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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

INTRODUCTION

A multitude of water quality concerns are associated with elevated nutrient concentrations in aquatic environments including reduced water quality 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 USA have consistently cited nutrients as one of the leading causes of water–quality impairment in rivers, lakes and estuaries, where 36 percent of assessed stream and rivers miles and 30 percent of assessed lakes, ponds, and reservoirs were found to be impaired for fish, shellfish, and wildlife protection or propagation designated uses (USEPA 2004). Furthermore, in that most recent report 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 a requirement for states and tribes to provide a list of impaired streams biennially to the USEPA and to develop Total Maximum Daily Loads (i.e., amount of a specific pollutant that can enter waterbodies without adverse effects) has led to much recent dedication in developing water quality targets for monitoring and improving aquatic conditions.

The two predominant basins that influence water quality in the Gulf of Mexico, the Mississippi and Atchafalaya Basins, have become a major area of 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 ocean 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 (1) decrease the overall size of the hypoxic zone, (2) reduce sediment and nutrient inputs to protect public health and aquatic life, and (3) reduce overall reducing negative impacts of water quality by 2015. Mitigating the export of nutrients from point and non–point 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, which contributes nutrients to the Gulf of Mexico. Although concentrations declined in that period, Alexander et al. (2008) suggested that pasture and rangeland within the Red River Basin had a greater percent flux of nutrients than similar landscapes in other major watersheds within the Mississippi River Basin. The Red River Basin is a multi–state watershed that provides the opportunity to protect designated uses of aquatic systems associated with water quality, fisheries, and recreation under individual state and tribal jurisdictions, while potentially reducing nutrient delivery to the Gulf of Mexico.

States and tribes within the USA have the opportunity to develop nutrient criteria for all waterbodies and, to 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 USA (e.g., see USEPA 2000b–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 has facilitated recent studies comparing nutrient concentrations to the USEPA recommended criteria for the nutrient ecoregions (e.g., Ice and Binkley 2003, Smith et al. 2003, Mueller and Spahr 2006). These comparisons are a critical starting point, because large differences between USEPA recommended criteria and more watershed specific data are often observed. Furthermore, nutrient criteria development for water bodies often spans multiple political boundaries (e.g., Red River Basin, USA) which require stakeholders and specifically government agencies to work cooperatively towards common goals.

The purpose of this study was to focus on the multi–state Red River Basin (Arkansas, Louisiana, Oklahoma, Texas, and New Mexico) and to compile water quality data for a ten year time period (1996–2006). This study supports nutrient criteria development for this watershed by providing states with preliminary data and statistical analyses to begin this process, which includes data acquisition, data compilation and integration among sources, and preliminary analysis of statistical distributions. Here, we summarize median concentrations of select water quality parameters over this ten year 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 Red River Basin align with these numeric recommendations.

METHODS

Study Area

The Red River is located in the South Central USA 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 east where its banks become the boundary between Oklahoma and Texas, except where it is impounded to form the 583 km^2 Lake Texoma. The river continues east and then south where it forms the boundary between Texas and Arkansas, and then flows into Louisiana where it ultimately is mixed with water from the Mississippi River. The outflow becomes the Atchafalaya River at this point of water input from the Mississippi River and then flows through the Atchafalaya Delta and Atchafalaya Bay before entering the Gulf of Mexico. For the purposes of data compilation for our time period of study, we designated Alexandria, Louisiana as the downstream point used to delineate the Red River Basin.

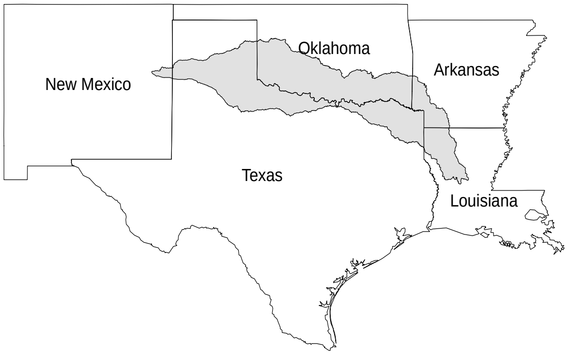


Figure 1. Location of the multi–jurisdictional Red River Basin from Louisiana to New Mexico in the south–central United States.

Data Sources and Data Acquisition

A total of six sources had or provided pertinent water quality data: U.S. Geological Survey (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 (TC EQ). No data was retrieved from New Mexico state agencies because there was only a very small section of headwater streams near the states eastern border that were within the Red River Basin.

Water quality data from USGS stations was acquired using the National Water Information System (NWIS); all water quality parameters were acquired via table format for the time period from 1996 to 2006. Requests were made to states to provide data for this time period and in a format that was accessible and one that facilitated compilation of data. The most effective format for compiling data was to use Microsoft Excel with spreadsheet columns designating sampling sites, dates, and water quality parameters of interest. This format allowed an initial and relatively easy assessment of the numbers of stations and numbers of measurements across stations for each water quality parameter. Furthermore, the datasets that were 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 considered "stream and river" stations for this study.

The water quality programs of each state are independent and following individual state protocols, and 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 decided to truncate the dataset at these values and simply removed all greater than or less than signs from each dataset. On a more qualitative level, some values were associated with subtle characters that inhibited data manipulation; any characters that were not values were removed and in some case these were removed and the data re–entered to ensure the cells contained the original source values only. The databases were scrutinized to make sure each cell contained values to facilitate statistical analyses.

Data Compilation and Station Attributes

Each source dataset was stored separately and reviewed regarding water quality parameter data gaps and overall comparability. Occurrences of parameters across sources were tallied, where the most complete dataset contained those parameters occurring across all sources. Data subsets were then developed for parameters occurring from at least one site but not from every source. Integrating data across sources first involved checks on parameter titles and units, and parameters were then compiled across sources to represent similar water quality constituents. A major contingency of the effectiveness of this large scale dataset for supporting nutrient criteria development was the availability of similar data across sources. Generally, all sources measured the same suite of water quality parameters and physico–chemical parameters (i.e. temperature, pH, DO, conductivity) and most had at least some of the nutrient series of concern (phosphorous and nitrogen). However, some parameters that were not included in the original source were calculated from the data provided and these new values were inserted in the dataset. For example, where total nitrogen (TN) was not reported we estimated values by adding organic–N (i.e., total Kjeldahl N, TKN) and nitrate–N (NO_3) plus nitrite–N (NO_2).

A geographic information system (GIS) was used to develop station attribute information that included watershed delineations and estimated watershed areas for all 589 stations, as well as land–use and land–cover (LULC) classifications using available 2001 satellite imagery, hydrologic unit codes (HUC) level 8, ecoregions including level III and level IV (Omernick 1987), and the recently developed nutrient ecoregions (USEPA 2000a). For this study we only used the GIS data related to the various spatial classifications (i.e. HUC 8 and ecoregions) with subsequent studies incorporating LULC information. All GIS analyses were conducted by the University of Arkansas Center for Advanced Spatial Technology (CAST).

Data Quality Control

One of the most important objectives to facilitate data checks and comparisons was to maintain the original source data in unmanipulated form (i.e., source files) to quality control manipulated datasets. These original source files were stored intact and, during the initial steps of data manipulation for calculating medians, we cross–checked at least 10 percent of the stations per source (i.e., compared raw data at 10 percent of stations to the data contained in the manipulated spreadsheets). Similarly, following the integration of raw data across sources we again checked 10 percent of the sites from the integrated data with the original source data. Although these checks were the formal quality control procedures and were conducted at major steps of the data compilation process, data was checked more or less continuously during all data manipulations to ensure that mistakes did not run the risk of compounding problems later in the process. This quality control process assisted in the identification of data cells that contained ambiguous information not in numerical format, which would therefore be inadvertently excluded during statistical analyses. Three primary datasets were produced following this process that contained (1) raw data values across sources in a 29 parameter x 19,989 record data matrix, (2) median and geomean values in a 28 parameter x 589 station data matrix, and (3) station attribute dataset in a 47 x 589 station data matrix. The additional number of fields (29 versus 28) in the raw data spreadsheet compared to the median spreadsheet was due to the addition of sampling date.

Data Analysis

Following compilation of data and completion of the quality control process, medians and geomeans were calculated for the ten year period and median distributions (min, 10th, 25th, 50th, 75th, 90th percentiles and max) for the water quality parameters NO_3–N plus NO_2–N (hereafter, NO_3–N), TN, dissolved orthophosphate (PO_4–P), total phosphorus (TP), chloride (Cl), and sestonic chlorophyll–a (chl–a). The minimum, median, percentiles, and maximum were calculated using the software program, Microsoft Excel; the percentile concentrations are estimated using an alternative linear interpolation method recommended by the National Institute of Standards and Technology, providing estimated percentiles between observed data. These frequency distributions were presented for several different spatial scales including HUC8 watersheds and ecoregion levels III and IV including nutrient ecoregions. We then compared our calculated site medians for these water–quality parameters of interest with the USEPA recommended criteria of these parameters for aggregate ecoregions.

RESULTS

A total of 10 water quality parameters occurred across all six data sources and an additional 13 parameters occurred from at least one source, for a total of 23 water quality parameters (Table 1). The number of sites (i.e., water quality stations) per source that had water quality data for this time period was: ADEQ (29), LDEQ (50), OCC (206), OWRB (160), TCEQ (112) and USGS (32), and the total number of parameters per source ranged from 14 to 22. TN and TP were reported by every source but varied in the total number of measurements over the ten year period (Figure 2), with TCEQ contributing relatively fewer measurements of TN for the time period. All parameters of interest related to nitrogen and phosphorus were available from each source, with the exception that

LDEQ provided no measurements of PO_4–P (e.g., dissolved P) over the ten year period. Sestonic chl–a concentration data was sparse and only acquired from two sources, TCEQ and OWRB. Benthic chl–a data was available only from OWRB, though from a limited number of observations (54 raw values). The bacteria parameters fecal coliform and *E coli* bacteria were acquired from all but one source, while *Enterococcus* was acquired only by OCC and OWRB. We focused on the distributions of NO_3–N plus NO_2–N, TN, PO_4–P, TP, and the limited sestonic chl–a data available.

Statistical distributions for median NO_3–N plus NO_2–N, TN, TP, PO_4–P, and sestonic chl–a concentrations are presented for the various spatial classifications including Red River Basin, state agencies, and nutrient ecoregions in Tables 2–4, and statistical distributions of these select water quality parameters across Level III ecoregions, level IV ecoregions, and HUC 8 watershed are available in the appendices, as these tables were not specifically discussed in this paper. These data summaries include counts (i.e., number of median values per spatial classification), minimum values, maximum values, medians, and percentiles (10^{th}, 25^{th}, 75^{th}, and 90^{th}). The number of station medians for comparisons with USEPA recommended criteria for nutrient ecoregions generally reflected the proportion of area occupied within the Red River Basin: 78 for TN, 83 for TP, and 24 for chl–a median values for the Central and Eastern Forested Uplands (CEFU); 16 TN, 33 TP, and 21 chl–a median values for the Great Plains Grasses and Schrublands (GPGS); 131 TN, 167 TP, and 63 chl–a median values for the South Central Cultivated Great Plains (SCCGP); and 167 TN, 185 TP, and 43 chl–a median values for the Southeastern Temperate Forested Plains and Hills (STFPH).

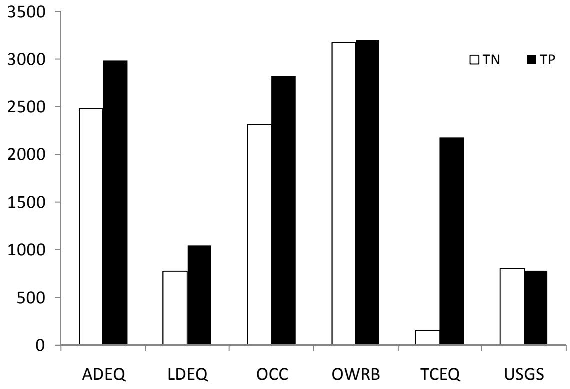


Figure 2. Total number of total nitrogen (TN) and total phosphorus (TP) measurements within the Red River Basin from each data source from 1996–2006.

The number of median concentrations that exceeded the USEPA recommended criteria was near the expected proportion, because the USEPA recommended criteria represents the 25^{th} percentile of the general nutrient population. This automatically suggests that about 75% of the median values from randomly selected (or even available) sites should be greater than the recommended criteria, which was generally observed in the median concentrations across the various ecoregions within the Red River Basin. For TN, the percent of median concentrations greater than the recommended criteria in each nutrient ecoregion were: CEFU (44%), GPGS (88%), SCCGP (72%), and STFP (60%).

Table 1. Water quality parameters acquired from six different sources (number of stations per source) across the Red River Basin, 1996–2006, including the Arkansas Department of Environmental Quality (ADEQ), Texas Commission on Environmental Quality (TCEQ), Louisiana Department of Environmental Quality (LDEQ), Oklahoma Conservation Commission (OCC), and Oklahoma Water Resources Board (OWRB), and the U.S. Geological Survey (USGS).

Parameter	ADEQ (29)	TCEQ (112)	LDEQ (50)	OCC (206)	OWRB (160)	USGS (32)
Temperature	•	•	•	•	•	•
Dissolved Oxygen	•	•	•	•	•	•
pH	•	•	•	•	•	•
Turbidity	•	•	•	•	•	•
Chloride	•	•	•	•	•	•
Ammonia	•	•	•	•	•	•
NO3 + NO2	•	•	•	•	•	•
TKN	•	•	•	•	•	•
Total N	•	•	•	•	•	•
Total P	•	•	•	•	•	•
Flow	•	•		•	•	•
Fecal Coliform		•	•	•	•	•
Orthophosphate	•	•		•	•	•
E. coli	•	•		•	•	•
Nitrate		•		•	•	•
Nitrite		•		•	•	•
Chlorophyll a (benthic)		•				
Chlorophyll a (sestonic)		•			•	
Sulfates	•	•			•	•
Total Suspended Solids	•	•	•		•	•
Conductivity		•	•	•	•	•
Enterococcus				•	•	
Total Hardness			•		•	
Total	15	21	14	18	22	19

Table 2. Frequency distributions of median concentrations of select water quality parameters from 589 stream and river monitoring stations across the Red River Basin, 1996–2006.

Parameter	UNITS	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
Cl	mg L^{-1}	519	1.6	5.3	10.0	41.2	195	1100	18300
NO_3–N	mg L^{-1}	444	0.01	0.04	0.08	0.14	0.45	1.13	20.1
TN	mg L^{-1}	393	0.02	0.20	0.39	0.76	1.22	1.87	20.2
PO_4–P	mg L^{-1}	381	0.00	0.01	0.01	0.03	0.05	0.16	6.07
TP	mg L^{-1}	468	0.01	0.02	0.04	0.08	0.13	0.25	6.66
chl–a	µg L^{-1}	152	0.10	1.00	3.20	7.40	13.1	29.9	263

Table 3. Frequency distributions of median nutrient and sestonic chlorophyll–a concentrations among states in the Red River Basin, 1996–2006.

NO_3–N (mg L^{-1})

State	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
ADEQ	29	0.01	0.06	0.09	0.16	0.40	2.13	5.01
LDEQ	50	0.02	0.05	0.07	0.11	0.15	0.26	1.55
OCC	177	0.01	0.04	0.06	0.16	0.63	1.16	7.39
OWRB	107	0.10	0.10	0.10	0.13	0.27	0.69	2.30
TCEQ	62	0.02	0.03	0.05	0.18	0.70	3.33	20.1
USGS	19	0.03	0.05	0.06	0.15	0.24	0.58	1.09

TN (mg L^{-1})

State	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
ADEQ	28	0.30	0.55	0.85	1.08	1.76	2.86	5.56
LDEQ	50	0.29	0.67	0.75	0.88	1.00	1.28	3.29
OCC	177	0.02	0.21	0.37	0.65	1.18	1.83	8.28
OWRB	107	0.15	0.30	0.47	0.78	1.33	1.90	4.64
TCEQ	12	0.26	0.53	0.57	0.70	1.18	1.85	1.95
USGS	19	0.05	0.18	0.25	0.77	1.27	1.41	1.95

PO_4–P (mg L^{-1})

State	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
ADEQ	29	0.01	0.02	0.02	0.03	0.06	1.14	2.07
LDEQ								
OCC	158	0.00	0.01	0.01	0.02	0.05	0.09	1.25
OWRB	107	0.01	0.01	0.01	0.02	0.04	0.07	0.73
TCEQ	70	0.01	0.02	0.04	0.04	0.18	0.65	6.07
USGS	17	0.01	0.01	0.01	0.02	0.02	0.05	0.08

TP (mg L^{-1})

State	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
ADEQ	29	0.03	0.04	0.07	0.12	0.21	1.14	1.99
LDEQ	50	0.05	0.07	0.08	0.10	0.13	0.19	0.38
OCC	182	0.01	0.02	0.03	0.06	0.11	0.16	1.48
OWRB	107	0.01	0.02	0.04	0.07	0.13	0.22	0.85
TCEQ	84	0.01	0.04	0.06	0.12	0.25	0.85	6.66
USGS	16	0.01	0.01	0.02	0.09	0.14	0.18	0.24

Cl (mg L^{-1})

State	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
ADEQ	29	2.1	2.8	5.9	10.6	30.1	89.5	145
LDEQ	50	5.0	5.9	8.4	15.9	36.6	56.8	195
OCC	182	2.1	4.0	6.3	23.3	72.9	246	4840
OWRB	147	5.0	10.0	10.0	62.3	250	988	12800
TCEQ	94	10.0	28.3	87.3	330	1460	4980	18300
USGS	17	1.6	2.6	40.7	170	423	2270	11000

chl–a (sestonic, µg L^{-1})

State	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
OWRB	81	0.10	0.60	2.08	5.61	13.7	29.9	263
TCEQ	71	1.00	1.53	5.00	10.0	12.3	29.4	86.8

Table 4. Frequency distribution of median nutrient and sestonic chlorophyll–a concentrations across Aggregate Level III Ecoregions within the Red River Basin, 1996–2006.

NO_3–N (mg L^{-1})

Nutrient Ecoregion	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
CEFU	78	0.01	0.04	0.06	0.09	0.10	0.15	2.02
GPGS	25	0.02	0.03	0.05	0.19	*0.84*	2.61	20.1
SCCGP	161	0.02	0.06	0.15	0.45	0.95	1.53	11.8
STFPH	180	0.01	0.05	0.08	0.11	0.21	0.42	5.01

TN (mg L^{-1})

Nutrient Ecoregion	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
CEFU	78	0.03	0.11	0.21	0.29	0.42	0.73	2.60
GPGS	25	0.06	0.27	0.61	0.76	1.25	2.87	20.2
SCCGP	152	0.09	0.35	0.86	1.17	1.64	2.54	11.8
STFPH	179	0.02	0.34	0.53	0.77	1.02	1.76	5.56

PO_4–P (mg L^{-1})

Nutrient Ecoregion	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
CEFU	70	0.00	0.01	0.01	0.01	0.01	0.02	2.07
GPGS	28	0.01	0.01	0.01	0.02	0.04	0.08	0.41
SCCGP	153	0.01	0.01	0.02	0.04	0.09	0.27	6.07
STFPH	130	0.01	0.01	0.02	0.03	0.05	0.10	1.36

TP (mg L^{-1})

Nutrient Ecoregion	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
CEFU	83	0.01	0.01	0.02	0.03	0.04	0.05	1.99
GPGS	32	0.01	0.02	0.02	0.05	0.06	0.67	4.72
SCCGP	168	0.01	0.05	0.07	0.11	0.19	0.44	6.66
STFPH	185	0.01	0.04	0.06	0.09	0.13	0.21	1.36

Cl (mg L^{-1})

Nutrient Ecoregion	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
CEFU	80	1.6	2.4	4.0	5.5	10.0	10.0	246
GPGS	34	30.1	183	301	2710	5980	12800	18300
SCCGP	203	5.0	19.1	39.5	99.0	531	1310	6520
STFPH	202	2.3	6.0	10.0	26.1	76.2	203	1440

chl–a (sestonic, µg L^{-1})

Nutrient Ecoregion	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
CEFU	25	0.10	0.40	0.75	1.41	3.43	7.54	263
GPGS	20	1.00	1.00	1.52	5.00	10.0	27.9	42.7
SCCGP	64	1.00	3.65	6.78	10.0	19.0	36.4	86.8
STFPH	43	0.10	1.72	3.76	7.07	12.6	21.2	45.9

For TP, the percent median concentrations greater were: CEFU (98%), GPGS (69%), SCCGP (76%), and STFPH (89%). For chl–a, it was: CEFU (88%), GPGS (70%), SCCGP (92%), and STFP (93%). The percents that are largely different from 75% likely suggest that these ecoregions and specific parameters have distributions of median concentrations specific to the Red River Basin, and not similar to the ecoregions as a whole. Table 5 shows the number of medians above and below the recommended criteria provided by the USEPA in each nutrient ecoregion (i.e., CEFU, GPGS, SCCGP, and STFPH).

Comparisons of the 25th percentiles of the median concentrations available from this study generally show similar concentrations for some nutrients to USEPA recommended criteria, especially TN data across the ecoregions (Table 6). However, the 25th percentiles of the median TP concentrations specific to data from the Red River Basin (i.e., this study) were similar to USEPA recommended criteria in the ecoregions GPGS (0.023 g L^{-1}) and SCCGP (0.067 mg L^{-1}) but different in the ecoregions CEFU (0.010 mg L^{-1}) and STFPH (0.037 mg L^{-1}). The 25th percentiles in this study from data specific to the CEFU (0.02 mg L^{-1}) and STFPH (0.06 mg L^{-1}) in the Red River Basin were twice and almost 1.5 times greater than the suggested criteria in these nutrient ecoregions. The greatest differences between 25th percentiles occurred with sestonic chl–a concentrations, where the 25th percentiles in this study from the CEFU (0.75 μg L^{-1}) and GPGS (1.52 μg L^{-1}) were less than USEPA recommended values and from the SCCGP (6.78 μg L^{-1}) and STFPH (3.76 μg L^{-1}) were more than two times greater than USEPA recommended values in each ecoregion.

DISCUSSION

We developed a large dataset of median concentrations for select water quality parameters available from sites within the Red River Basin from the time period 1996–2006, and here reported on the statistical distributions of five major water quality constituents of interest. This dataset represents a “general nutrient population” because streams were not classified according to the degree of watershed impacts (i.e. anthropogenically altered versus reference conditions). The USEPA (2000) has suggested that the 25th percentile of the general nutrient population as an option in nutrient criteria development. Therefore, the development of statistical distributions from median nutrient concentrations across site within the target drainage area (i.e., large river basin) is an important first step in criteria development. Alternatively, the USEPA (2000a) has suggested that the 75th

Table 5. Numbers of median concentration above (top number) and below (bottom number) the USEPA recommended criteria for streams and rivers of the larger aggregate nutrient ecoregions included within the Red River Basin (EPA 2000b-e); USEPA recommended criteria for total nitrogen (TN), total phosphorus (TP), and sestonic chlorophyll-a (chl-a) are under the individual nutrient ecoregion names.

Nutrient Ecoregion	TN	TP	Chl-a
Central and Eastern Forested Uplands TN = 0.31 mg L^{-1}, TP = 0.01 mg L^{-1}, chl–a = 1.6 μg L^{-1}	35/43	81/2	11/13
Great Plains Grasses and Shrublands TN = 0.56 mg L^{-1}, TP = 0.023 mg L^{-1}, chl–a = 2.4 μg L^{-1}	14/2	23/10	15/6
South Central Cultivated Great Plains TN = 0.88 mg L^{-1}, TP = 0.067 mg L^{-1}, chl–a = 3.0 μg L^{-1}	94/37	126/41	58/5
Southeastern Temperate Forested Plains and Hills TN = 0.69 mg L^{-1}, TP = 0.036 mg L^{-1}, chl–a = 0.9 μg L^{-1}	101/66	166/19	40/3

Table 6. Comparison of the 25th percentiles of median concentrations for TN, TP, and chl–a across aggregate nutrient ecoregions and level III ecoregions specific to data from the Red River Basin, 1996–2006, and USEPA recommended criteria for the larger aggregate nutrient ecoregions (USEPA 2000a). [The descriptive ecoregion numbers are within parentheses, and ranges of level III ecoregion criteria within aggregate nutrient ecoregions are given as footnotes.]

	25th percentile of general nutrient population					
	TN (mg L^{-1})		TP (mg L^{-1})		Chl-a (µg L^{-1})	
Ecoregion	Our study	EPA	Our study	EPA	Our study	EPA
Central and Eastern Forested Uplands	0.21	0.31	0.02	0.01	0.75	1.61
Ouachita Mountains (36)	0.21		0.02		0.75	
Great Plains Grasses and Shrublands	0.61	0.56	0.021	0.023	1.52	2.4
Southwestern Tablelands (26)	0.61		0.02		1.52	
South Central Cultivated Great Plains	0.86	0.88	0.07	0.067	6.78	3.0
Western High Plains (25)	•		0.047		86.8	
Central Great Plains (27)	0.86		0.07		6.95	
Texas Blackland Prairies (32)	•		0.015		5.98	
Southeastern Temperate Forested Plains and Hills	0.53	0.69	0.06	0.037	3.76	0.93
East Central Texas Plains (33)	0.64		0.05		5.0	
South Central Plains (35)	0.59		0.07		2.7	
Arkansas Valley (37)	0.56		0.07		5.64	
Central Oklahoma/Texas Plains (29)	0.41		0.04		10.0	

Ranges of Level III Ecoregion 25th percentiles: TN: CEFU (0.21 - 0.58), GPGS (0.36 - 0.65), SCCGP (0.84 - 1.07), STFPH (0.07 - 1.00); TP: CEFU (.000563 - 0.01047), GPGS (0.008 - 0.157), SCCGP (0.041 - 0.090), STFPH (0.0225 - 0.1); Chl-a: CEFU (0.25 - 3.26), GPGS (2.00 - 4.44), SCCGP (2.51 - 3.20), STFPH (0.05 - 5.74).

• denotes that median concentrations were not available to estimate the 25th percentile for the Level III Ecoregions

percentile of median nutrient concentrations in streams draining reference or minimally impacted watersheds as an option in criteria development. The thought was that these values (25th percentile from general nutrient population, and 75th percentile from reference population) would be similar per USEPA guidance materials. The statistical distributions presented in this paper provide critical information specific to the nutrient ecoregions to the states within the multi–jurisdictional Red River Basin.

Dodds et al. (1998) first suggested a trophic classification scheme for temperature streams based on the distributions of nutrients and chlorophyll concentrations, and since then studies have focused on the frequency distribution of stream nutrient data across large geographic areas (e.g., Suplee et al. 2007, Mueller and Spahr 2006, Binkley et al. 2004, Herlihy and Sifneos 2008). For example, Rohm et al. (2002) determined frequencies in nutrient patterns across the 14 nutrient ecoregions using data from 928 sites sampled as part of the USEPA National Eutrophication Strategy (NES, Omernick 1977). All median TN concentrations specific to the four nutrient regions in our study were less than the calculated medians reported in Rohm et al. (2002), while two nutrient ecoregions (CEFU and STFPH) had median TP concentrations (from our study) greater than those found using the NES data. Similar to other studies that have compiled frequency distributions and then compared nutrient data to the USEPA recommended criteria (e.g., Mueller and Spahr 2006), we found that our data often exceeded the nutrient and chl–a numeric criteria at about the expected proportion (~75%). However, there were some differences in the distributions of the median concentrations for TP and sestonic chl–a. While we focused exclusively on USGS NWIS and available stage agency data, USEPA collected data from a different variety of sources (USEPA 2000b–e). In addition, our time period of interest was 1996–2006, while water quality data collected by USEPA varied from 1990–2000 for the CEFU and STFPH nutrient ecoregions and from 1990–1998 for the GPGS and STFPH nutrient ecoregions. These variations in data acquisition likely influence some of the differences observed between the calculated 25th percentiles, although there are more similarities than differences in these values determined for the different datasets. Perhaps, the observation that the Red River Basin lies at the geographic edge of the four aggregate ecoregions is the reason for these local variations in the frequency distributions for TP and sestonic chl–a. Wickham et al. (2005) showed that catchment land–cover composition explained more of the variance in stream nutrient concentrations than the defined nutrient ecoregions, suggesting that this landscape feature should help guide criteria development.

Although we have not attempted to classify these selected sites based upon watershed impacts, other studies have evaluated nutrient concentrations and frequency distributions in streams from relatively low–impacted watersheds (e.g., Smith et al. 2003, Binkley et al. 2004, Herlihy and Sifneos 2008). For example, Ice and Binkley (2003) observed that measured nutrient concentrations across 300 streams draining small forested watersheds often exceeded the USEPA recommended criteria; these nutrient distributions from forested streams were likely the product of natural patterns (e.g., plants, geology, and atmospheric deposition) and more temporal variation in nutrient concentrations when compared to larger river systems. In the Red River, the ecoregion CEFU that likely contains the greatest densities of small shaded forested streams had the least percent of median TN concentrations (40%) greater than USEPA recommended criteria, yet had a relatively larger number of medians exceeding the recommended TP criteria (98%). This demonstrates that nutrient patterns within the CEFU and the Red River Basin were influenced by local geology, land use and land cover, where TP concentrations might be naturally elevated compared to the USEPA recommended criteria. Nutrient criteria development for the Red River Basin will benefit from focusing on reference conditions and or general nutrient populations specific to the Red River Basin; this study provides a general nutrient population dataset to progress the development of nutrient criteria using percentile ranks as chosen by the states (i.e., Arkansas, Louisiana, New Mexico, Oklahoma and Texas). This is likely a relatively more robust dataset to facilitate criteria development than a reference dataset due to the potentially limited number of watersheds that have not been influenced by anthropogenic factors (e.g., human activities).

While the application of the frequency distribution of median nutrient concentrations (i.e., 25th percentile of general nutrient population or 75th percentile of reference population) offers an approach for establishing criteria, this should be used as a first step to develop multiple lines of evidence to support nutrient criteria development for streams and rivers. The sparse biological data (i.e., sestonic chl–a) for the Red River Basin might limit the utility of the frequency distributions of chl–a, and it likely limits the ability to determine stressor–response relationships that contribute to a broader approach in nutrient criteria development. Sestonic chl–a has been shown to be positively correlated to dissolved and TP concentrations in streams, further suggesting that sestonic chl–a might be an appropriate criterion in larger rivers compared to small systems (Royer et al. 2008). Other studies (e.g., see Stone et al. 2005, Heatherly et al. 2007, Wang et al. 2007) have shown that biological conditions (or integrity) in streams change along nutrient gradients, further supporting the link between nutrients and potential designated use impairments in streams. Along this line of building evidence to support nutrient criteria development, several recent studies have used change–point analysis (CPA) to identify thresholds in ecological responses across a gradient of nutrient concentrations (see Qian et al. 2003). The final piece of evidence that can be used to assist states in developing nutrient criteria would be a comprehensive literature review, detailing suggested nutrient criteria in refereed literature and other documentation. This study simply provides this first important step in understanding the general nutrient population of streams within the Red River Basin, and how these (watershed specific) frequency distributions compare to other studies nationwide.

Overall, the process of nutrient criteria development must take into account regional and local environmental influences on nutrients while using the USEPA recommended criteria as an objective means to initially compare regional nutrient concentrations. Smith et al. (2003) states "the results of this study indicate that as much as an order of magnitude of variation in natural background concentrations of TN and TP exists within the boundaries of many of the USEPA nutrient ecoregions on a national scale." We assessed some variability in our general nutrient population by statistical tests of ecoregion level III medians within the nutrient ecoregions. For example, the STFPH nutrient ecoregion had sufficient data to statistically compare medians, and median TN, TP, and Chl–a concentrations were not significantly different across the component level III ecoregions ($P=0.15$, 0.63, and 0.09, respectively; ANOVA on Ranks Test). This suggests that nutrient criteria development might need to focus on the larger aggregate ecoregions specific to the Red River Basin, as differences in the distributions of median concentrations in the component Level III ecoregions might not occur within the Red River Basin.

Our compiled datasets provide a valuable line of evidence to assist the states within the transboundary Red River Basin during nutrient criteria development. This initial data compilation is a first step in the overall process and provides states with initial statistical distributions across a general nutrient population for the entire basin, as well as for various geographic classifications. Our results suggested that the states should consider using frequency distributions specific to the Red River Basin, because some distinct differences were noted with the USEPA recommended nutrient criteria; other states have taken similar approaches. For example, Pennsylvania estimated potential nutrient criteria at a regional level because the aggregate nutrient ecoregions (and recommended criteria) "spanned larger geographical areas." Furthermore, Herlihy and Sifneos (2008) investigated a large dataset across the 48 conterminous U.S. states and determined that nutrient ecoregions were too coarse a scale for establishing criteria, because nutrient concentrations varied among level III ecoregions *within* nutrient ecoregions. The states within the Red River Basin should use the frequency distributions of median nutrient and sestonic chl–a concentrations as guidelines to assist in the establishment of nutrient criteria; these distributions also provide estimations of the percent of stream reaches that would exceed defined nutrient criteria, because this study represents the general nutrient population across the Red River Basin. As studies focused on the goal of nutrient criteria development become more common in the published literature, we will gain valuable information to further address national difference in nutrient concentrations across regions defined as ecologically similar.

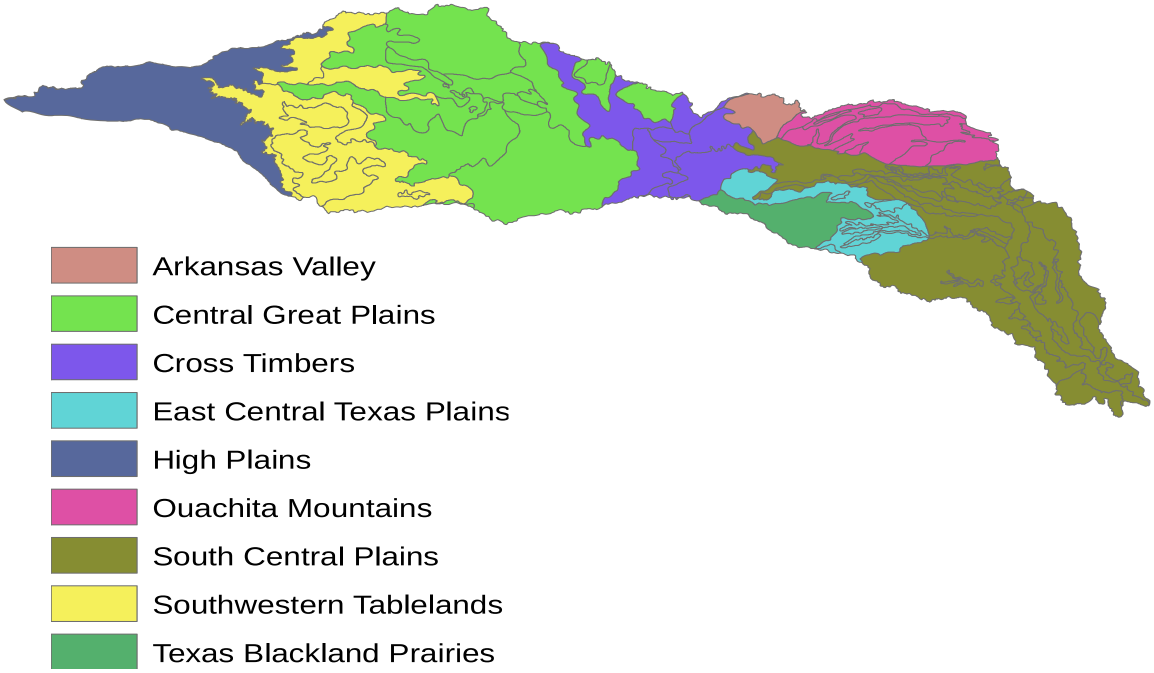
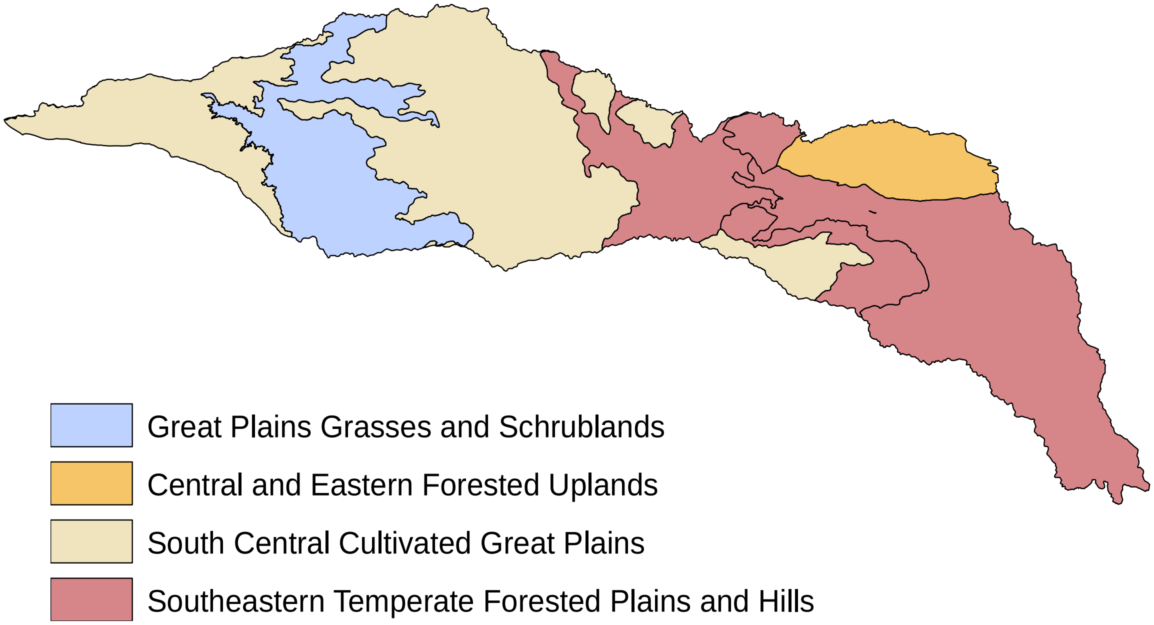


Figure 3. USEPA defined Level III Ecoregions across the multi–state Red River Basin.

Figure 4. USEPA defined Nutrient Ecoregions across the multi–state Red River Basin.



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Appendix 1. Frequency distribution of median concentrations with the Level III Ecoregions across the Red River Basin, 1996–2006.

NO_3–N (mg L^{-1})

Level III Ecoregion	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
Arkansas Valley	9	0.04	0.07	0.08	0.1	0.17	0.38	1.08
Central Great Plains	154	0.02	0.07	0.16	0.45	0.88	1.46	10.0
Cross Timbers	40	0.04	0.05	0.1	0.16	0.33	0.40	1.99
East Central Texas Plains	10	0.05	0.08	0.14	0.20	0.66	2.19	2.95
High Plains	2				.02			
Ouachita Mountains	78	0.01	0.04	0.06	0.09	0.10	0.15	2.01
South Central Plains	121	0.01	0.05	0.08	0.11	0.17	0.40	5.01
Southwestern Tablelands	10	0.02	0.19	0.29	0.36	1.30	3.95	4.75
Texas Blackland Prairies	5	0.06	0.20	0.44	0.97	3.47	8.46	11.8

TN (mg L^{-1})

Level III Ecoregion	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
Arkansas Valley	9	0.40	0.49	0.56	0.78	1.00	1.28	2.38
Central Great Plains	131	0.19	0.56	0.86	1.23	1.67	2.55	8.28
Cross Timbers	38	0.17	0.31	0.41	0.53	1.11	1.42	4.24
East Central Texas Plains	4	0.60	0.61	0.64	0.75	0.84	0.84	0.85
High Plains								
Ouachita Mountains	78	0.03	0.11	0.21	0.29	0.42	0.73	2.60
South Central Plains	117	0.02	0.40	0.59	0.82	1.04	1.79	5.56
Southwestern Tablelands	16	0.53	0.57	0.61	0.77	1.15	1.61	1.95
Texas Blackland Prairies								

PO_4–P (mg L^{-1})

Level III Ecoregion	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
Arkansas Valley	9	0.01	0.01	0.03	0.04	0.06	0.09	0.09
Central Great Plains	147	0.01	0.01	0.02	0.04	0.07	0.24	1.25
Cross Timbers	40	0.01	0.01	0.01	0.02	0.04	0.08	0.65
East Central Texas Plains	11	0.02	0.02	0.03	0.08	0.12	0.54	1.19
High Plains	1				5.74			
Ouachita Mountains	70	0.00	0.01	0.01	0.01	0.01	0.02	2.07
South Central Plains	70	0.01	0.01	0.02	0.03	0.05	0.10	1.36
Southwestern Tablelands	28	0.01	0.01	0.01	0.02	0.04	0.08	0.41
Texas Blackland Prairies	5	0.16	0.17	0.18	0.25	4.19	5.32	6.07

Appendix 1. continued.

TP (mg L^{-1})

Level III Ecoregion	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
Arkansas Valley	9	0.05	0.05	0.07	0.09	0.12	0.13	0.14
Central Great Plains	163	0.01	0.05	0.07	0.11	0.19	0.32	1.48
Cross Timbers	39	0.02	0.03	0.04	0.07	0.16	0.27	0.57
East Central Texas Plains	10	0.03	0.05	0.05	0.09	0.13	0.29	0.90
High Plains	1	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Ouachita Mountains	83	0.01	0.01	0.02	0.03	0.04	0.05	1.99
South Central Plains	127	0.01	0.04	0.07	0.10	0.13	0.20	1.36
Southwestern Tablelands	32	0.01	0.02	0.02	0.05	0.06	0.67	4.72
Texas Blackland Prairies	4	0.13	0.14	0.15	0.50	2.31	4.92	6.66

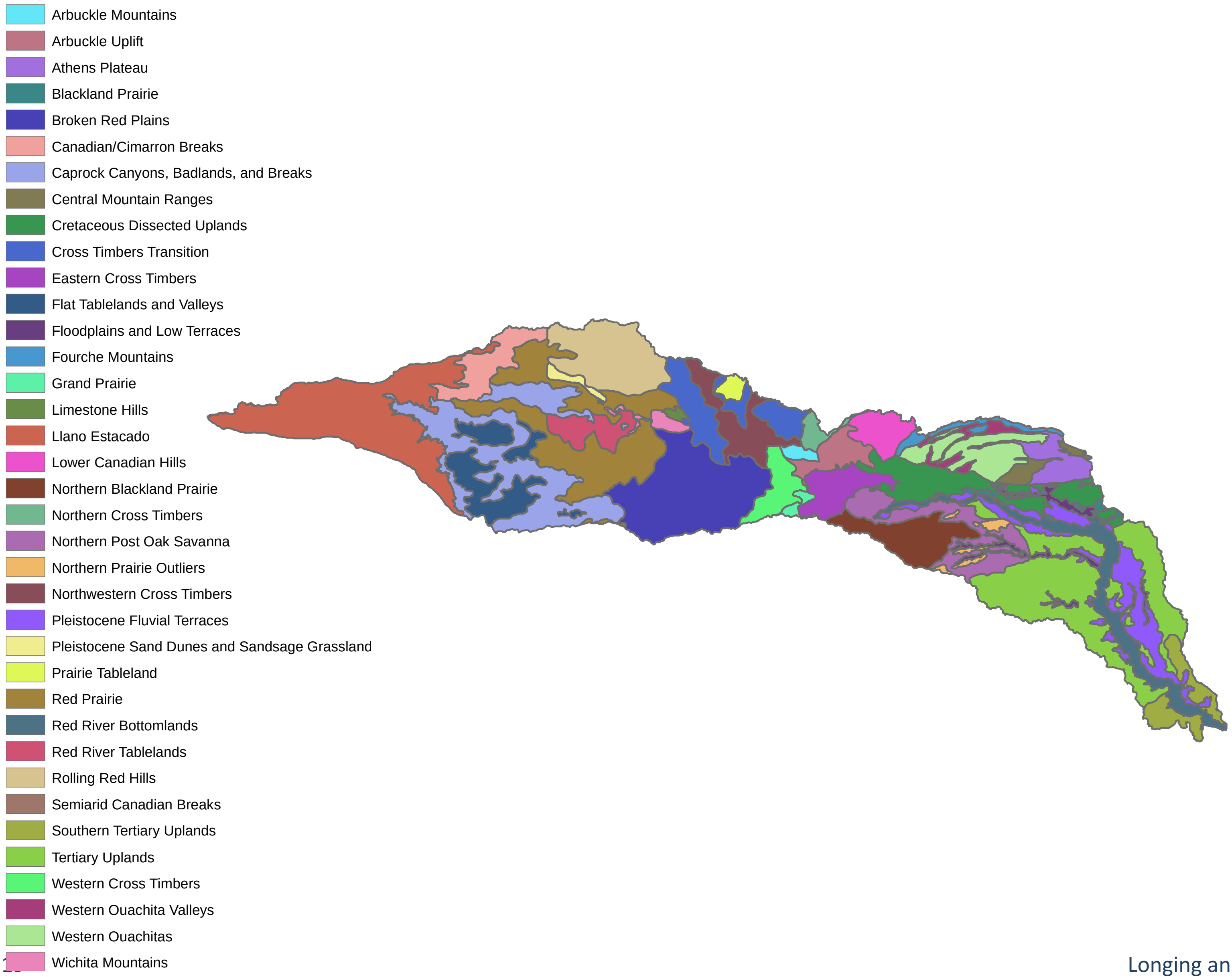
Cl (mg L^{-1})

Level III Ecoregion	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
Arkansas Valley	10	4.1	8.4	11.3	24.0	48.5	87.9	249
Central Great Plains	195	5.0	19.2	39.5	97.9	656	1340	6520
Cross Timbers	52	2.9	5.2	20.3	80.5	235	910	1440
East Central Texas Plains	12	12.2	15.9	24.2	55.3	115	293	330
High Plains	3	130	136	145	160	171	177	182
Ouachita Mountains	80	1.6	2.4	4.0	5.5	10.0	10.0	246
South Central Plains	128	2.3	6.0	10.0	18.5	41.4	104	300
Southwestern Tablelands	34	30.1	183	301	2710	5980	12800	18300
Texas Blackland Prairies	5	15.2	23.1	35.0	42.3	169	217	248

chl–a (sestonic, µg L^{-1})

Level III Ecoregion	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
Arkansas Valley	5	0.10	2.31	5.64	7.07	12.3	12.7	13.0
Central Great Plains	59	1.00	3.50	6.96	10.0	19.3	34.5	55.4
Cross Timbers	7	5.37	5.93	10.0	17.7	25.6	36.6	45.9
East Central Texas Plains	5	3.68	4.21	5.00	5.00	10.0	16.8	21.4
High Plains	1	86.8	86.8	86.8	86.8	86.8	86.8	86.8
Ouachita Mountains	25	0.10	0.40	0.75	1.41	3.43	7.54	263
South Central Plains	26	0.29	1.31	2.70	6.22	10.0	18.2	27.9
Southwestern Tablelands	20	1.00	1.00	1.52	5.00	10.0	27.9	42.7
Texas Blackland Prairies	4	5.00	5.39	5.98	8.15	10.5	11.3	11.9

Appendix 2a. USEPA defined Level IV Ecoregions within the Red River Basin.



Appendix 2b–g. Frequency distribution of median concentrations in the Level IV Ecoregions across the Red River Basin, 1996–2006.

NO_3–N (mg L^{-1})

Level IV Ecoregion	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
Arbuckle Uplift	10	0.08	0.09	0.12	0.19	0.34	0.42	0.63
Athens Plateau	22	0.03	0.05	0.06	0.09	0.12	0.58	2.01
Blackland Prairie	2	0.09	0.091	0.093	0.095	0.098	0.099	0.10
Broken Red Plains	38	0.02	0.04	0.07	0.21	0.65	1.71	10.0
Canadian/Cimarron Breaks	2	0.04	0.05	0.08	0.11	0.14	0.16	0.18
Caprock Canyons, Badlands, and Breaks	18	0.02	0.03	0.04	0.14	0.97	4.70	20.1
Central Mountain Ranges	5	0.10	0.10	0.10	0.11	0.13	0.14	0.15
Cretaceous Dissected Uplands	32	0.01	0.04	0.10	0.12	0.25	0.68	2.58
Cross Timbers Transition	36	0.04	0.12	0.18	0.57	1.07	1.24	2.02
Eastern Cross Timbers	11	0.04	0.05	0.07	0.10	0.31	0.33	0.35
Flat Tablelands and Valleys	5	0.07	0.13	0.24	0.29	0.50	2.24	3.40
Floodplains and Low Terraces	10	0.07	0.09	0.11	0.17	0.27	0.71	3.87
Fourche Mountains	6	0.05	0.06	0.07	0.10	0.13	0.15	0.16
Grand Prairie	2	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Llano Estacado	2	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Lower Canadian Hills	9	0.04	0.07	0.08	0.10	0.17	0.38	1.08
Northern Blackland Prairie	5	0.05	0.20	0.44	0.97	3.47	8.46	11.8
Northern Cross Timbers	2	0.24	0.25	0.27	0.30	0.30	0.33	0.36
Northern Post Oak Savanna	10	0.04	0.08	0.14	0.20	0.66	2.18	2.95
Northwestern Cross Timbers	10	0.04	0.04	0.15	0.16	0.36	0.48	1.01
Pleistocene Fluvial Terraces	21	0.04	0.06	0.08	0.10	0.12	0.41	5.01
Pleistocene Sand Dunes and Sandsage Grassland	5	0.27	0.34	0.45	0.75	1.05	2.27	3.08
Prairie Tableland	3	0.06	0.07	0.08	0.10	0.27	0.38	0.45
Red Prairie	27	0.04	0.08	0.11	0.35	0.90	1.81	3.37
Red River Bottomlands	35	0.05	0.06	0.07	0.11	0.15	0.23	1.55
Red River Tablelands	11	0.11	0.15	0.59	0.99	1.83	2.32	7.38
Rolling Red Hills	32	0.02	0.13	0.25	0.37	0.80	1.08	1.83
Southern Tertiary Uplands	4	0.02	0.02	0.02	0.03	0.07	0.10	0.12
Tertiary Uplands	17	0.01	0.03	0.07	0.09	0.13	0.19	1.18
Western Cross Timbers	5	0.04	0.04	0.04	0.10	0.10	1.23	1.99
Western Ouachita Valleys	18	0.04	0.05	0.06	0.08	0.10	0.10	0.18
Western Ouachitas	27	0.01	0.01	0.03	0.07	0.10	0.10	0.21
Wichita Mountains	2	0.04	0.08	0.14	0.23	0.33	0.39	0.43

Appendix 2c.

TN (mg L^{-1})

Level IV Ecoregion	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
Arbuckle Uplift	10	0.17	0.24	0.36	0.61	1.17	1.41	1.46
Athens Plateau	22	0.07	0.17	0.22	0.31	0.45	1.10	2.60
Blackland Prairie	2	0.44	0.45	0.48	0.51	0.55	0.57	0.58
Broken Red Plains	22	0.25	0.57	0.95	1.49	1.84	3.18	3.51
Canadian/Cimarron Breaks								
Caprock Canyons, Badlands, and Breaks	15	0.53	0.56	0.61	0.81	1.19	1.68	1.95
Central Mountain Ranges	5	0.17	0.26	0.39	0.40	0.41	0.48	0.53
Cretaceous Dissected Uplands	32	0.02	0.24	0.49	0.67	0.91	1.82	4.64
Cross Timbers Transition	36	0.37	0.52	0.87	1.27	1.65	1.94	3.16
Eastern Cross Timbers	9	0.27	0.29	0.42	0.53	1.14	1.36	1.79
Flat Tablelands and Valleys	1	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Floodplains and Low Terraces	10	0.52	0.56	0.60	0.86	1.13	1.95	4.60
Fourche Mountains	6	0.15	0.20	0.27	0.43	0.65	0.82	0.95
Grand Prairie	2	0.48	0.48	0.49	0.50	0.51	0.52	0.53
Llano Estacado								
Lower Canadian Hills	9	0.40	0.49	0.56	0.78	1.00	1.28	2.38
Northern Blackland Prairie								
Northern Cross Timbers	2	0.47	0.48	0.49	0.50	0.52	0.53	0.54
Northern Post Oak Savanna	4	0.60	0.61	0.64	0.75	0.84	0.84	0.85
Northwestern Cross Timbers	10	0.32	0.39	0.50	0.82	1.21	1.38	1.60
Pleistocene Fluvial Terraces	20	0.23	0.39	0.52	0.74	1.05	1.86	5.56
Pleistocene Sand Dunes and Sandsage Grassland	5	0.61	0.86	1.23	1.65	2.10	3.02	3.63
Prairie Tableland	3	0.77	0.81	0.87	0.97	1.07	1.13	1.18
Red Prairie	20	0.26	0.61	0.74	1.12	1.58	1.93	2.55
Red River Bottomlands	34	0.05	0.69	0.78	0.89	1.00	1.18	3.29
Red River Tablelands	11	0.82	1.09	1.20	1.95	3.05	3.67	8.28
Rolling Red Hills	32	0.19	0.58	0.70	1.08	1.49	1.79	2.55
Southern Tertiary Uplands	4	0.54	0.61	0.72	0.80	0.86	0.92	0.97
Tertiary Uplands	15	0.50	0.59	0.78	1.05	1.77	1.83	2.51
Western Cross Timbers	5	0.36	0.37	0.40	0.53	0.55	2.76	4.24
Western Ouachita Valleys	18	0.19	0.20	0.26	0.31	0.44	0.62	0.90
Western Ouachitas	27	0.03	0.07	0.11	0.23	0.34	0.41	0.53
Wichita Mountains	2	0.26	0.32	0.42	0.58	0.74	0.84	0.90

Appendix 2d.

PO_4–P (mg L^{-1})

Level IV Ecoregion	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
Arbuckle Uplift	10	0.01	0.01	0.01	0.02	0.04	0.08	0.41
Athens Plateau	22	0.00	0.01	0.01	0.01	0.01	0.06	2.07
Blackland Prairie	2	0.01	0.01	0.02	0.02	0.02	0.02	0.02
Broken Red Plains	38	0.01	0.02	0.04	0.09	0.27	0.69	1.22
Canadian/Cimarron Breaks	2	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Caprock Canyons, Badlands, and Breaks	22	0.01	0.01	0.01	0.02	0.04	0.12	0.41
Central Mountain Ranges	4	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cretaceous Dissected Uplands	29	0.01	0.01	0.01	0.03	0.05	0.18	1.29
Cross Timbers Transition	29	0.01	0.01	0.02	0.05	0.06	0.10	0.43
Eastern Cross Timbers	11	0.01	0.01	0.01	0.02	0.04	0.40	0.65
Flat Tablelands and Valleys	4	0.01	0.02	0.03	0.04	0.05	0.06	0.06
Floodplains and Low Terraces	6	0.01	0.02	0.02	0.03	0.03	0.05	0.07
Fourche Mountains	6	0.01	0.01	0.01	0.02	0.02	0.03	0.04
Grand Prairie	2	0.01	0.01	0.02	0.02	0.02	0.02	0.03
Llano Estacado	1	5.74	5.74	5.74	5.74	5.74	5.74	5.74
Lower Canadian Hills	9	0.01	0.01	0.03	0.04	0.06	0.09	0.09
Northern Blackland Prairie	5	0.16	0.17	0.18	0.25	4.19	5.32	6.07
Northern Cross Timbers	2	0.01	0.01	0.02	0.02	0.02	0.02	0.02
Northern Post Oak Savanna	11	0.02	0.02	0.03	0.08	0.12	0.54	1.19
Northwestern Cross Timbers	10	0.01	0.01	0.02	0.03	0.05	0.08	0.08
Pleistocene Fluvial Terraces	11	0.01	0.01	0.01	0.04	0.08	0.15	0.48
Pleistocene Sand Dunes and Sandsage Grassland	5	0.01	0.01	0.01	0.02	0.02	0.03	0.03
Prairie Tableland	3	0.02	0.02	0.02	0.02	0.04	0.05	0.06
Red Prairie	27	0.01	0.01	0.02	0.03	0.07	0.12	0.16
Red River Bottomlands	15	0.01	0.02	0.02	0.03	0.04	0.07	1.36
Red River Tablelands	11	0.01	0.01	0.02	0.03	0.04	0.06	1.25
Rolling Red Hills	32	0.01	0.01	0.01	0.03	0.04	0.05	0.10
Southern Tertiary Uplands								
Tertiary Uplands	7	0.02	0.03	0.03	0.04	0.05	0.06	0.07
Western Cross Timbers	5	0.01	0.01	0.02	0.04	0.04	0.04	0.05
Western Ouachita Valleys	18	0.01	0.01	0.01	0.01	0.01	0.01	0.02
Western Ouachitas	20	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Wichita Mountains	2	0.01	0.01	0.02	0.03	0.04	0.04	0.05

Appendix 2e.

TP (mg L^{-1})

Level IV Ecoregion	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
Arbuckle Uplift	9	0.02	0.04	0.05	0.06	0.19	0.30	0.57
Athens Plateau	22	0.01	0.02	0.02	0.03	0.04	0.10	1.99
Blackland Prairie	2	0.04	0.04	0.05	0.05	0.06	0.06	0.06
Broken Red Plains	46	0.01	0.07	0.12	0.22	0.46	0.86	1.44
Canadian/Cimarron Breaks	2	0.07	0.07	0.08	0.08	0.09	0.09	0.09
Caprock Canyons, Badlands, and Breaks	26	0.01	0.02	0.02	0.04	0.05	0.51	4.72
Central Mountain Ranges	5	0.01	0.01	0.01	0.02	0.02	0.03	0.04
Cretaceous Dissected Uplands	32	0.01	0.03	0.04	0.07	0.12	0.26	1.36
Cross Timbers Transition	36	0.02	0.05	0.07	0.11	0.15	0.20	0.75
Eastern Cross Timbers	11	0.02	0.03	0.04	0.09	0.19	0.40	0.50
Flat Tablelands and Valleys	4	0.02	0.03	0.04	0.05	0.22	0.53	0.73
Floodplains and Low Terraces	10	0.04	0.05	0.06	0.10	0.13	0.19	0.38
Fourche Mountains	6	0.02	0.03	0.04	0.05	0.07	0.09	0.11
Grand Prairie	2	0.06	0.06	0.06	0.07	0.08	0.08	0.09
Llano Estacado	1	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Lower Canadian Hills	9	0.05	0.05	0.07	0.09	0.12	0.13	0.14
Northern Blackland Prairie	4	0.13	0.14	0.15	0.50	2.31	4.92	6.66
Northern Cross Timbers	2	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Northern Post Oak Savanna	10	0.03	0.05	0.05	0.09	0.13	0.29	0.90
Northwestern Cross Timbers	10	0.03	0.04	0.05	0.09	0.15	0.20	0.21
Pleistocene Fluvial Terraces	23	0.01	0.04	0.08	0.09	0.14	0.20	0.57
Pleistocene Sand Dunes and Sandsage Grassland	5	0.05	0.05	0.06	0.07	0.07	0.08	0.09
Prairie Tableland	3	0.06	0.07	0.08	0.10	0.15	0.18	0.20
Red Prairie	29	0.01	0.03	0.05	0.08	0.14	0.21	0.25
Red River Bottomlands	39	0.05	0.08	0.10	0.11	0.13	0.19	1.30
Red River Tablelands	11	0.03	0.05	0.07	0.10	0.16	0.29	1.48
Rolling Red Hills	31	0.04	0.05	0.06	0.08	0.11	0.13	0.20
Southern Tertiary Uplands	4	0.05	0.05	0.05	0.06	0.07	0.07	0.07
Tertiary Uplands	17	0.07	0.07	0.08	0.10	0.14	0.21	0.25
Western Cross Timbers	5	0.03	0.04	0.06	0.08	0.12	0.32	0.45
Western Ouachita Valleys	19	0.01	0.01	0.02	0.03	0.04	0.05	0.08
Western Ouachitas	31	0.01	0.01	0.02	0.02	0.03	0.04	0.04
Wichita Mountains	2	0.03	0.03	0.04	0.05	0.07	0.07	0.08

Appendix 2f.

Cl (mg L^{-1})

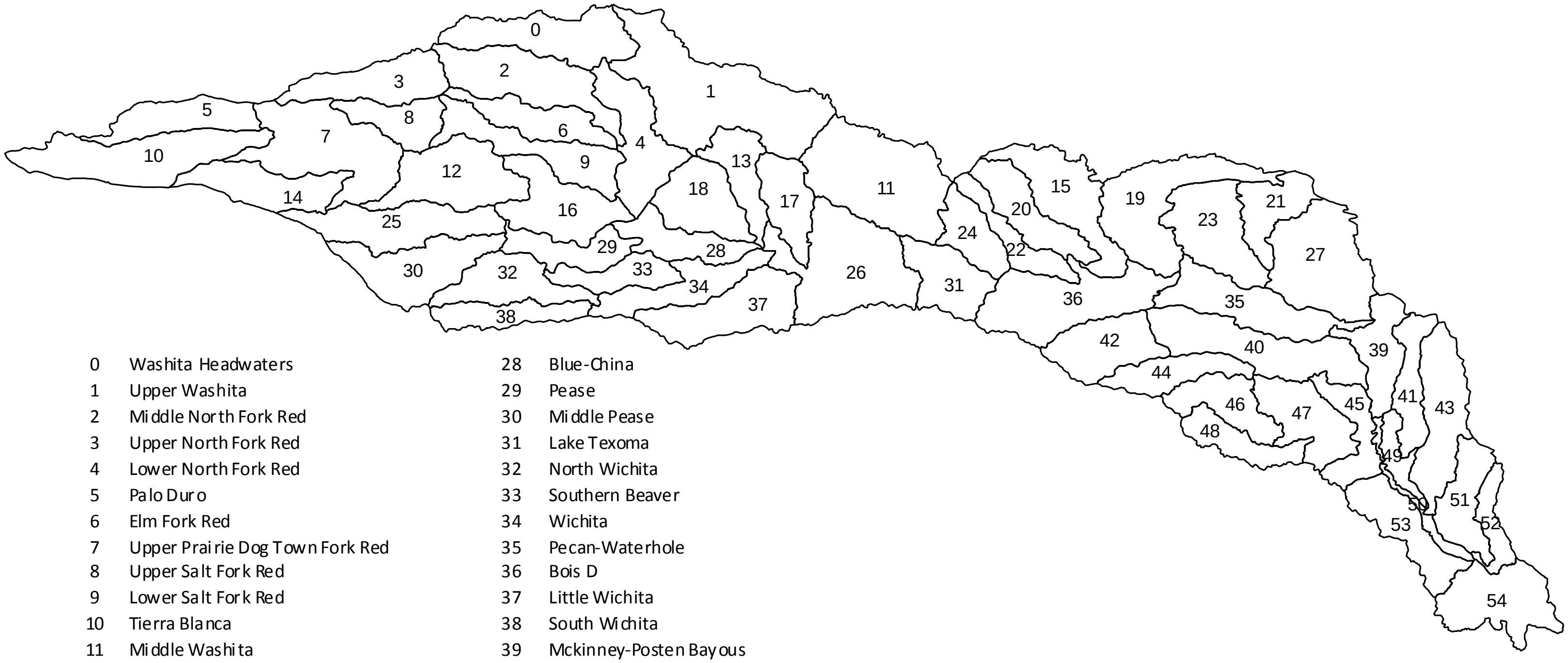
Level IV Ecoregion	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
Arbuckle Uplift	10	2.9	3.1	4.6	12.6	58.4	76.9	96.9
Athens Plateau	22	1.6	2.2	2.6	4.0	5.8	10.0	246
Blackland Prairie	2	10.0	10.3	10.8	11.5	12.3	12.7	13.0
Broken Red Plains	49	5.0	26.9	74.9	662	1120	1380	1710
Canadian/Cimarron Breaks	2	30.1	41.7	59.1	88.1	117	134	146
Caprock Canyons, Badlands, and Breaks	28	62.5	273	326	2710	5280	12700	18300
Central Mountain Ranges	5	7.0	8.2	10.0	10.0	10.0	10.0	10.0
Cretaceous Dissected Uplands	32	2.3	6.0	10.0	13.6	30.8	41.1	170
Cross Timbers Transition	38	7.0	11.7	14.9	31.5	73.2	158	292
Eastern Cross Timbers	12	5.0	5.5	11.8	52.8	753	998	1120
Flat Tablelands and Valleys	4	280	2030	4670	8560	12000	13800	15000
Floodplains and Low Terraces	10	5.8	6.2	7.9	13.6	20.5	26.6	38.5
Fourche Mountains	4	6.0	7.2	9.0	11.9	14.7	16.3	17.4
Grand Prairie	2	21.9	23.7	26.3	30.7	35.0	37.7	39.4
Llano Estacado	3	130	136	145	160	171	177	182
Lower Canadian Hills	10	4.1	8.4	11.3	24.0	48.5	87.9	249
Northern Blackland Prairie	5	15.2	23.1	35.0	42.3	169	217	248
Northern Cross Timbers	2	26.0	27.0	28.5	31.0	33.4	34.9	35.9
Northern Post Oak Savanna	12	12.2	15.9	24.2	55.3	115	293	330
Northwestern Cross Timbers	17	13.1	39.3	84.5	151	256	654	1440
Pleistocene Fluvial Terraces	23	5.2	6.0	7.7	13.0	24.2	43.0	195
Pleistocene Sand Dunes and Sandsage Grassland	16	10.0	36.5	72.7	167	464	604	1180
Prairie Tableland	3	15.1	30.2	52.9	90.7	94.3	96.5	97.9
Red Prairie	33	29.9	51.7	116	472	2250	4720	6520
Red River Bottomlands	40	5.0	10.0	16.3	45.4	114	195	300
Red River Tablelands	11	99.0	139	398	752	914	1990	2080
Rolling Red Hills	43	23.2	27.3	33.5	48.1	71.7	142	401
Southern Tertiary Uplands	4	5.0	5.1	5.3	5.6	7.1	9.3	10.8
Tertiary Uplands	17	5.7	6.3	9.3	27.1	41.2	72.6	89.5
Western Cross Timbers	9	5.0	46.0	62.2	129	576	694	982
Western Ouachita Valleys	18	1.8	2.7	4.3	5.4	7.7	10.0	10.4
Western Ouachitas	31	2.1	3.1	4.7	5.5	10.0	10.0	12.6
Wichita Mountains	2	23.4	68.1	135	247	358	425	470

Appendix 2g.

chl–a (sestonic, µg L^{-1})

Level IV Ecoregion	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
Arbuckle Uplift	2	13.7	14.1	14.7	15.7	16.7	17.3	17.7
Athens Plateau	3	0.91	1.12	1.43	1.94	67.3	106	133
Blackland Prairie	1	5.42	5.42	5.42	5.42	5.42	5.42	5.42
Broken Red Plains	24	1.00	5.97	9.83	11.6	21.9	30.4	55.4
Canadian/Cimarron Breaks	2	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Caprock Canyons, Badlands, and Breaks	15	1.00	1.00	1.24	5.77	10.0	28.0	42.7
Central Mountain Ranges	4	0.32	0.52	0.82	1.53	67.3	185	263
Cretaceous Dissected Uplands	9	0.29	0.35	2.11	3.15	7.02	8.28	8.50
Cross Timbers Transition	2	19.9	20.3	21.0	22.2	23.3	24.0	24.5
Eastern Cross Timbers	2	5.37	5.46	5.60	5.84	6.07	6.21	6.30
Flat Tablelands and Valleys	3	5.00	5.00	5.00	5.00	15.9	22.4	26.8
Floodplains and Low Terraces	2	2.86	2.96	3.10	3.35	3.59	3.74	3.84
Fourche Mountains	4	0.60	0.72	0.91	2.22	3.57	3.83	4.01
Grand Prairie								
Llano Estacado	1	86.8	86.8	86.8	86.8	86.8	86.8	86.8
Lower Canadian Hills	5	0.10	2.31	5.64	7.07	12.3	12.7	13.0
Northern Blackland Prairie	4	5.00	5.39	5.98	8.15	10.5	11.3	11.9
Northern Cross Timbers								
Northern Post Oak Savanna	5	3.68	4.21	5.00	5.00	10.0	16.8	21.4
Northwestern Cross Timbers	2	20.9	21.9	23.3	25.6	28.0	29.4	30.4
Pleistocene Fluvial Terraces	4	1.00	1.19	1.47	2.13	7.29	15.7	21.3
Pleistocene Sand Dunes and Sandsage Grassland	1	7.40	7.40	7.40	7.40	7.40	7.40	7.40
Prairie Tableland								
Red Prairie	16	1.96	3.19	5.29	10.0	19.0	41.6	45.4
Red River Bottomlands	9	4.70	8.94	10.0	10.6	17.0	21.1	27.9
Red River Tablelands	3	17.9	20.3	23.9	29.9	33.7	36.0	37.5
Rolling Red Hills	13	2.69	2.97	3.38	7.56	9.83	12.4	14.1
Southern Tertiary Uplands								
Tertiary Uplands	1	8.30	8.30	8.30	8.30	8.30	8.30	8.30
Western Cross Timbers	1	45.9	45.9	45.9	45.9	45.9	45.9	45.9
Western Ouachita Valleys	4	0.90	1.65	2.76	3.80	4.49	4.98	5.30
Western Ouachitas	10	0.10	0.20	0.54	0.78	1.73	2.70	9.04
Wichita Mountains								

Appendix 3a. Hydrologic Unit Code (HUC) 8 watersheds within the Red River Basin.



0	Washita Headwaters	28	Blue-China
1	Upper Washita	29	Pease
2	Middle North Fork Red	30	Middle Pease
3	Upper North Fork Red	31	Lake Texoma
4	Lower North Fork Red	32	North Wichita
5	Palo Duro	33	Southern Beaver
6	Elm Fork Red	34	Wichita
7	Upper Prairie Dog Town Fork Red	35	Pecan-Waterhole
8	Upper Salt Fork Red	36	Bois D
9	Lower Salt Fork Red	37	Little Wichita
10	Tierra Blanca	38	South Wichita
11	Middle Washita	39	Mckinney-Posten Bayous
12	Lower Prairie Dog Town Fork Red	40	Lower Sulphur
13	Cache	41	Bodcau Bayou
14	Tule	42	Sulphur Headwaters
15	Muddy Boggy	43	Loggy Bayou
16	Groesbeck-Sandy	44	White Oak Bayou
17	Northern Beaver	45	Cross Bayou
18	West Cache	46	Lake O
19	Kiamichi	47	Caddo Lake
20	Clear Boggy	48	Little Cypress
21	Mountain Fork	49	Red Chute
22	Blue	50	Middle Red-Coushatta
23	Upper Little	51	Black Lake Bayou
24	Lower Washita	52	Saline Bayou
25	North Pease	53	Bayou Pierre
26	Farmers-Mud	54	Lower Red-Lake Iatt
27	Lower Little		

Appendix 3b–g. Frequency distribution of median concentrations for all HUC8 watersheds within the larger Red River Basin, 1996–2006.

NO_3–N (mg L^{-1})

HUC8 Watershed	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
Bayou Pierre	7	0.04	0.09	0.13	0.14	0.27	0.40	0.41
Black Lake Bayou	8	0.02	0.06	0.07	0.09	0.11	0.14	0.20
Blue	11	0.04	0.04	0.05	0.10	0.18	0.26	0.37
Blue–China	3	0.14	0.16	0.18	0.23	0.24	0.24	0.25
Bodcau Bayou	2	0.06	0.061	0.063	0.065	0.065	0.068	0.07
Bois D	20	0.04	0.05	0.12	0.21	1.01	3.00	11.8
Cache	5	0.04	0.07	0.13	0.55	2.14	2.15	2.16
Clear Boggy	11	0.04	0.04	0.07	0.10	0.10	0.10	0.17
Cross Bayou	7	0.07	0.07	0.08	0.11	0.15	0.73	1.55
Elm Fork Red	10	0.04	0.09	0.14	0.25	0.79	1.06	1.45
Farmers–Mud	18	0.04	0.05	0.07	0.17	0.49	0.70	1.99
Groesbeck–Sandy	6	0.65	0.82	1.09	1.51	2.12	2.83	3.37
Kiamichi	28	0.04	0.05	0.06	0.09	0.10	0.10	0.18
Lake Texoma	3	0.05	0.06	0.07	0.10	0.21	0.28	0.33
Little Wichita	3	0.17	0.17	0.18	0.18	0.24	0.27	0.30
Loggy Bayou	10	0.01	0.06	0.08	0.10	0.11	0.17	0.36
Lower Little	16	0.03	0.08	0.14	0.24	0.83	2.30	3.87
Lower North Fork Red	13	0.10	0.11	0.35	0.43	0.52	1.59	7.39
Lower Prairie Dog Town Fork Red	4	0.07	0.12	0.19	0.26	1.07	2.46	3.40
Lower Red–Lake Iatt	12	0.02	0.02	0.05	0.08	0.15	0.20	0.24
Lower Salt Fork Red	7	0.22	0.55	0.97	1.38	1.40	1.78	2.32
Lower Sulphur	2	0.10	0.59	1.33	2.55	3.78	4.51	5.01
Lower Washita	7	0.08	0.09	0.10	0.14	0.23	0.35	0.40
Mckinney–Posten Bayous	4	0.05	0.08	0.13	0.17	0.23	0.32	0.38
Middle North Fork Red	13	0.04	0.06	0.10	0.27	0.45	0.98	3.08
Middle Pease	2	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Middle Red–Coushatta	3	0.06	0.07	0.08	0.11	0.14	0.15	0.17
Middle Washita	21	0.04	0.07	0.13	0.24	0.46	0.59	1.01
Mountain Fork	23	0.01	0.05	0.05	0.08	0.11	0.16	0.41
Muddy Boggy	14	0.06	0.08	0.10	0.11	0.15	0.35	1.08
North Pease	1	0.08	0.08	0.08	0.08	0.08	0.08	0.08
North Wichita	1	0.21	0.21	0.21	0.21	0.21	0.21	0.21
Northern Beaver	11	0.16	0.50	0.60	0.88	1.24	1.39	2.91
Pease	4	0.04	0.05	0.08	0.61	1.38	1.82	2.12
Pecan–Waterhole	8	0.03	0.04	0.05	0.07	0.10	0.10	0.10
Red Chute	5	0.05	0.06	0.08	0.10	0.12	0.12	0.13
Saline Bayou	5	0.06	0.06	0.07	0.12	0.16	0.77	1.18
South Wichita	1	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Southern Beaver	3	0.14	0.15	0.17	0.20	0.23	0.25	0.26
Tierra Blanca	1	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Upper Little	31	0.01	0.01	0.04	0.10	0.11	0.21	1.42
Upper North Fork Red	1	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Upper Prairie Dog Town Fork	6	0.02	0.05	0.18	0.60	9.43	16.22	20.1
Upper Salt Fork Red	1	2.24	2.24	2.24	2.24	2.24	2.24	2.24
Upper Washita	44	0.04	0.13	0.18	0.52	1.01	1.12	2.02
Washita Headwaters	10	0.02	0.08	0.16	0.30	0.36	0.38	0.54
West Cache	7	0.04	0.04	0.05	0.11	0.32	0.58	0.76
Wichita	12	0.02	0.04	0.04	0.07	0.59	1.44	10.0

Appendix 3c.

TN (mg L^{-1})

HUC8 Watershed	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
Bayou Pierre	7	0.95	0.96	1.00	1.05	1.21	1.59	2.11
Black Lake Bayou	8	0.50	0.56	0.65	0.72	0.78	1.12	1.81
Blue	11	0.18	0.22	0.37	0.46	0.61	1.02	4.64
Blue–China	3	1.31	1.33	1.36	1.40	1.49	1.54	1.57
Bodcau Bayou	2	0.98	0.99	1.00	1.03	1.05	1.06	1.07
Bois D	8	0.05	0.36	0.57	0.72	0.84	1.14	1.83
Cache	5	0.26	0.36	0.50	1.04	3.00	3.12	3.20
Clear Boggy	11	0.36	0.40	0.47	0.55	0.61	0.62	0.70
Cross Bayou	7	0.68	0.70	0.73	0.78	0.93	1.90	3.29
Elm Fork Red	10	0.60	0.67	0.94	1.15	1.27	1.92	2.55
Farmers–Mud	17	0.36	0.51	0.55	1.43	1.79	2.84	4.24
Groesbeck–Sandy	4	1.88	1.92	1.98	2.22	2.72	3.29	3.67
Kiamichi	28	0.15	0.19	0.24	0.33	0.46	0.62	0.90
Lake Texoma	2	0.30	0.31	0.32	0.35	0.37	0.39	0.40
Little Wichita								
Loggy Bayou	10	0.82	0.83	0.89	1.55	1.76	1.79	1.84
Lower Little	16	0.22	0.35	0.55	0.88	1.52	3.03	4.60
Lower North Fork Red	13	0.71	0.82	0.90	1.11	1.25	1.97	8.28
Lower Prairie Dog Town Fork Red	1	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Lower Red–Lake Iatt	12	0.54	0.70	0.78	0.89	0.98	1.02	1.16
Lower Salt Fork Red	7	0.81	1.06	1.59	1.95	2.40	3.01	3.25
Lower Sulphur	2	1.18	1.62	2.28	3.37	4.47	5.12	5.56
Lower Washita	7	0.25	0.26	0.33	0.42	0.62	0.89	1.14
Mckinney–Posten Bayous	4	1.01	1.02	1.04	1.07	1.21	1.42	1.57
Middle North Fork Red	11	0.19	0.26	0.45	0.75	1.44	2.10	3.63
Middle Pease								
Middle Red–Coushatta	3	0.84	0.85	0.87	0.91	0.95	0.98	1.00
Middle Washita	21	0.17	0.37	0.47	0.79	1.22	1.40	1.60
Mountain Fork	23	0.07	0.11	0.18	0.26	0.39	0.45	1.52
Muddy Boggy	14	0.21	0.32	0.55	0.76	0.92	1.01	2.38
North Pease								
North Wichita	3	0.61	0.63	0.67	0.73	0.83	0.90	0.94
Northern Beaver	11	0.53	0.86	1.17	1.62	1.88	3.16	3.51
Pease	6	0.47	0.61	0.75	0.82	0.97	1.07	1.13
Pecan–Waterhole								
Red Chute	5	0.79	0.81	0.84	0.88	0.90	1.01	1.08
Saline Bayou	5	0.29	0.41	0.59	0.72	0.82	1.83	2.51
South Wichita	3	0.55	0.56	0.57	0.58	0.63	0.66	0.68
Southern Beaver								
Tierra Blanca								
Upper Little	31	0.02	0.06	0.17	0.37	0.41	0.63	1.88
Upper North Fork Red								
Upper Prairie Dog Town Fork								
Upper Salt Fork Red								
Upper Washita	44	0.50	0.64	0.87	1.35	1.65	1.81	2.68
Washita Headwaters	10	0.56	0.57	0.72	0.90	1.28	1.33	1.34
West Cache	7	0.25	0.35	0.52	0.87	1.20	1.57	1.66
Wichita	2	0.53	0.59	0.67	0.82	0.96	1.04	1.10

Appendix 3d.

PO_4–P (mg L^{-1})

HUC8 Watershed	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
Bayou Pierre								
Black Lake Bayou								
Blue	11	0.01	0.01	0.01	0.02	0.03	0.04	0.24
Blue–China	3	0.02	0.02	0.02	0.03	0.09	0.13	0.16
Bodcau Bayou	1	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Bois D	21	0.02	0.02	0.03	0.09	0.25	1.19	6.07
Cache	5	0.01	0.01	0.01	0.03	0.73	0.90	1.02
Clear Boggy	11	0.01	0.01	0.03	0.04	0.06	0.09	0.09
Cross Bayou								
Elm Fork Red	10	0.01	0.01	0.01	0.01	0.02	0.03	0.10
Farmers–Mud	18	0.01	0.02	0.02	0.04	0.06	0.11	0.27
Groesbeck–Sandy	6	0.01	0.01	0.01	0.02	0.03	0.04	0.04
Kiamichi	28	0.01	0.01	0.01	0.01	0.01	0.02	0.02
Lake Texoma	3	0.01	0.01	0.01	0.01	0.33	0.52	0.65
Little Wichita	3	0.23	0.23	0.24	0.25	0.28	0.29	0.31
Loggy Bayou	7	0.02	0.03	0.03	0.04	0.05	0.05	0.06
Lower Little	16	0.01	0.01	0.01	0.03	0.12	1.20	2.07
Lower North Fork Red	13	0.01	0.01	0.03	0.04	0.05	0.14	1.25
Lower Prairie Dog Town Fork Red	3	0.01	0.02	0.03	0.04	0.04	0.04	0.05
Lower Red–Lake Iatt								
Lower Salt Fork Red	7	0.01	0.01	0.01	0.02	0.03	0.04	0.06
Lower Sulphur	2	0.04	0.04	0.05	0.06	0.07	0.08	0.09
Lower Washita	7	0.01	0.01	0.01	0.02	0.03	0.18	0.40
Mckinney–Posten Bayous	4	0.02	0.03	0.03	0.10	0.46	1.00	1.36
Middle North Fork Red	13	0.01	0.01	0.02	0.02	0.02	0.04	0.10
Middle Pease								
Middle Red–Coushatta								
Middle Washita	21	0.01	0.01	0.01	0.03	0.05	0.08	0.41
Mountain Fork	22	0.00	0.01	0.01	0.01	0.01	0.01	0.06
Muddy Boggy	14	0.01	0.01	0.01	0.02	0.04	0.04	0.05
North Pease								
North Wichita	4	0.02	0.02	0.02	0.02	0.03	0.03	0.04
Northern Beaver	6	0.03	0.03	0.05	0.20	0.43	0.57	0.69
Pease	4	0.04	0.05	0.07	0.09	0.11	0.14	0.16
Pecan–Waterhole	13	0.01	0.01	0.02	0.04	0.05	0.07	0.15
Red Chute								
Saline Bayou								
South Wichita	4	0.01	0.01	0.02	0.02	0.02	0.02	0.02
Southern Beaver	3	0.04	0.05	0.06	0.09	0.14	0.16	0.18
Tierra Blanca								
Upper Little	20	0.01	0.01	0.01	0.01	0.01	0.01	0.07
Upper North Fork Red								
Upper Prairie Dog Town Fork	4	0.06	0.08	0.11	0.22	0.33	0.38	0.41
Upper Salt Fork Red	1	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Upper Washita	42	0.01	0.02	0.02	0.04	0.06	0.08	0.43
Washita Headwaters	10	0.01	0.01	0.01	0.02	0.03	0.03	0.04
West Cache	7	0.01	0.01	0.02	0.07	0.09	0.11	0.13
Wichita	12	0.02	0.02	0.04	0.04	0.36	0.70	1.22

Appendix 3e.

TP (mg L^{-1})

HUC8 Watershed	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
Bayou Pierre	7	0.12	0.13	0.14	0.17	0.18	0.19	0.20
Black Lake Bayou	8	0.07	0.07	0.08	0.08	0.10	0.13	0.14
Blue	11	0.02	0.02	0.04	0.05	0.07	0.09	0.34
Blue–China	4	0.10	0.11	0.12	0.14	0.17	0.19	0.20
Bodcau Bayou	2	0.10	0.10	0.11	0.12	0.13	0.14	0.14
Bois D	18	0.03	0.05	0.07	0.12	0.21	0.87	6.66
Cache	5	0.02	0.02	0.03	0.07	0.85	1.03	1.15
Clear Boggy	11	0.03	0.03	0.06	0.10	0.10	0.12	0.14
Cross Bayou	7	0.08	0.08	0.09	0.10	0.13	0.23	0.36
Elm Fork Red	10	0.02	0.02	0.02	0.04	0.06	0.08	0.19
Farmers–Mud	18	0.06	0.07	0.09	0.17	0.28	0.44	0.57
Groesbeck–Sandy	6	0.05	0.05	0.05	0.06	0.07	0.09	0.11
Kiamichi	28	0.01	0.02	0.02	0.03	0.04	0.06	0.08
Lake Texoma	3	0.03	0.03	0.03	0.03	0.22	0.33	0.40
Little Wichita	5	0.17	0.17	0.18	0.27	0.28	0.41	0.50
Loggy Bayou	11	0.07	0.07	0.09	0.11	0.19	0.23	0.38
Lower Little	16	0.02	0.03	0.04	0.06	0.22	1.23	1.99
Lower North Fork Red	13	0.02	0.05	0.08	0.10	0.13	0.20	1.48
Lower Prairie Dog Town Fork Red	3	0.02	0.02	0.03	0.05	0.05	0.05	0.06
Lower Red–Lake Iatt	12	0.05	0.06	0.08	0.09	0.12	0.12	0.20
Lower Salt Fork Red	7	0.01	0.01	0.03	0.04	0.13	0.23	0.29
Lower Sulphur	2	0.13	0.14	0.14	0.15	0.15	0.16	0.16
Lower Washita	7	0.02	0.03	0.04	0.05	0.07	0.26	0.50
Mckinney–Posten Bayous	4	0.12	0.13	0.13	0.20	0.52	0.99	1.30
Middle North Fork Red	13	0.01	0.02	0.05	0.06	0.09	0.10	0.12
Middle Pease	2	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Middle Red–Coushatta	3	0.09	0.09	0.09	0.09	0.11	0.12	0.13
Middle Washita	20	0.03	0.04	0.04	0.08	0.19	0.24	0.57
Mountain Fork	23	0.01	0.01	0.01	0.02	0.03	0.04	0.11
Muddy Boggy	14	0.02	0.04	0.05	0.07	0.10	0.11	0.13
North Pease								
North Wichita	4	0.05	0.05	0.05	0.05	0.05	0.06	0.06
Northern Beaver	11	0.02	0.06	0.07	0.11	0.31	0.67	0.68
Pease	4	0.04	0.05	0.07	0.11	0.17	0.21	0.25
Pecan–Waterhole	15	0.09	0.10	0.11	0.11	0.15	0.20	0.35
Red Chute	5	0.10	0.10	0.10	0.11	0.11	0.16	0.19
Saline Bayou	5	0.07	0.07	0.07	0.07	0.08	0.18	0.25
South Wichita	5	0.01	0.01	0.02	0.04	0.05	0.05	0.05
Southern Beaver	3	0.13	0.15	0.20	0.27	0.30	0.31	0.32
Tierra Blanca								
Upper Little	36	0.01	0.01	0.02	0.03	0.04	0.04	0.17
Upper North Fork Red								
Upper Prairie Dog Town Fork	6	0.16	0.31	0.53	0.79	0.98	2.87	4.72
Upper Salt Fork Red	1	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Upper Washita	44	0.04	0.07	0.09	0.11	0.15	0.20	0.75
Washita Headwaters	10	0.06	0.06	0.06	0.07	0.08	0.09	0.12
West Cache	7	0.01	0.01	0.07	0.15	0.18	0.20	0.21
Wichita	18	0.04	0.05	0.08	0.14	0.64	1.33	1.44

Appendix 3f.

Cl (mg L^{-1})

HUC8 Watershed	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
Bayou Pierre	7	24.7	24.9	27.6	31.0	48.6	110.3	195.0
Black Lake Bayou	8	5.2	5.6	6.0	7.1	9.4	21.0	36.7
Blue	11	2.9	6.2	10.0	10.9	15.7	19.4	41.1
Blue–China	5	154	376	708	1620	1990	2150	2250
Bodcau Bayou	2	10.5	11.1	12.0	13.6	15.1	16.1	16.7
Bois D	22	12.2	24.0	29.8	64.1	214	295	330
Cache	5	23.4	26.2	30.5	34.1	74.9	79.4	82.5
Clear Boggy	13	4.1	9.1	20.5	35.9	44.7	81.0	170
Cross Bayou	7	24.6	31.6	38.7	48.7	61.5	74.7	76.7
Elm Fork Red	10	463	471	993	2310	4210	6760	12800
Farmers–Mud	19	19.5	30.9	51.6	129	1010	1130	1230
Groesbeck–Sandy	6	518	842	1370	2960	4610	5680	6520
Kiamichi	27	1.8	3.9	5.4	9.3	10.0	11.3	23.0
Lake Texoma	3	56.3	60.5	66.9	77.6	80.7	82.5	83.8
Little Wichita	5	10.0	17.5	28.8	38.2	46.0	79.0	101
Loggy Bayou	11	5.9	7.5	11.4	22.7	26.5	43.6	89.5
Lower Little	16	1.6	2.2	3.1	5.9	11.2	25.5	89.9
Lower North Fork Red	13	52.2	90.8	110	139	752	1830	5500
Lower Prairie Dog Town Fork Red	3	280	2420	5640	11000	13000	14200	15000
Lower Red–Lake Iatt	12	5.0	5.0	5.8	10.1	24.9	68.5	78.1
Lower Salt Fork Red	7	62.5	186	273	281	736	866	1010
Lower Sulphur	2	16.7	18.8	22.1	27.5	32.9	36.1	38.3
Lower Washita	8	3.8	4.6	5.0	9.7	16.7	225	693
Mckinney–Posten Bayous	4	5.9	13.2	24.0	49.9	78.4	93.8	104
Middle North Fork Red	39	10.0	32.0	45.9	110	405	473	1180
Middle Pease	2	275	316	377	479	581	642	683
Middle Red–Coushatta	3	26.1	34.1	46.1	66.0	85.0	96.4	104
Middle Washita	31	3.2	13.1	25.6	74.7	200	335	1134
Mountain Fork	23	2.1	2.4	3.0	4.0	10.0	10.0	246
Muddy Boggy	11	5.0	11.0	13.2	17.4	30.3	70.1	249
North Pease								
North Wichita	4	3210	3590	4160	4840	5570	6250	6700
Northern Beaver	12	11.1	13.1	15.7	20.0	89.3	116	228
Pease	5	649	991	1510	3170	3470	5890	7500
Pecan–Waterhole	15	10.0	13.8	17.0	42.0	163	181	194
Red Chute	5	6.5	8.9	12.7	13.8	15.1	24.0	29.9
Saline Bayou	5	8.2	8.6	9.3	9.6	10.8	20.6	27.1
South Wichita	5	2990	3380	3970	12700	15000	17000	18300
Southern Beaver	3	26.3	42.6	67.2	108	385	551	662
Tierra Blanca								
Upper Little	36	3.0	4.0	5.0	6.1	10.0	10.0	32.5
Upper North Fork Red								
Upper Prairie Dog Town Fork	8	98.0	141	176	315	529	2610	6130
Upper Salt Fork Red	2	60.0	85.0	123	185	248	285	310
Upper Washita	46	7.0	14.7	27.4	55.9	96.1	159	1440
Washita Headwaters	10	26.1	41.4	45.7	50.7	59.7	64.1	73.7
West Cache	7	5.0	5.8	16.7	133	621	1080	1180
Wichita	19	257	802	997	1120	1420	1640	3230

Appendix 3g.

chl–a (sestonic, µg L^{-1})

HUC8 Watershed	COUNT	MIN	10th	25th	MEDIAN	75th	90th	MAX
Bayou Pierre								
Black Lake Bayou								
Blue	4	2.11	2.42	2.89	3.93	6.95	11.0	13.7
Blue–China	3	7.41	8.07	9.06	10.7	28.1	38.5	45.4
Bodcau Bayou								
Bois D	11	3.68	5.00	5.00	10.0	11.0	12.2	19.4
Cache	1	6.92	6.92	6.92	6.92	6.92	6.92	6.92
Clear Boggy	3	2.62	3.10	3.81	5.00	6.04	6.66	7.07
Cross Bayou								
Elm Fork Red	3	3.85	4.20	4.73	5.61	19.7	28.2	33.8
Farmers–Mud	5	5.37	5.45	5.57	18.7	26.3	38.1	45.9
Groesbeck–Sandy	3	10.0	10.0	10.0	10.0	23.8	32.0	37.5
Kiamichi	10	0.80	0.89	1.26	3.80	5.39	8.31	9.04
Lake Texoma	1	6.30	6.30	6.30	6.30	6.30	6.30	6.30
Little Wichita	4	10.0	10.1	10.2	11.2	16.5	24.2	29.4
Loggy Bayou								
Lower Little								
Lower North Fork Red	3	5.25	7.78	11.6	17.9	23.9	27.5	29.9
Lower Prairie Dog Town Fork Red	2	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Lower Red–Lake Iatt								
Lower Salt Fork Red	2	3.22	6.74	12.0	20.8	29.6	34.9	38.4
Lower Sulphur								
Lower Washita								
Mckinney–Posten Bayous								
Middle North Fork Red	7	1.96	2.30	3.76	5.30	7.20	10.0	14.0
Middle Pease	2	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Middle Red–Coushatta								
Middle Washita	3	17.7	19.1	21.1	24.5	27.4	29.2	30.4
Mountain Fork	7	0.10	0.35	0.72	0.98	1.78	54.2	133
Muddy Boggy	9	0.10	0.25	0.60	4.01	7.02	12.4	13.0
North Pease								
North Wichita	1	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Northern Beaver								
Pease	4	5.77	7.04	8.94	25.1	40.9	42.2	43.2
Pecan–Waterhole	11	1.00	2.64	8.40	10.0	19.1	21.4	27.9
Red Chute								
Saline Bayou								
South Wichita	2	1.00	1.90	3.25	5.50	7.75	9.10	10.0
Southern Beaver	2	10.0	10.4	10.9	11.8	12.7	13.2	13.6
Tierra Blanca								
Upper Little	11	0.21	0.32	0.48	1.41	2.47	3.84	263
Upper North Fork Red								
Upper Prairie Dog Town Fork	6	1.00	5.50	10.6	19.5	38.7	64.5	86.8
Upper Salt Fork Red	1	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Upper Washita	9	2.69	3.15	6.64	11.2	14.1	20.1	20.9
Washita Headwaters	5	2.90	3.16	3.56	7.56	7.60	7.92	8.13
West Cache	1	9.30	9.30	9.30	9.30	9.30	9.30	9.30
Wichita	14	1.00	1.49	6.38	12.3	22.8	36.3	55.4