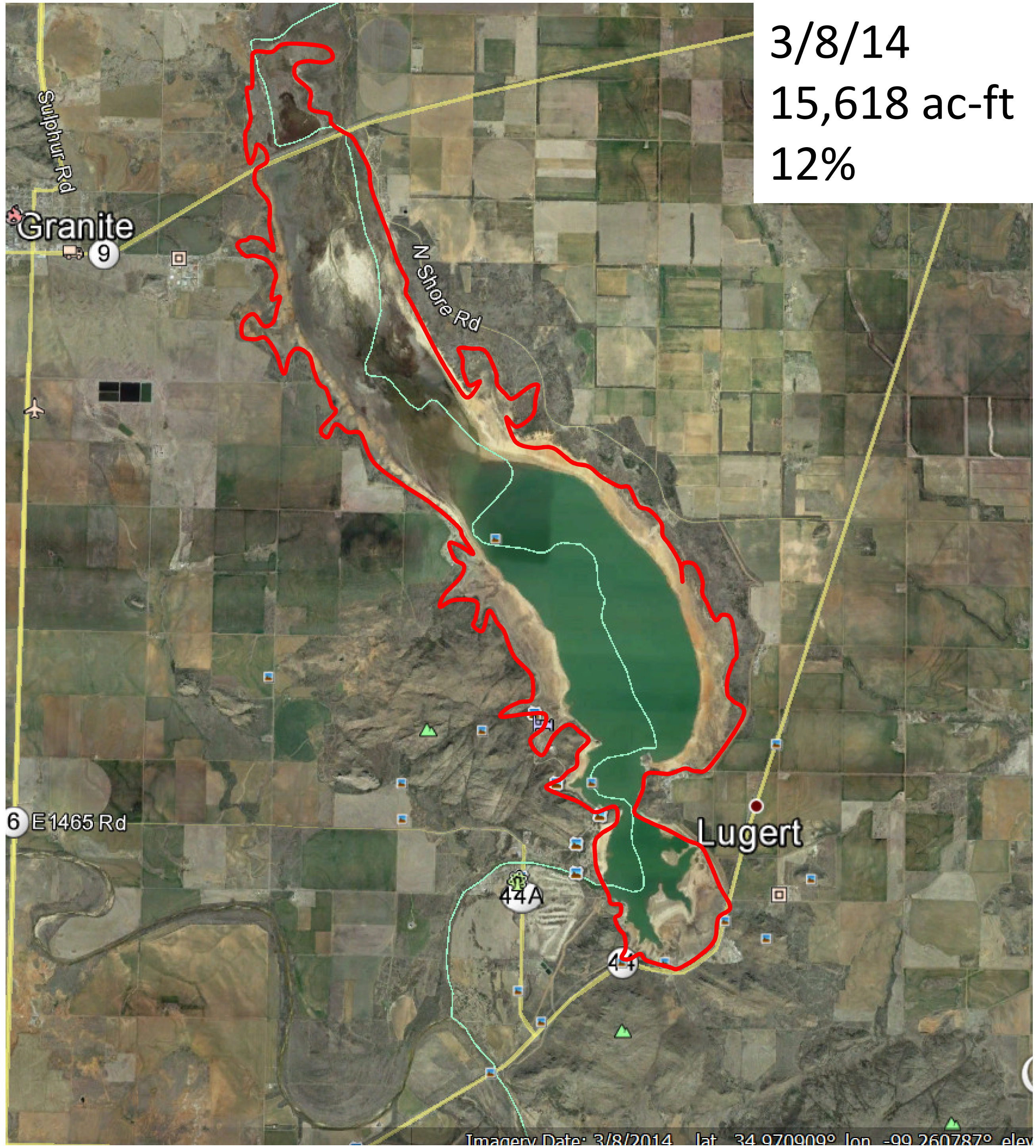


No irrigation since 2011. Cotton fields converted to winter wheat.

Rock bottom and recovery

- 1/7/15
  12,595 ac-ft
  9.8%

- Refilled with 108,000 ac-ft inflow in May 2015



3/8/14
15,618 ac-ft
12%

Key questions

To what extent did HUMAN FACTORS contribute to the record low lake level (inflow) during the crisis of 2011-2014?

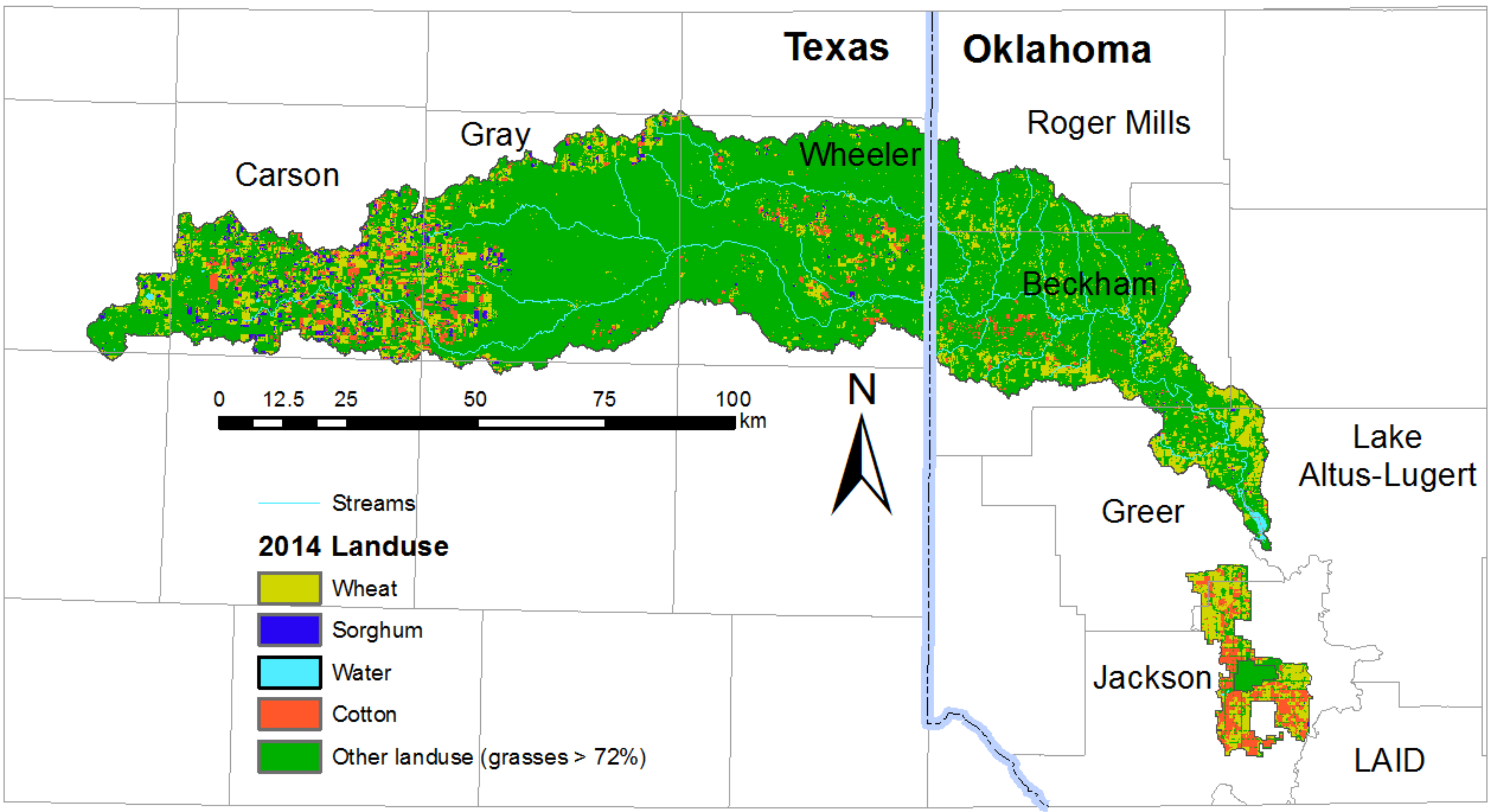
- How has lake inflow changed?
- Has weather changed (precipitation and ET)?
- Have watershed characteristics changed (land use and groundwater withdrawals)?

- Which factors are driving changes in flow?

Krueger, E.S., Y.T. Yimam, and T.E. Ochsner. 2016. Threats to a surface water irrigation district in the US southern Great Plains: Changes in streamflow driven more by human than climate factors. Agricultural Water Management, In review.

Photo credit: Nick Moody

Scope of the problem



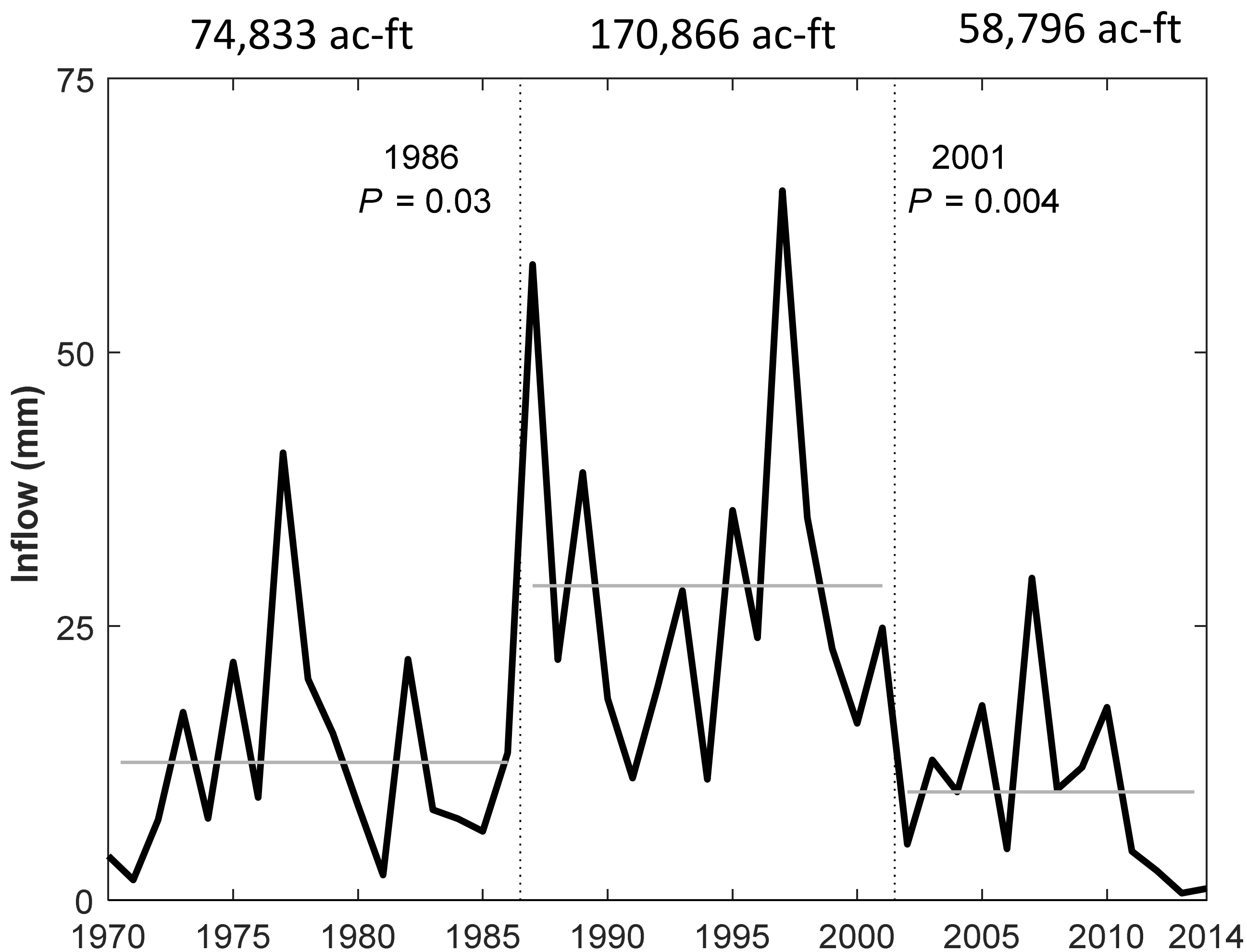
Methods

- Compiled data on weather (10 stations), land use, groundwater use, and lake inflows
- Calculated potential evapotranspiration (ET) by Hargreaves method
- Determined watershed averages for precipitation and potential evapotranspiration by Thiessen polygon
- Long term trends and change points in time series
- Used climate elasticity approach to separate influence of climate and human factors
- Used correlation and multiple linear regression to identify possible key drivers of streamflow change

Photo credit: rmccallay

How has Lake Inflow Changed?

- Inflow increased around 1987 and decreased around 2001
- Recent low flow is not unprecedented

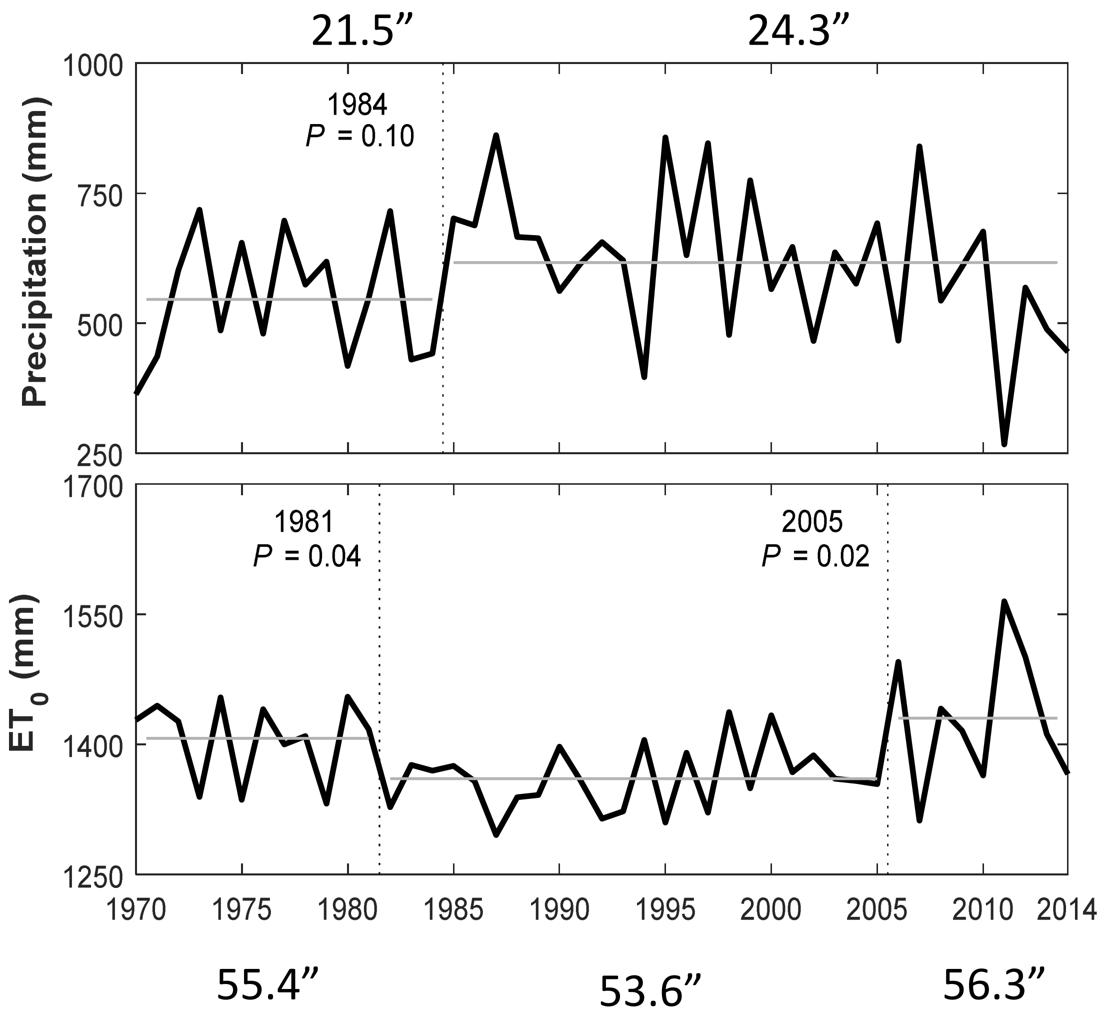


1” = 25.4 mm

Has Weather Changed?

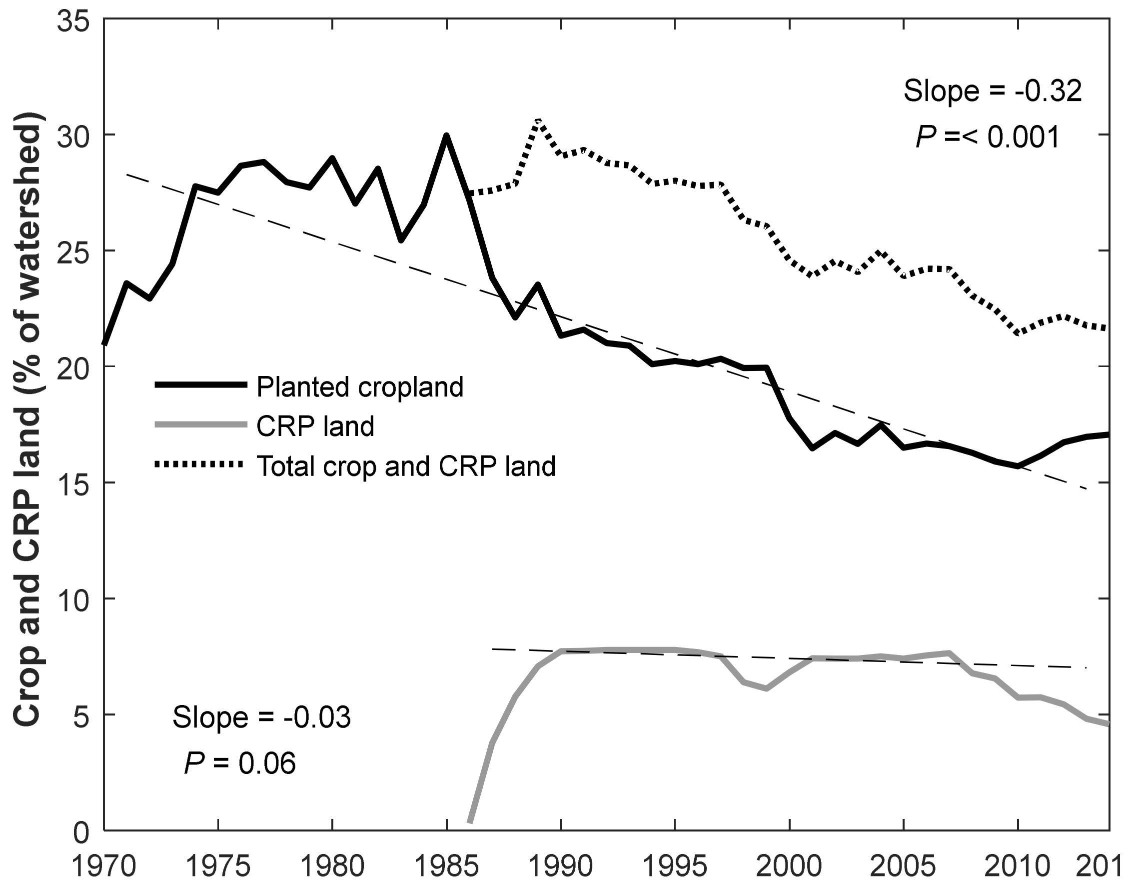
- Increase in precipitation around 1985
- Average 17.4” of precipitation from 2011-2014

- Decrease in potential evapotranspiration around 1981
- Increase in potential evapotranspiration around 2006



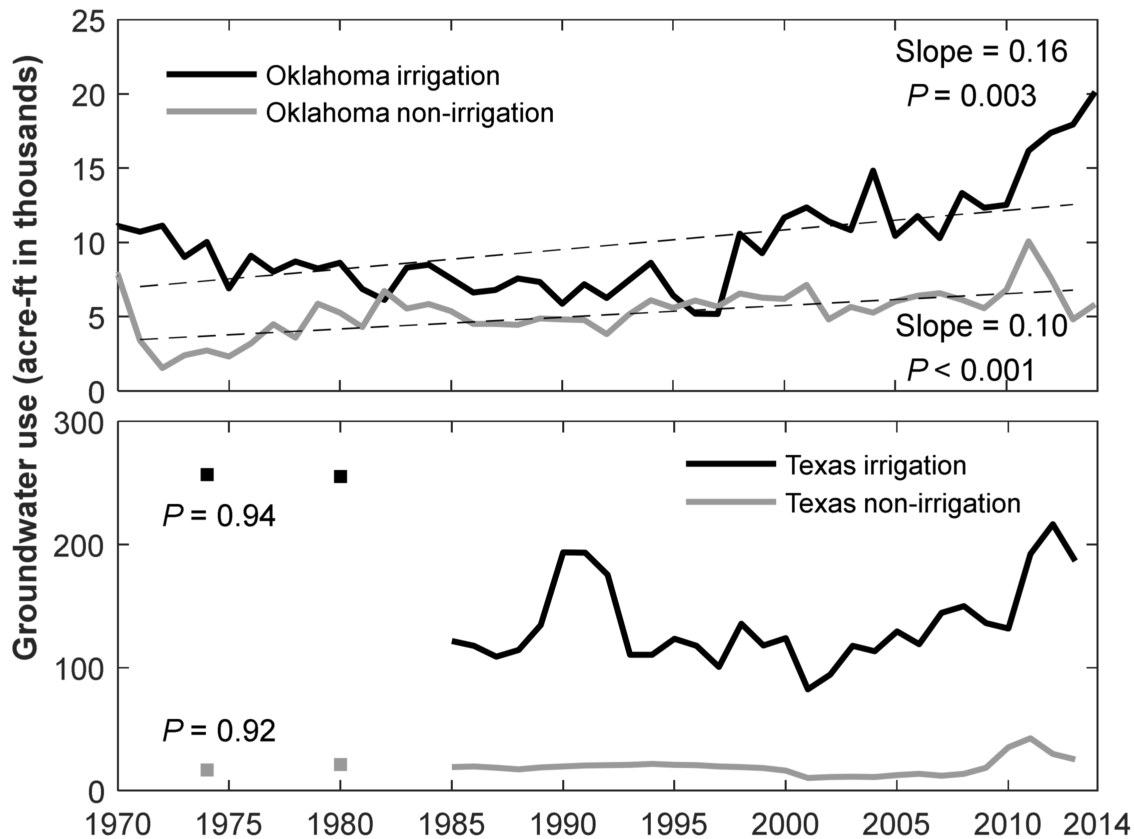
How has Land Use Changed?

- Cropland area peaked in 1985
- Conservation Reserve Program reduced cropland area almost 50%



How has Groundwater Use Changed?

- Groundwater use in OK portion of watershed (North Fork of Red River alluvial aquifer) increasing since around 1998
- Groundwater use in TX portion (High Plains aquifer) decreased between 1980-1985 and increasing since around 2000



To what extent did HUMAN FACTORS contribute to recent record low streamflow into the lake?

	Climate Elasticity		1986 Change 1			2001 Change 2		
Variable	P	ET_0	mm	%C	%H	mm	%C	%H
Streamflow	2.37	-1.23	16.4	49	**51**	-18.0	44	**56**

- Weather variables explain less than half of each change in flow
- Other factors, presumably human-influenced, explain 51-56% of each change
- What are those human factors?

Which Factors Might Drive Changes in Flow?

	Streamflow[1]	P	ET_0	Irrigation		Non-Irrigation		Planted
				OK	TX	OK	TX	
	mm			million m^3				%
1970-1986	12.6 a	563 a	1394 b	10.7 a	220 b	5.2 a	25 a	27 c
1987-2001	28.7 b	656 b	1359 a	9.7 a	136 a	6.7 b	23 a	21 b
2002-2014	9.9 a	560 a	1410 b	17.0 b	154 ab	7.7 b	24 a	17 a

[1] Values within a given column followed by the same lower case letter are not significantly different at $P < 0.1$.

- High inflow from 1987-2001 corresponded with high precipitation and low ET
- Groundwater use for irrigation in OK and TX were at their lowest during this period
- No apparent relationships between streamflow and non-irrigation ground water use or cropland area planted

Which Factors Might Drive Changes in Flow?

Correlation

	Streamflow[1]	Climate		Irrigation		Non-Irrigation		Cropland
		P	ET_0	OK	TX	OK	TX	Planted
P	**0.67**							
P -1 yr.	**0.32**	-0.15	0.07	-0.16	-0.11	0.05	-0.10	-0.07
ET_0	**-0.55**	**-0.75**						
ET_0 -1 yr.	**-0.30**	0.23	0.01	**0.34**	0.13	0.00	0.18	-0.11
OK irrigation	**-0.66**	**-0.45**	**0.46**					
OK irrigation -1 yr.	**-0.60**	-0.17	0.26	**0.84**	0.14	0.19	0.12	**-0.54**
TX irrigation	**-0.43**	**-0.40**	**0.46**	0.18				
TX irrigation -1 yr.	**-0.46**	-0.20	0.05	0.08	**0.61**	-0.30	0.24	**0.37**
OK non-irrigation	-0.05	-0.19	0.26	**0.34**	-0.19			
OK non-irrigation -1 yr.	**-0.31**	-0.11	0.29	**0.37**	-0.02	**0.50**	0.24	**-0.51**
TX non-Irrigation	-0.26	-0.29	**0.40**	0.23	0.25	**0.45**		
TX non-irrigation -1 yr.	**-0.40**	-0.27	**0.42**	0.33	**0.50**	**0.37**	**0.79**	0.02
Area planted	0.14	0.05	-0.13	**-0.57**	0.31	**-0.52**	-0.02	
Area planted -1 yr.	0.20	0.08	-0.19	**-0.62**	0.17	**-0.48**	-0.05	**0.95**

[1] Bold font indicates statistical significance at *P* = 0.05

- Precipitation and OK irrigation were most highly correlated with streamflow

Which Factors Might Drive Changes in Flow?

Multiple Regression

	Parameter		Model	
Variable	Estimate	P value	Adj. R^2	P value
Intercept	3.0	< 0.001	$\boxed{0.81}$	< 0.001
P	0.004	< 0.001		
OK irrigation -1 yr.	-0.122	< 0.001		
TX irrigation -1 yr.	-0.008	0.003		

- Precipitation and groundwater withdrawals in the OK and TX portions of the watershed are statistically significant predictors of inflow

- Statistical model explains 81% of variation

What Did We Learn?

- Weather was a strong driver of streamflow changes, BUT human influences contributed >50% of each change in flow.
- 81% of streamflow variability is explained by precipitation and irrigation in OK and TX.
- Groundwater use in OK portion of the watershed is increasing (up 400% since 1997).
- Statistical relationships SUGGEST that groundwater-surface water interactions helped drive streamflow changes

What Can We Do?

- Business as usual?
- Increased groundwater development, more water retention structures, out of basin supplies?
- Water Conservation/Improved irrigation efficiency?
- Transition from irrigated to rainfed farming?
- Conjunctive water management?