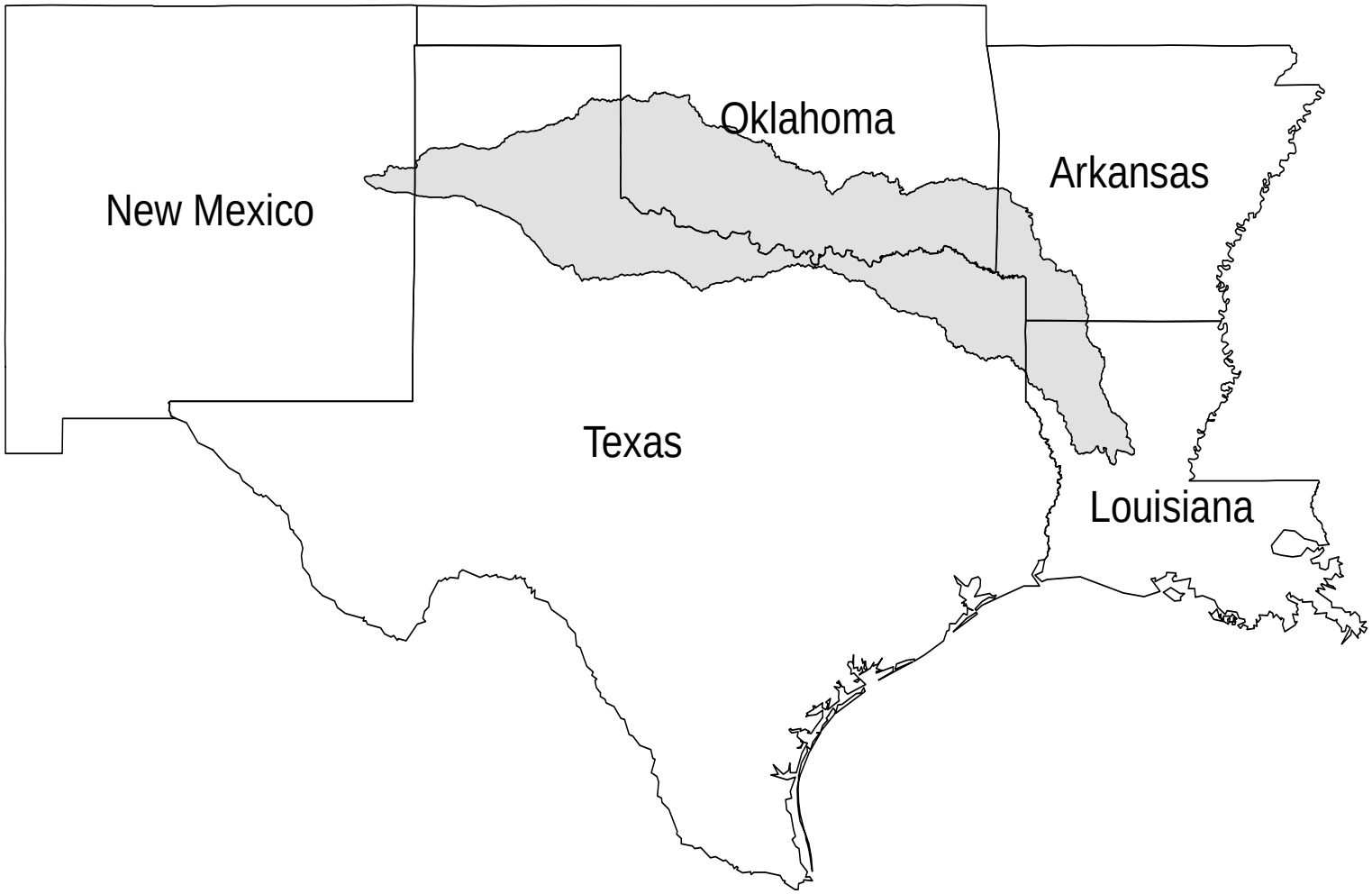
Nutrient Thresholds with Sestonic Chl-a in the Red River Basin

Brian Haggard and Thad Scott

Arkansas Water Resources Center

University of Arkansas

Red River Basin Regional Project



The first deliverable was…

UofA UNIVERSITY OF ARKANSAS DIVISION OF AGRICULTURE

July 2009

AWRC

FREQUENCY DISTRIBUTIONS OF MEDIAN NUTRIENT AND CHLOROPHYLL CONCENTRATIONS ACROSS THE RED RIVER BASIN, 1996-2006

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Frequency Distributions of Median Nutrient and Chlorophyll Concentrations across the Red River Basin, 1996–2006

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Acquisition and compilation of water quality data for a ten year time period (1996 – 2006) from 589 stream and river stations was conducted to support nutrient criteria development for the multi–state Red River Basin shared by Arkansas, Louisiana, New Mexico, Oklahoma and Texas, USA. Twenty–three water quality parameters were collected from five data sources (USGS, ADEQ, LDEQ, OCC, OWRB, and TCEQ) and an additional 13 parameters were acquired from at least one source. Data for the primary biological parameter of interest, chlorophyll a, was sparse and available from only two sources. Following compilation of data, medians were calculated for the ten year period and median distributions (min, 10th, 25th, 50th, 75th, 90th percentiles and max) were presented for several different spatial scales including state specific data, HUC8 designated watersheds, and various ecoregions. Across this basin, median values for total nitrogen (TN), total phosphorus (TP), and sestonic chlorophyll–a (chl–a) ranged from <0.02 to 20.2 mg L^{-1}, <0.01 to 6.66 mg L^{-1}, and 0.10 to 26 µg L^{-1}, respectively. Overall, the 25th percentiles of median TN data specific to the Red River Basin were generally similar to the USEPA recommended eco–region nutrient criteria. Whereas, median TP and chl–a data specific to the Red River Basin showed 25th percentiles greater than the USEPA recommended criteria. The unique location of the Red River Basin in the south–central USA places it near the boundaries of several aggregate eco–regions; therefore, the development of eco–region nutrient criteria likely requires using data specific to the Red River Basin, as shown in these analyses. This study provided basin–specific distribution of medians as the first step supporting states in developing nutrient criteria to protect designated uses in the multi–jurisdictional Red River Basin and in potentially reducing nutrient export from the Red River Basin to the Gulf of Mexico.

Keywords: nutrient criteria, USEPA Region 6, water quality, Red River Basin, Gulf of Mexico

This information was published in JEQ…

Distributions of Median Nutrient and Chlorophyll Concentrations across the Red River Basin, USA

S. D. Longing and B. E. Haggard* University of Arkansas

Acquisition and compilation of water-quality data for an 11-yr time period (1996–2006) from 589 stream and river stations were conducted to support nutrient criteria development for the multistate Red River Basin shared by Arkansas, Louisiana, New Mexico, Oklahoma, and Texas. Ten water-quality parameters were collected from six data sources (USGS, Arkansas Department of Environmental Quality, Louisiana Department of Environmental Quality, Oklahoma Conservation Commission, Oklahoma Water Resources Board, and Texas Commission on Environmental Quality), and an additional 13 parameters were acquired from at least one source. Median concentrations of water-quality parameters were calculated at each individual station and frequency distributions (minimum, 10th, 25th, 50th, 75th, 90th percentiles, and maximum) of the median concentrations were calculated. Across the Red River Basin, median values for total nitrogen (TN), total phosphorus (TP), and sestonic chlorophyll-a (chl-a) ranged from <0.02 to 20.2 mg L^{-1}, <0.01 to 6.66 mg L^{-1}, and 0.10 to 262 μg L^{-1}, respectively. Overall, the 25th percentiles of TN data specific to the Red River Basin were generally similar to the USEPA-recommended ecoregion nutrient criteria of 0.31 to 0.88 mg L^{-1}, whereas median TP and chl-a data specific to the Red River Basin showed 25th percentiles higher than the USEPA-recommended criteria (0.010–0.067 mg TP L^{-1}; 0.93–3.00 μg chl-a L^{-1}). The unique location of the Red River Basin in the south-central United States places it near the boundaries of several aggregate ecoregions; therefore, the development of ecoregion nutrient criteria likely requires using data specific to the Red River Basin, as shown in these analyses. This study provided basin-specific frequency distribution of median concentrations of water-quality parameters as the first step to support states in developing nutrient criteria to protect designated uses in the multijurisdictional Red River Basin.

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A multitude of water-quality concerns are associated with elevated nutrient concentrations in aquatic environments, including increased algal blooms and compromised biological integrity, increased water supply treatment processes and costs, disruption of natural ecosystem services provided by aquatic environments (including carbon sequestration and nutrient processing), potential threats to human health due to toxic algae, and widespread effects on ecosystem services provided by estuaries and coastal areas (Carpenter et al., 1998). Recent National Water Quality Inventories for the United States have consistently cited nutrients as one of the leading causes of water-quality impairment in rivers, lakes, and estuaries, where 36% of assessed streams and rivers and 30% of assessed lakes, ponds, and reservoirs were found to be impaired for fish, shellfish, and wildlife protection and/or propagation designated uses (USEPA, 2004). Furthermore, USEPA listed nutrients as the most important cause of impairment to lakes, ponds, and reservoirs and the fifth most important cause of impairment to streams and rivers (USEPA, 2004). This, along with 303(d) listings of impaired water reaches and development of total maximum daily loads (i.e., amount of a specific pollutant that can enter water bodies without adverse effects), has led to recent dedication to developing water-quality targets and improving aquatic conditions.

The Mississippi and Atchafalaya basins have become the focus of nutrient management because the hypoxic zone in the Gulf of Mexico has been linked to nutrient export from these basins. The hypoxic zone covers expansive areas in the northern Gulf of Mexico (CENR, 2000), with harmful effects on aquatic life, including important fisheries resources and major threats to estuarine ecosystems in the coastal zone (Vitousek et al., 1997; NRC, 2000). The Gulf Hypoxia Action Plan (2008) was developed for "reducing, mitigating, and controlling hypoxia in the Mississippi River Basin." This plan details three goals that seek to (i) decrease the overall size of the hypoxic zone, (ii) reduce sediment and nutrient inputs to protect public health and aquatic life, and (iii) reduce overall negative impacts of water quality by

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Abbreviations: ADEQ, Arkansas Department of Environmental Quality; CEFU, Central and Eastern Forested Uplands; chl-a, chlorophyll-a; GIS, geographic information system; GPGS, Great Plains Grasses and Shrublands; HUC 8, 8-digit hydrologic unit code; LDEQ, Louisiana Department of Environmental Quality; LULC, land use and land cover; OCC, Oklahoma Conservation Commission; OWRB, Oklahoma Water Resources Board; SCCGP, South Central Cultivated Great Plains; STFPH, Southeastern Temperate Forested Plains and Hills; TCEQ, Texas Commission on Environmental Quality; TN, total nitrogen; TP, total phosphorus.

2015. Mitigating the export of nutrients from point and nonpoint sources throughout all contributing watersheds (e.g., Red River within the Atchafalaya Basin) is critical to reduce the size of the hypoxic zone and protect the overall quality of this coastal resource. Turner and Rabalais (2004) showed declining trends in nutrient concentrations from 1973 to 1994 across the Red River Basin. Although concentrations declined in that period, Alexander et al. (2008) suggested that pasture and rangeland within the Red River Basin had a greater percentage flux of nutrients than did similar landscapes in other major watersheds within the Mississippi River Basin.

States and tribes within the United States can develop nutrient criteria for all water bodies and the USEPA can assist states with developing nutrient criteria. The USEPA has prepared technical guidance (USEPA, 2000a) and recommended criteria for 14 aggregate level III ecoregions (i.e., nutrient ecoregions) across the United States (e.g., USEPA 2000b,c,d,e). In lieu of the national recommendations, states and tribes can elect to develop nutrient criteria associated with the physical, chemical, and biological conditions unique to water bodies within specific regions. The progression of nutrient criteria development in recent years and the readily accessible data from various water-quality programs have facilitated recent studies comparing nutrient concentrations to the USEPA-recommended criteria for the nutrient ecoregions. These comparisons are a critical starting point when developing nutrient criteria for a specific basin because large differences between USEPA-recommended criteria and watershed specific data are often observed (e.g., Ice and Binkley, 2003; Smith et al., 2003; Mueller and Spahr, 2006). Furthermore, nutrient criteria development for water bodies often spans multiple political boundaries (e.g., Red River Basin), requiring stakeholders and government agencies to work cooperatively toward common goals.

The purpose of this study was to compile and analyze water-quality data collected over an 11-yr period (1996–2006) to support nutrient criteria development for the Red River Basin. This study provided states with preliminary data and statistical analyses, which included data acquisition, data compilation and integration among sources, and preliminary analysis of statistical distributions of median concentrations of water-quality parameters for streams and rivers. Here, we summarize median concentrations of select water-quality parameters over this 11-yr period for a variety of spatial groupings delineated for the Red River Basin. We then compare our calculated median values with the USEPA-recommended criteria for nutrient ecoregions to elucidate how median concentrations for the streams and rivers within the Red River Basin align with these numeric recommendations and identify areas with elevated nutrient concentrations (i.e., hotspots) within the watershed.

Materials and Methods

Study Area

The Red River is located in the south-central United States and is the southernmost major watershed of the Mississippi River Basin that drains portions of five states (Arkansas, Oklahoma, Louisiana, New Mexico, and Texas) and ultimately enters the Gulf of Mexico (Fig. 1). The headwaters of the Red River drain the Texas panhandle and eastern New Mexico, and the river flows eastward where its banks are the boundary between Oklahoma and Texas, except where it is impounded to form Lake Texoma. The river continues east and then south, flowing into Louisiana where it ultimately mixes with water from the Mississippi River, forming the Atchafalaya River. The Atchafalaya River then flows through the Atchafalaya Delta and the Atchafalaya Bay before entering the Gulf of Mexico. For the purposes of data compilation for our period of study, we designated Alexandria, LA, as the downstream point used to delineate the Red River Basin.

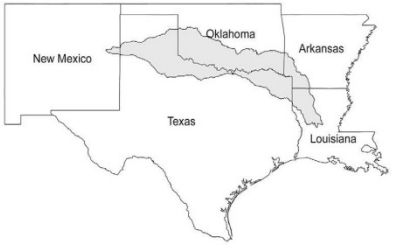


Fig. 1. Location of the multijurisdictional Red River Basin from Louisiana to New Mexico in the south-central United States.

Data Sources and Data Acquisition

A total of six sources had or provided pertinent water-quality data: the USGS, Arkansas Department of Environmental Quality (ADEQ), Louisiana Department of Environmental Quality (LDEQ), Oklahoma Conservation Commission (OCC), Oklahoma Water Resources Board (OWRB), and the Texas Commission on Environmental Quality (TCEQ). No data were retrieved from New Mexico state agencies because only a very small section of headwater streams near the state's eastern border was within the Red River Basin.

Water-quality data from USGS stations were acquired using the National Water Information System for the time period 1996 to 2006, and requests were made to the states to provide data for the same time period; this time period was selected in consultation with environmental agencies for each state. The datasets compiled from each source focused on streams and rivers; all lake, reservoir, and other water bodies were not included in this study. Because of the physiography of some parts of the watershed (e.g., Louisiana and southern Arkansas), many stations were located on bayous. These bayou stations were not removed and were considered "stream and river" stations for this study.

The water-quality programs of each state are independent and follow individual state protocols; therefore, the data varied in terms of extraneous characters attached to some values. For example, a large number of cells within each spreadsheet often contained the method detection limit (MDL) or lower detection limit (LDL) of a specific parameter and a value was preceded by a greater than or less than sign. We truncated the dataset at these values and simply removed all greater than or less than signs from each dataset. In addition, some values were

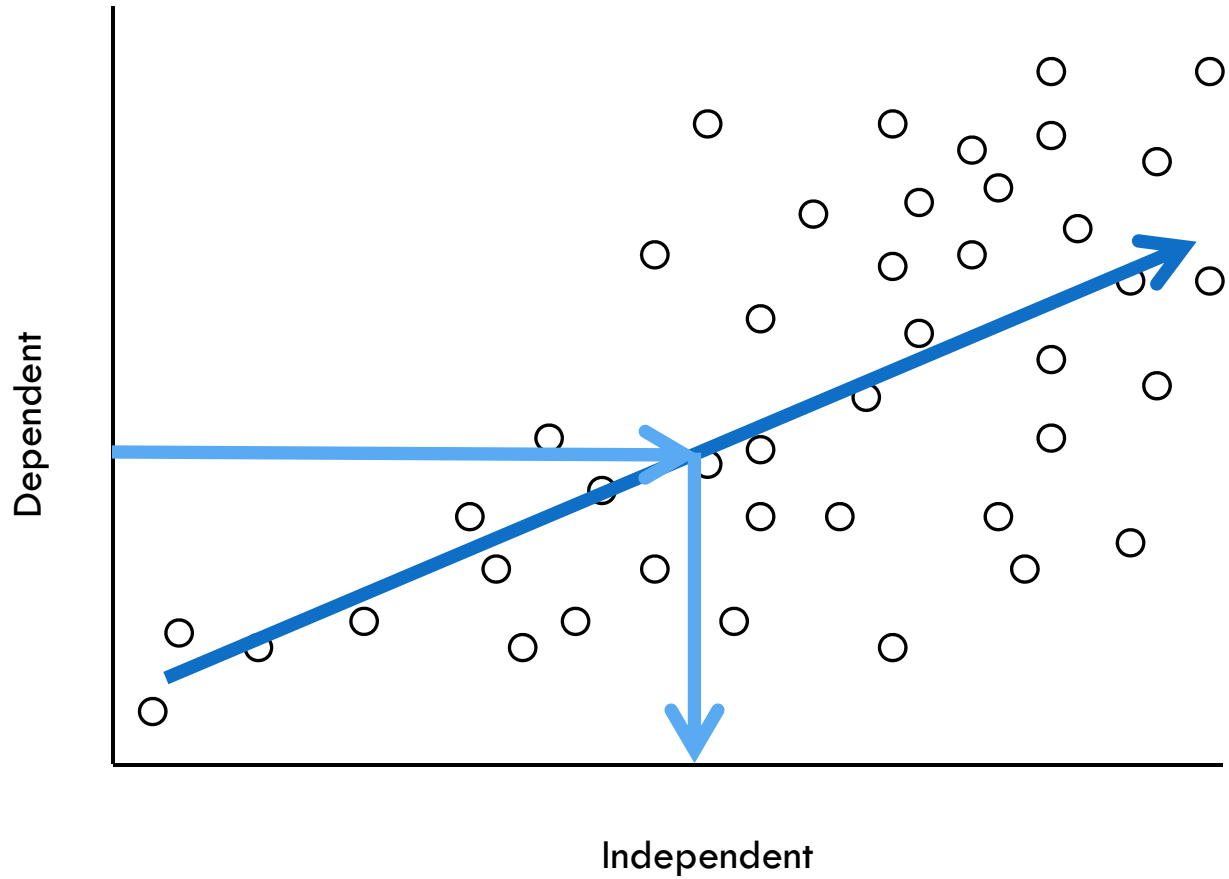
So, the frequency distributions have been completed (a long time ago).

- This is the first piece of information for the States to consider when developing nutrient criteria.
- We have frequency distributions for various levels:
  - Red River Basin (Entire)
  - Aggregate Level III (or, Nutrient) Eco-regions
  - Level III Eco-regions
  - Level IV Eco-regions
  - HUC 8 Watersheds
- This probably represents the most spatially explicit frequency distributions for any large watershed.

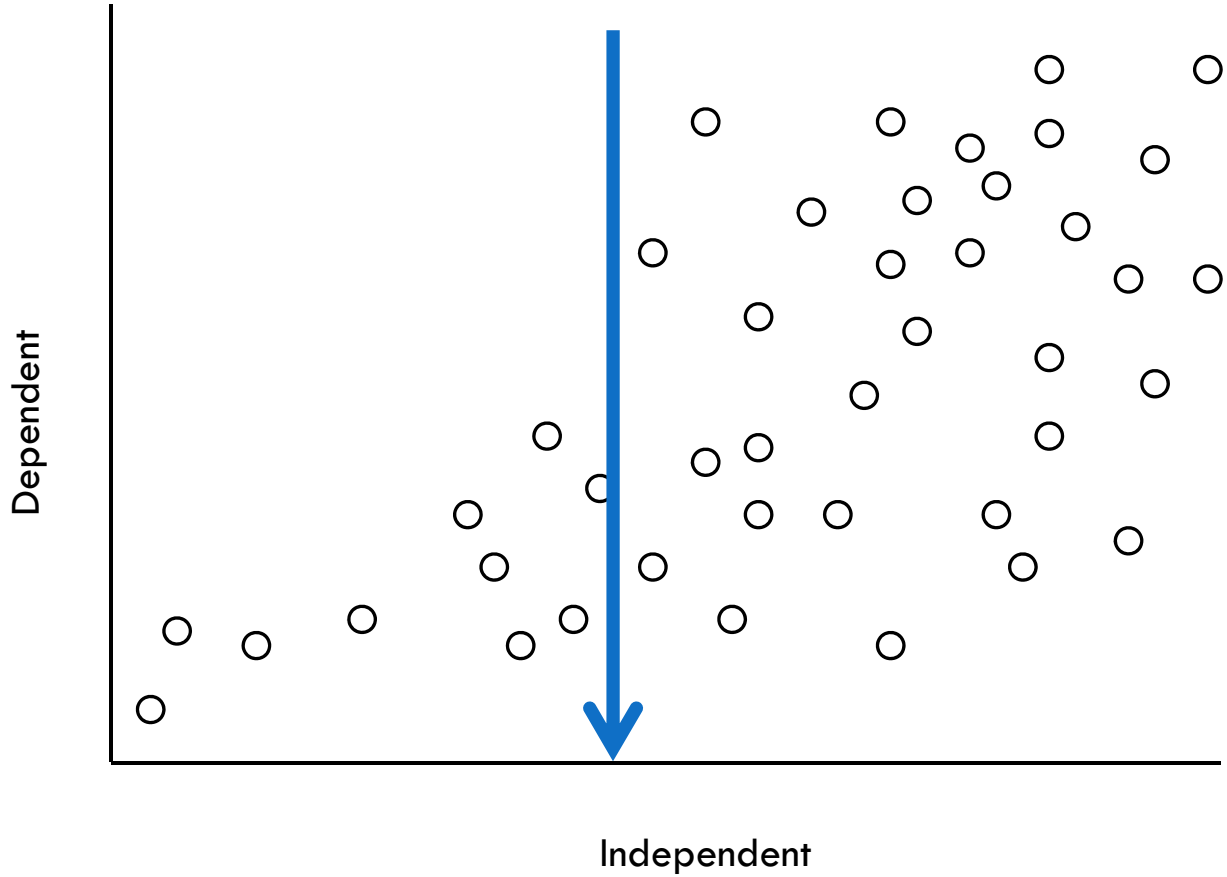
What's next?

Next, we need to evaluate relations between biotic variables and nutrients…

We can use linear regression…



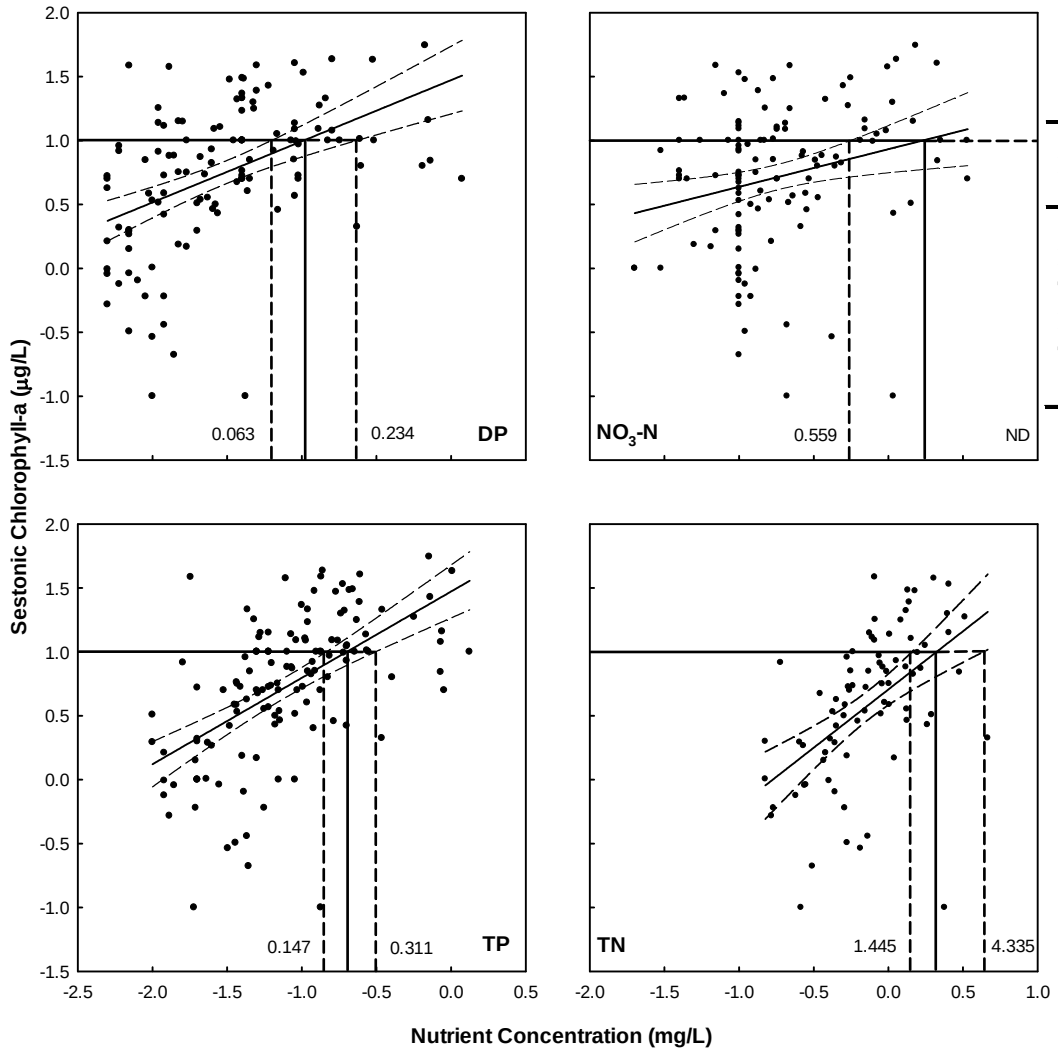
We can also use change in variation.



So, there are fewer sites with sufficient sestonic chlorophyll-a data…

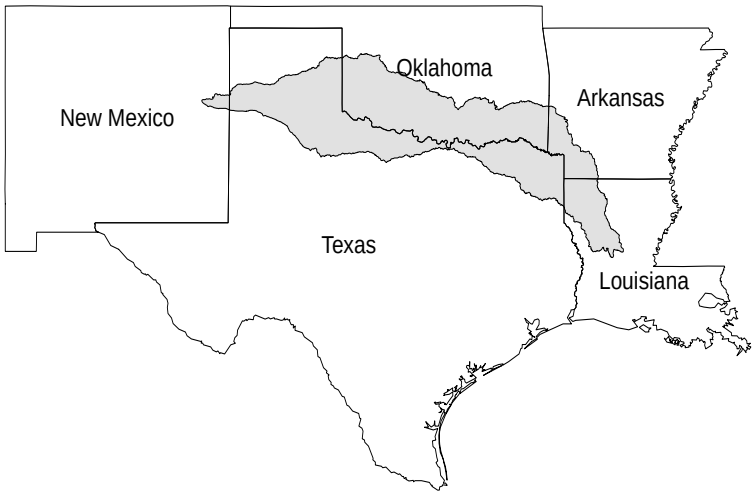
- Sestonic chl-a is really the only biotic response variable in the database assembled to date.
- We have approximately 153 sites with chl-a data, paired with median nutrient concentrations…
  - Red River Basin (Entire)
  - Fewer Paired Eco-region Data
- But, this data does show some significant linear regressions and even some change points
  - Using Classification and Regression Trees (CART)

Nutrient – chl-a Regressions – All Data

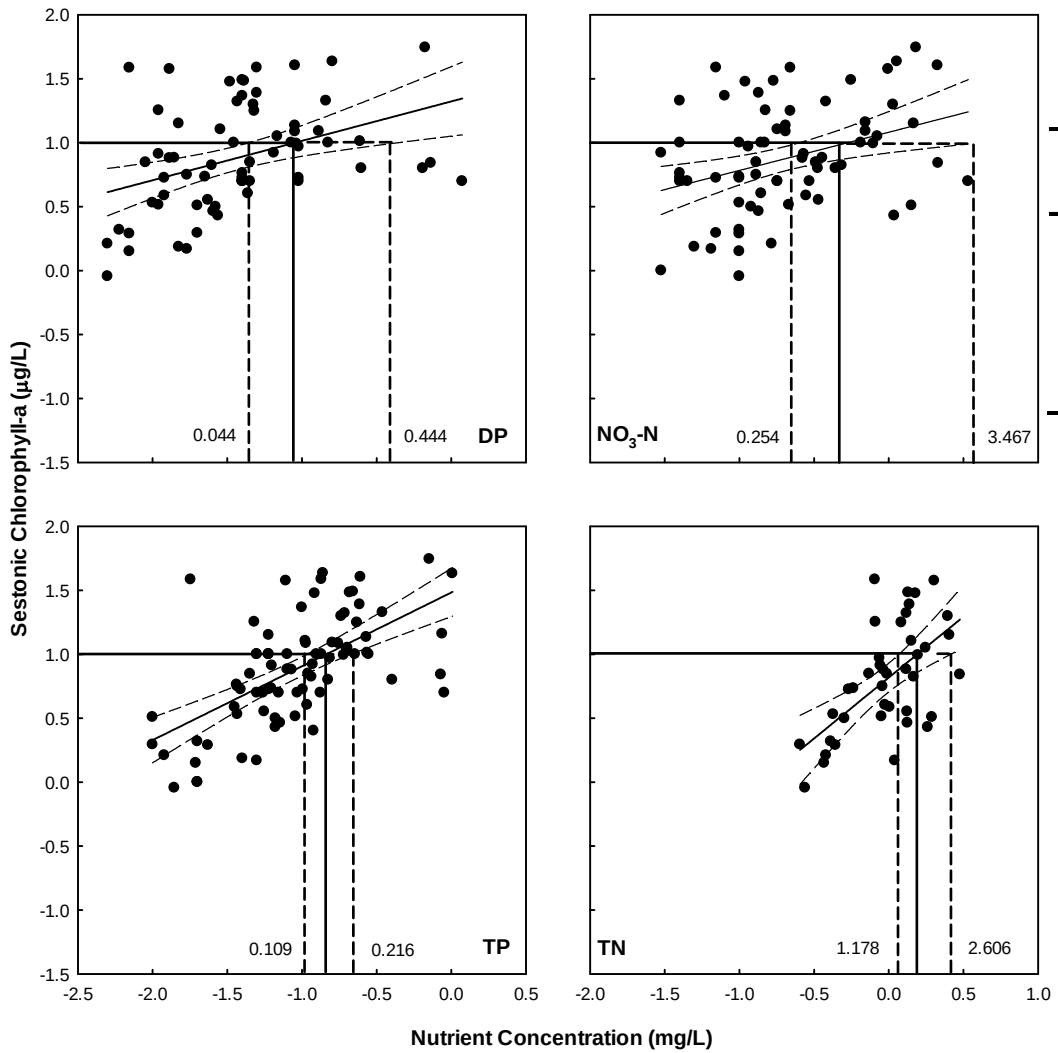


REGRESSION STATISTICS – ALL DATA

Nutrient	Slope	Intercept	n	r^2	P	X (mg L^{-1}) if Y (10 µg chl-a L^{-1})	BCF
DP	0.478	1.473	120	0.218	0.000	0.103	1.684
TP	0.676	1.472	132	0.312	0.000	0.200	1.612
NO_3-N	0.295	0.932	119	0.061	0.007	1.701	1.760
TN	0.911	0.705	79	0.268	0.000	2.106	2.026

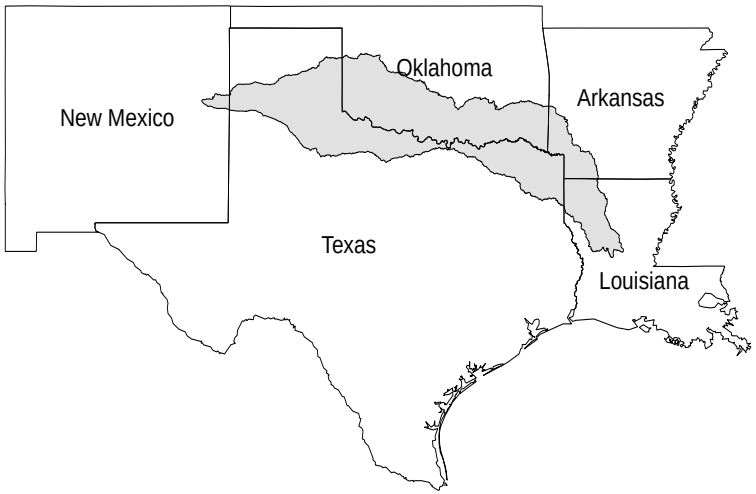


Nutrient – chl-a Regression – "Qualifier" Data, where sites were required to have 4 observations.



REGRESSION STATISTICS – "QUALIFIER"

Nutrient	Slope	Intercept	n	r^2	P	X (mg L^{-1}) if Y (10 µg chl-a L^{-1})	BCF
DP	0.308	1.322	67	0.153	0.001	0.090	1.506
TP	0.577	1.482	81	0.373	0.000	0.146	1.389
NO_3-N	0.299	1.082	70	0.124	0.003	0.533	1.489
TN	0.952	0.817	40	0.352	0.000	1.556	1.370



Nutrient – chl-a Regressions by Eco-Regions

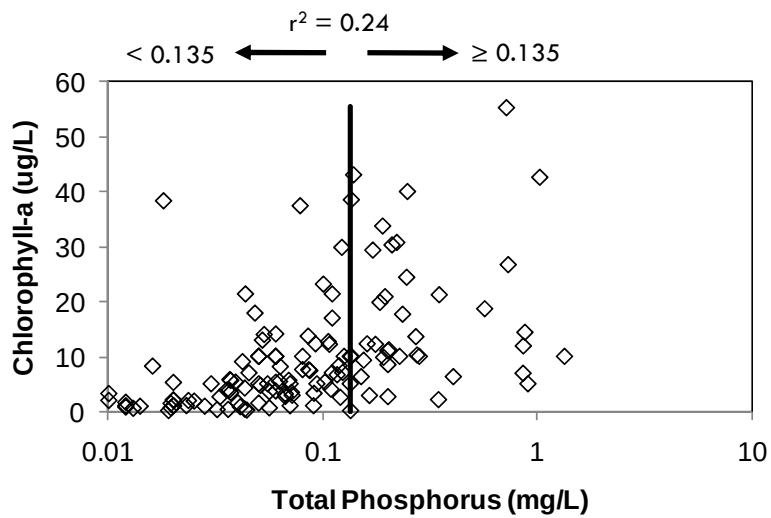
Nutrient	Slope	Intercept	n	r^2	P	X (mg L^{-1}) if Y (10 µg chl-a L^{-1})	BCF
			Great Plains Grasses and Schrublands				
NO_3	0.228	0.829	12	0.130	0.250	-	-
OP	0.017	0.737	11	0.000	0.966	-	-
TN	-2.285	0.936	3	0.358	0.592	-	-
TP	0.572	1.451	16	0.287	0.032	0.163	1.790
			Central and Eastern Forested Uplands				
NO_3	1.886	2.213	7	0.149	0.392	-	-
OP	0.600	1.576	7	0.495	0.078	0.110	1.089
TN	1.269	0.801	7	0.610	0.038	1.435	1.071
TP	0.734	1.489	7	0.643	0.030	0.216	1.063
			South Central Cultivated Great Plains				
NO_3	0.195	1.134	37	0.064	0.130	-	-
OP	0.241	1.363	35	0.100	0.065	0.031	1.380
TN	0.712	0.840	23	0.210	0.028	1.678	1.266
TP	0.455	1.442	44	0.226	0.001	0.107	1.286
			Southeastern Temperate Forested Plains and Hills				
NO_3	0.097	1.005	14	0.008	0.758	-	-
OP	0.121	1.058	14	0.042	0.482	-	-
TN	2.081	1.129	7	0.981	0.000	0.867	1.010
TP	0.441	1.284	17	0.306	0.040	0.227	1.224

Change Point Analysis – Sestonic Chl-a

The change point analysis showed that variability in chlorophyll-a concentrations significantly changed as a function of nitrogen and phosphorus concentrations, as well as conductivity.

Variable	Units	Threshold Value	Variance Explained (r^2)	Sestonic Chlorophyll-a Mean ± Standard Error [n] Below Threshold	Above Threshold
NO_3-N	mg L^{-1}	0.493	0.14	7.82±0.85 [97]	17.9±3.16 [22]
TN	mg L^{-1}	0.745	0.30	2.90±0.43 [39]	12.5±1.61 [40]
SRP	mg L^{-1}	0.028	0.17	5.72±0.96 [59]	14.8±1.52 [61]
TP	mg L^{-1}	0.135	0.24	6.71±0.76 [94]	18.2±2.14 [38]
Conductivity	µS cm^{-1}	1037	0.18	5.69±0.72 [69]	14.7±1.65 [63]

EXAMPLE OF CHANGE POINT ANALYSIS



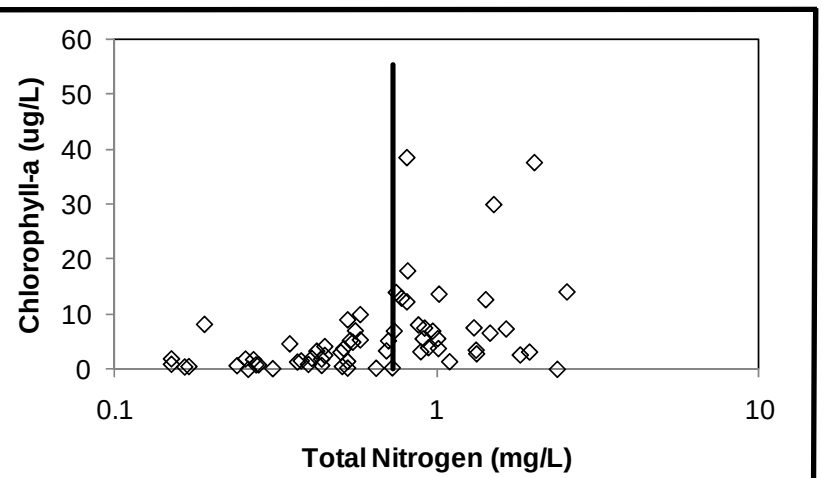
This split leads into the regression tree analysis, showing hierarchical structure.

Regression Tree – Sestonic Chl-a

TOTAL PHOSPHORUS < 0.135 mg L^{-1}

Partial r^2 = 0.14

< 0.735 ← → ≥ 0.735



Mean = 2.79 µg/L Chl-a
SE = 0.43
n = 37

Mean = 10.4 µg/L Chl-a
SE = 1.09
n = 28

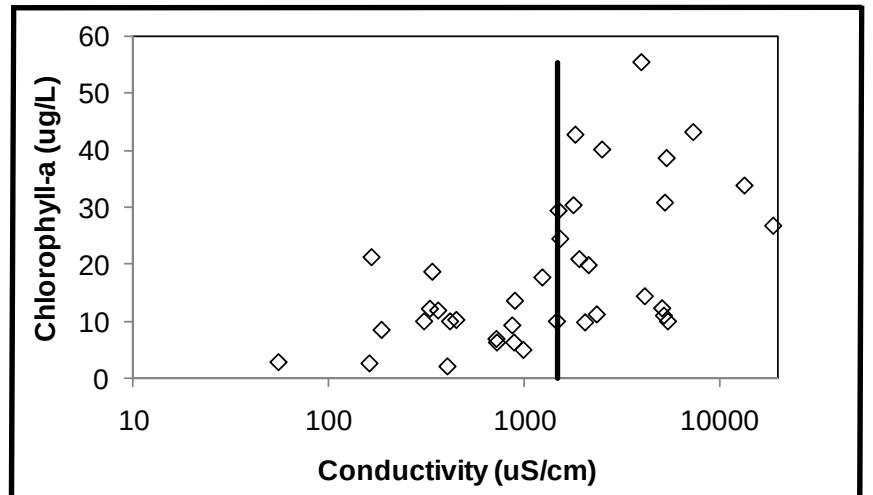
The regression tree analysis showed that variability in chlorophyll-a concentrations changed as a function of total nitrogen concentrations, within the chl-a data with TP < 0.135 mg L^{-1}.

Regression Tree – Sestonic Chl-a

TOTAL PHOSPHORUS > 0.135 mg L^{-1}

Partial r^2 = 0.18

< 1470 ← → ≥ 1470



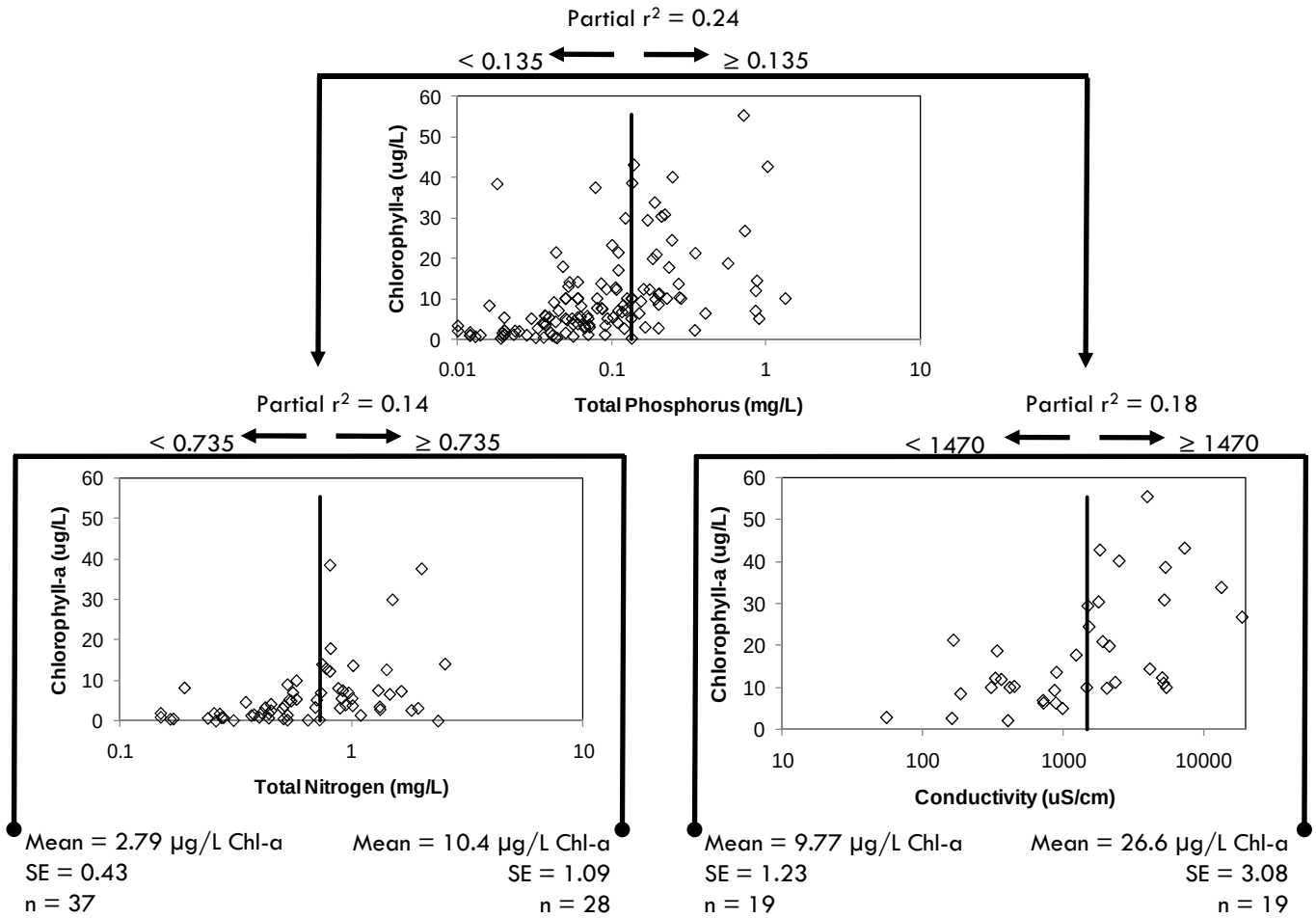
Mean = 9.77 µg/L Chl-a
SE = 1.23
n = 19

Mean = 26.6 µg/L Chl-a
SE = 3.08
n = 19

The regression tree analysis showed that variability in chlorophyll-a concentrations changed along the conductivity gradient, within the chl-a data with TP > 0.135 mg L^{-1}.

The regression tree shows the hierarchical structure hidden in the data.

The deliverable will be another AWRC document summarizing the stats that was submitted to JEQ.

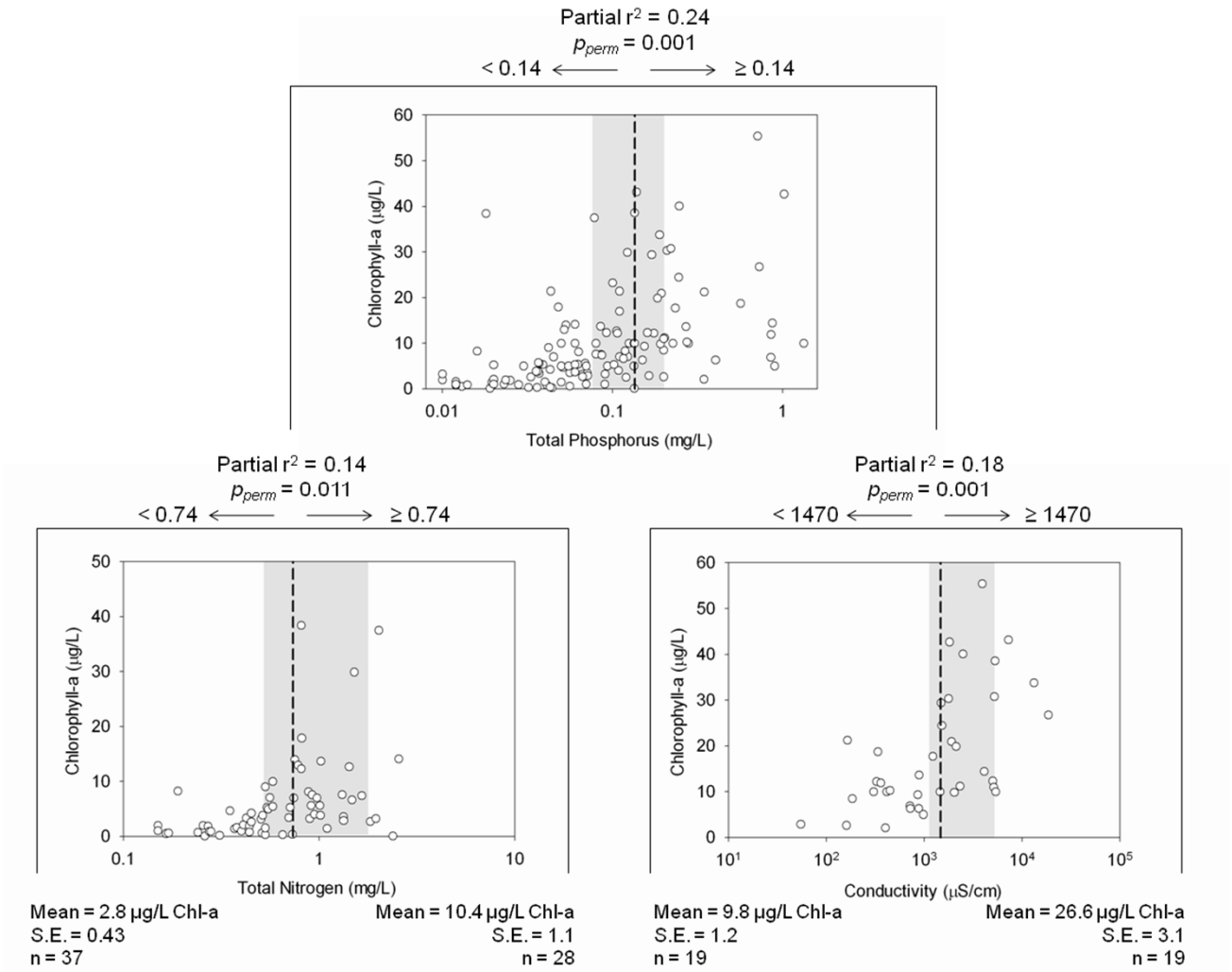


The overall model explained more than half the variability in sestonic chl-a (model $r^2 = 0.56$), showing that there are three distinct data groups.

HOT OFF THE PRESS!

95% confidence intervals and P values were also just recently estimated about these CPs…

This information was not in the final report, but it was included in the JEQ submission.



What do all the statistics tell us?

SUMMARY

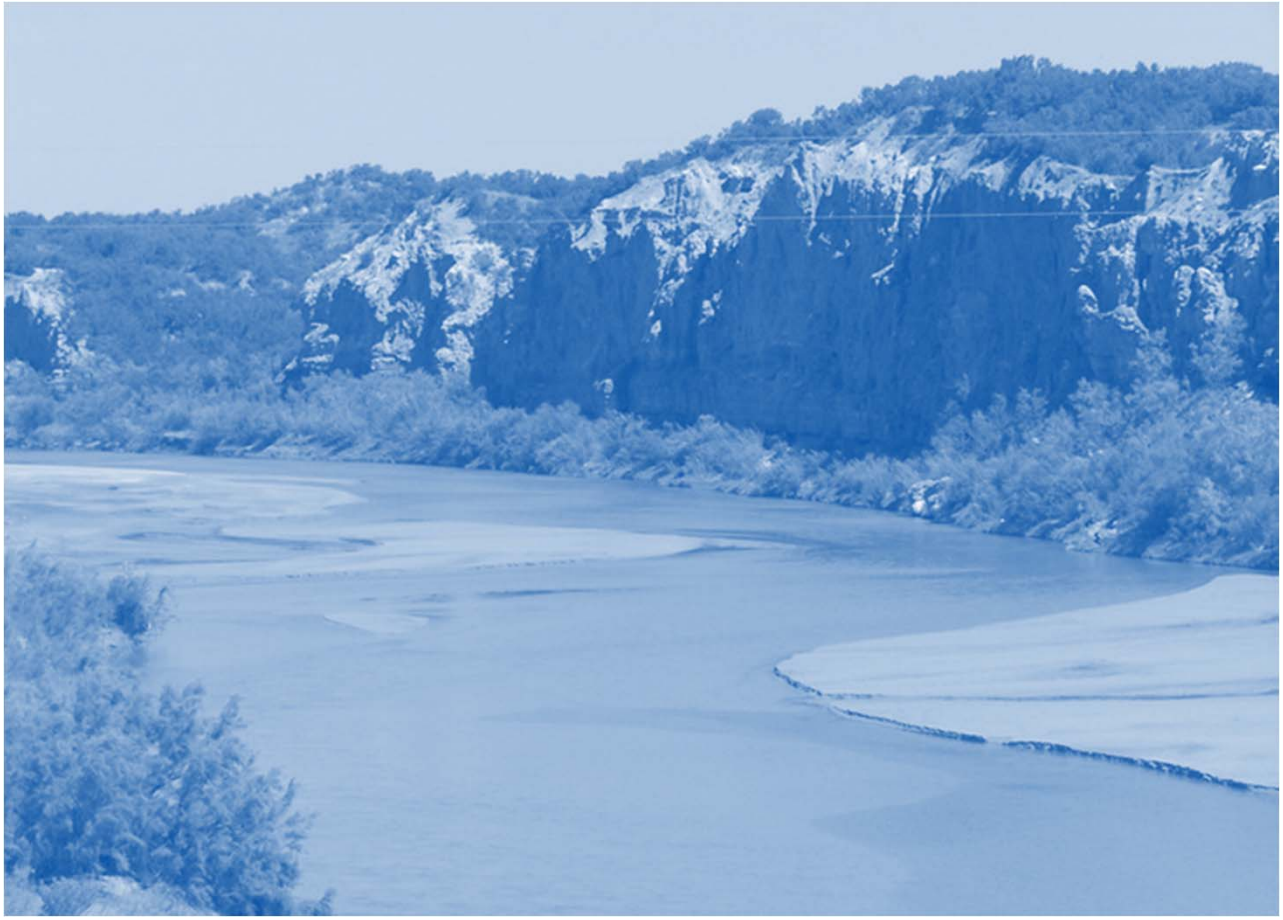
Percentiles (25th) do not match up with numbers from sestonic chl-a change points in variation or thresholds like (10 µg chl-a L^{-1}).

- Total Phosphorus
  - 0.02 – 0.07 mg L^{-1}, 25th Percentiles
  - 0.10 – 0.22 mg L^{-1}, If Y = 10 µg chl-a L^{-1}
  - 0.14 mg L^{-1}, CPA and Regression Tree
- Total Nitrogen
  - 0.21 – 0.86 mg L^{-1}, 25th Percentiles
  - 0.87 – 2.61 mg L^{-1}, If Y = 10 µg chl-a L^{-1}
  - 0.75 mg L^{-1}, CPA and Regression Tree

Nutrient Criteria Workshops

NUTRIENT CRITERIA DEVELOPMENT WORKSHOPs

- We met with each State agency giving the workshop.
- The number attendees varied…
  - From those on the ground (in the water) to branch managers or administrators.
  - From only agency staff to multiple state agencies and even stakeholders.
  - From 5 to more than 20 attendees.
- A written report detailing the workshops and archiving the presentations was provided to EPA and the States.

Regional Red River Project Update

QUESTIONS?