Project 17-300

Water Quality Monitoring in the Upper Poteau River Watershed

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EXECUTIVE SUMMARY

The Upper Poteau River Watershed (UPRW) has been listed as a priority watershed in Arkansas since 1998 due to nutrient and sediment enrichment from point and nonpoint sources (NPS). According to the Arkansas NPS pollution management plan, the goals for the UPRW is to reduce pollutant levels that will restore all designates uses and target subwatersheds where implementation of management practices can have the greatest impact. Over the last several years, many 319(h) projects have been implemented and point sources have been reduced in order to improve water quality in the UPRW. The purpose of this study was to monitor 15 sites in the UPRW, three on existing U.S. Geological Survey (USGS) monitoring sites and 12 additional sites on the HUC-12 scale, for streamflow, nutrients, and sediments to add to the water quality database used by policy and decision makers of Arkansas.

This project successfully collected water samples across a range of flows at 15 sites over three years, collected stage and discharge measurements at 8 of the 12 HUC-12 sites, developed rating curves for sites with stage and discharge measurements, estimated monthly and annual constituent loads for sites with discharge measurements, conducted water quality trend analyses at the three USGS sites, and analyzed the relationship between nutrient concentrations and land use. At the three USGS sites, constituent loads were generally greatest in the 2019 project year, and long term trend analyses suggested flow-adjusted sediments were decreasing over time. However, flow adjusted N was increasing at both the Poteau River and James Fork, and flow-adjusted SRP was increasing at just the James Fork. At the HUC-12 sites, constituent loads were generally greatest in 2020, and the largest magnitude of loads occurred from the Lower Poteau river site which is just downstream of the waste

water treatment plant in Waldron, Arkansas. Finally, average and flow-weighted concentrations increased with increasing human development (which mostly consists of agricultural land in the UPRW) across sites (with the exclusion of sites 3 and 9). Ultimately, the data collected in this project is important for understanding small-watershed pollutant sources and long-term trends in water quality at the UPRW.

INTRODUCTION

Excess pollutants entering waterbodies can lead to an array of environmental health concerns (e.g. reduced water clarity and increased algal and plant growth), and cause waterbodies to not meet their designated use(s) (Correll 1998; Jonge et al. 2002; Paerl et al. 2016). With increasing population and land use changes, non-point source (NPS) pollutants have jeopardized aquatic ecosystems, mainly through rainfall and runoff from agricultural and urban landscapes. Therefore, it is important to identify diffuse pollution sources to develop total maximum daily loads (TMDLs) and implement best management practices (BMPs) and improve water quality.

In Arkansas, the NPS Pollution Management Plan seeks to reduce, manage, control, or abate NPS pollution through watershed prioritization, TMDL development, management practices and stakeholder involvement (ANRC 2018). The Upper Poteau River Watershed (UPRW) has been listed as a priority watershed in Arkansas since 1998 due to nutrient and sediment enrichment from point and nonpoint sources. According to the NPS pollution plan, the long term goal for the UPRW is to reduce pollutant levels that will restore all designated uses. The short term goal is to reduce pollutants of concern and target subwatersheds where implementation of management practices can have the greatest impact.

Several U.S. Environmental Protection Agency (EPA) 319(h) projects have been completed in the UPRW including the Poteau River Agricultural Watershed Project (06-300), Arkansas Forestry Commission Silviculture Project (05-300), the Litter Transport from designated Nutrient Surplus Area (NSA) in Arkansas (05-1600), NPS Pollution BMP E-Education (09-1700), and Water Quality Monitoring for Selected Priority Watersheds in Arkansas: Upper Saline, Poteau, and Strawberry (11-800). Additionally, municipal and industrial point source reductions have occurred in the past decade (ANRC 2018). These efforts may lead to improvement in water quality at the aggregate or larger watershed level. Therefore, the purpose of this study was to aid in documentation of water quality improvements or impairments in this watershed, by monitoring 15 sites within the watershed, three of these existing at U.S. Geological Survey (USGS) discharge monitoring sites, and the remaining 12 sites on the hydrologic unit code (HUC) 12 scale. This monitoring project sought to estimate monthly and annual loads which can be used for future watershed modelling efforts, analyze water quality trends at the USGS sites, contribute data to the historical water quality databases, and collect data that will aid in future developments or updates to watershed management plans in the area.

METHODS

Study Site Description

The UPRW (HUC 11110105) occupies an area of 1,400 km^2 in Arkansas (Figure 1, Table 1). In 2001, land use in the area was 60.0% forested, 6.3% urban, 25.9% agriculture, 3.7% grassland, and 0.8% open water (USGS 2001). In 2016, forested area increased to 65.3%, agriculture area decreased to 21.9%, and urban area was 6.4%, grassland was 4.0%, and open water was 0.9% (USGS 2016). The headwaters of the Poteau River begin near Waldron, Arkansas, and flow west into Oklahoma. The two main tributaries to the Poteau River within the UPRW in Arkansas are the Black Fork and the James Fork.

The UPRW is listed as a priority watershed within the Arkansas Nonpoint Source Pollution Plan, and has been a focus of trans-boundary water quality issues for the last several decades (ANRC 2018). In 2012, this 1,400 km^2 watershed contained over 350 poultry farms and produced nearly 100 million birds (USDA 2012). Portions of the Poteau River are listed on the Arkansas 303 (d) list for dissolved oxygen, turbidity, chlorides, sulfates and total dissolved solids (ADEQ 2018). A TMDL was developed in 2006 for the Poteau River, which concluded a 35% reduction in total phosphorus (TP) from non-point sources was necessary for water quality protection (USEPA 2006).

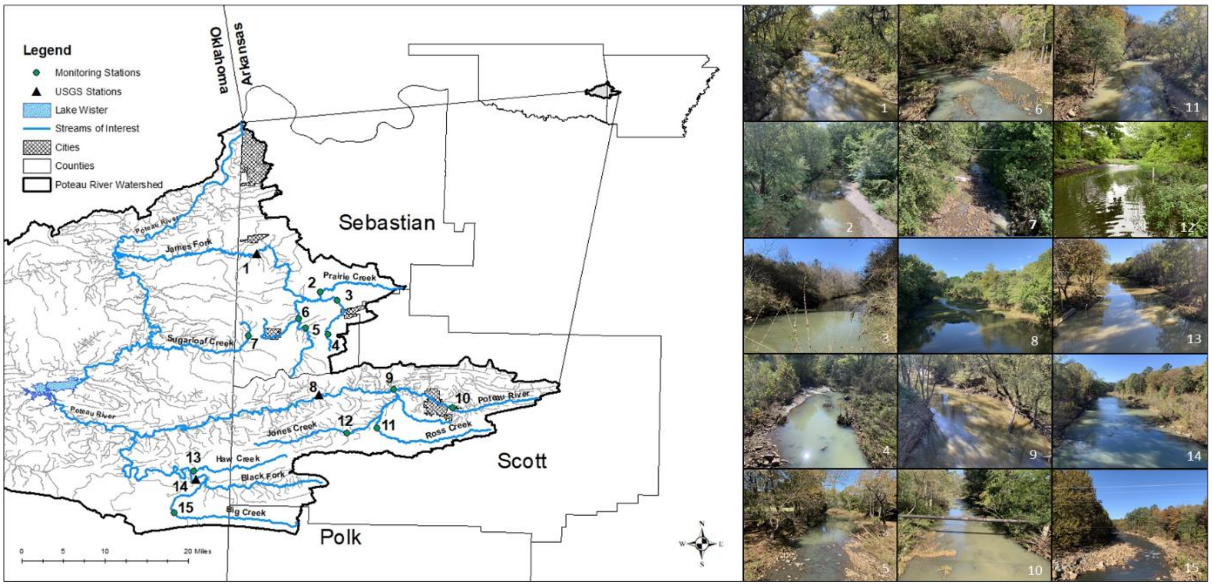


Figure 1: Upper Poteau River Watershed in Arkansas. Monitoring site numbers on map and images correspond to site numbers on in Table 1.

Table 1: Monitoring site ID's (corresponding to Figure 1), locations, watershed areas, and land use in the Upper Poteau River Watershed.

Site ID	Site Name	Lat N	Long W	Watershed Area (km^2)	%F[1]	%U[2]	%AG[3]
	James Fork Watershed - HUC 1111010508						
1	USGS 07249400 - James Fork	35 09.755	94 24.424	381	50.3	4.8	40.8
2	Prairie Creek	35 05.709	94 17.776	70	23.0	5.1	61.4
3	Lower Cherokee Creek	35 04.839	94 16.013	80	45.1	6.0	46.4
4	Cherokee Creek Headwaters*	35 01.379	94 16.985	14	84.5	1.1	9.4
5	James Fork Headwaters*	35 01.984	94 19.315	39	84.7	1.2	8.9
6	Lower James Fork*	35 02.820	94 20.302	95	69.9	3.5	18.3
	Lower Poteau River Watershed - HUC 1111010506						
7	Upper Sugar Loaf Creek	35 01.177	94 25.285	7	88.6	1.6	1.3
	Headwaters Poteau River Watershed - HUC 1111010501						
8	USGS 07247000 - Poteau River	34 55.129	94 17.918	527	63.7	5.6	21.3
9	Lower Poteau River*	34 55.666	94 10.124	193	51.6	7.7	32.0
10	Poteau River Headwaters*	34 53.769	94 03.975	39	52.7	5.5	33.1
11	Ross Creek*	34 51.647	94 11.910	77	71.8	4.6	13.9
12	Upper Jones Creek*	34 51.895	94 12.835	73	84.8	2.7	2.2
	Black Fork Watershed - HUC 1111010502						
13	Haw Creek	34 47.257	94 30.924	62	90.3	1.8	1.1
14	USGS 07247250 - Black Fork	34 46.428	94 30.748	245	88.3	3.5	9.8
15	Big Creek*	34 42.970	94 33.006	60	92.3	6.2	0.0

% Forest (%F) includes deciduous, evergreen, and mixed forest; [2] % Urban (%U) includes open space, low, medium and high intensity development; [3] % Agriculture (%Ag) includes pasture, hay, and cultivated crops. *Indicates where a SonTek-IQ was deployed.

Three USGS discharge monitoring sites exist in the UPRW on the James Fork, Poteau River, and Black Fork (Figure 1, Table 1), and these were monitored in this study. Catchment land use across the USGS sites ranged from 50 to 88% forested, 3.5 to 5.6% urban, and 10 to 41 % agriculture (Table 1). An additional 12 sites were selected at bridge crossings near the outflow of HUC-12 subwatersheds within the UPRW (Figure 1, Table 1). Sites were selected to represent a range of land use and baseflow water quality conditions. Catchment land use across these sites ranged from 23 to 92.3% forested, 1.1 to 7.7% urban, and 0 to 61.4% agriculture (mostly pasture). Barren land represented less than 1% of catchment area for all watersheds, and the remainder of the watershed areas were open water, shrubs, and grasslands (USGS 2016). The catchment area ranged from 7 to 381 km^2 across all sites, including the USGS sites (Table 1).

Data Collection

At the HUC-12 sites, HOBO water level logger (i.e., pressure transducer; Onset Computer Corporation, Bourne, Massachusetts) was deployed at each site in December 2017 or January 2018 to obtain continuous stage records, and HOBO barometric pressure transducers were installed within 16 km of each sample site to account for fluctuations in atmospheric pressure. The HOBOs were installed and maintained according to standard operating procedures (OCC 2018), where the HOBO water level loggers were typically suspended within a polyvinyl chloride (PVC) pipe attached to a bridge post, and atmospheric HOBOs were bound to trees outside of the stream channel (Figure 2A and 2B, respectively). Sensors were set to record measurements on 15-minute intervals, and data were downloaded from the HOBOs on a monthly basis.

Figure 2: A) Pressure transducer installation on a bridge post, B) atmospheric pressure transducer attached to a tree outside of floodplain, C) SonTek-IQ attached to concrete block in stream channel, D) SonTek-IQ in stream channel, and E) ammo can attached to tree outside of the flood plain to store battery.

SonTek-IQ acoustic Doppler instruments (SonTek/Xylem Inc., San Diego, California), were rotated among eight of the HUC-12 sites to measure discharge during high flow events. SonTek-IQs measure the velocity of water using the Doppler shift and internally calculate discharge once calibrated to the stream channel geometry. Roving discharge monitoring stations were installed at each site to allow for easy rotation of the SonTek-IQs among sites between flood events. Roving discharge monitoring stations include a concrete base staked into the streambed, a container to store the battery and wiring (e.g. an ammo can), and PVC pipe from the concrete base up the stream bank and to the battery container (Figure 2 C-E). The battery container is attached to a tree outside of the floodplain (Figure 2E).

Rating Curve Development

Rating curves were developed for the eight HUC-12 sites using the high-flow data captured during SonTek-IQ deployment, and baseflow discharge measurements collected on a monthly basis using velocity-area methods, since the SonTek-IQ flow measurements are not reliable when water depths are less than 0.45 m (SonTek-IQ 2017). Since all instantaneous flow measurements obtained by the SonTek-IQ were not necessary for rating curve development, we selected various points along the hydrograph to use in the rating curve. Therefore, the final rating curves consisted of the averages (i.e., five values on 15 minute intervals) around the peak flows, 75% of the peak flows, and 50% of the peak flows from the SonTek-IQ, averages around the corresponding stages, and baseflow measurements.

Rating curves were developed using simple linear regression, locally weighted regression (LOESS), and Manning's equation. Below the range of measured flow data, 2-point regression was applied to estimate low flows, and nonparametric LOESS regression was used to fit the range of measured flow and stage data with a sampling proportion of 0.5. Manning's equation was used for flow estimations above of the range of measured data (Equation 1):

$$Q = \left(\frac{K}{n}\right) A R^{\frac{2}{3}} \sqrt{S}$$

where Q is the flow (ft^3/s), K is a constant equal to 1.49 $ft^{1/3}/s$, *n* is the surface roughness ($s/ft^{1/3}$), A is the cross-sectional area of flow (ft^2), R is the hydraulic radius (ft), and S is the slope of the channel (ft/ft).

To estimate A and R from Manning's equation, an unsteady flow analysis was conducted in the Hydrologic Engineering Center's River Analysis System (HEC-RAS) (USACE 2016). With inputs including the stream channel survey, LOESS rating curve data, and a stage hydrograph, the unsteady flow analysis computes the A and the wetted perimeter (WP) for a range of user defined depths. The R at each depth is then computed as A divided by the WP. The final rating curves were analyzed using Nash-Sutcliffe Efficiency (NSE), and are shown for each site in the results section. The rating curves were then used to develop a record of continuous, instantaneous flow on a 15-minute time interval.

At the three USGS discharge monitoring sites, instantaneous flow was available through the USGS National Water Information Systems (USGS 2020). Discharge was downloaded for each site at the end of the project period to use in constituent load estimations.

Constituent Load Estimations

Water samples were collected across the range of discharge measurements (i.e., baseflow and stormflow) at all 15 sites to estimate constituent loads. Sample collection began in October 2017, and continued through the end of the project period in September 2020. Water samples were analyzed at the Arkansas Water Resources Center Water Quality Lab (AWRC WQL) for nitrate plus nitrite (NN), chloride (Cl), fluoride (Fl), soluble reactive P (SRP), TP, total nitrogen (TN), total suspended solids (TSS), sulfate (SO_4^{2-}), turbidity and electrical conductivity (EC). The equipment, methods and method detection limits for the certified AWRC lab are available online (AWRC 2020).

Constituent loads (L_i) were estimated by multiplying constituent concentrations (C_i) by instantaneous flow (Q_i). A generalized additive model (GAM), in the mgcv package in R (R Core Team 2016; Wood 2017), was applied to predict constituent loads using a spine based smooth function (s) of each predictor variable, log transformed instantaneous flow and day of year (DOY, to capture seasonality) (Equation 2):

$$\log_{10} L_i = s(\log_{10} Q_i) + s(DOY)$$

The performance of the GAM models were evaluated using R^2 and NSE. A continuous record of constituent loads with 95% confidence intervals was developed using each GAM. Daily constituent loads were estimated by integrating continuous loads over time, and daily loads were then summed to estimate monthly and annual loads.

Trend Analyses

The long-term data used to evaluate trends at the USGS sites come from the USGS NWIS, which includes flow, stage, and various water quality parameters. Constituents of interest at each site were instantaneous discharge (Q_i), TN, NN, TP, SRP, and SS (Table 2). These data were available from the 1970s to 2018 depending on site and parameter (Table 2).

Table 2: USGS parameter codes, constituents, percentage of censored values, and data availability for the James Fork (USGS 07247250, Site 1), Poteau River (USGS 07247000, Site 8), and Black Fork (USGS 0729400, Site 14) in the Upper Poteau River Watershed.

USGS parameter code	Constituent	% Censored			Data availability		
		James Fork	Poteau River	Black Fork	James Fork	Poteau River	Black Fork
p00600	Total nitrogen, unfiltered, mg L^{-1} as N	9.2%	11.5%	16.4%	1975-1981, 1995-2020	1995-2020	1991-2018
p00630	Nitrate plus nitrite, unfiltered, mg L^{-1} as N	0.0%	NA	NA	1977-1994	NA	NA
p00631	Nitrate plus nitrite, filtered, mg L^{-1} as N	10.8%	11.5%	1.4%	1976-1981, 1994-2020	1995-2020	1991-2018
p00665	Phosphorus, water, unfiltered, mg L^{-1} as P	9.6%	0.3%	9.3%	1972-1981, 1983-2020	1995-2020	1992-2018
p00671	Orthophosphate, water, filtered, mg L^{-1} as P	13.9%	6.2%	38.7%	1995-2020	1995-2020	1991-2018
p80154	Suspended sediment concentration, mg L^{-1}	0.0%	0.0%	1.0%	1978-1981, 1995-2020	1995-2020	1991-2018

Raw data from the USGS contained censored and estimated values. Estimated values were assumed sufficient, and these values were used in analysis. Less than 15% of the data were censored across all sites and constituents, except for TN and SRP at the Black Fork, where 16% and 39% of the data was censored, respectively (Table 2). Censored values were replaced with the average of the censored values for each parameter to reduce the potential influence of changing reporting limits. The U.S. Environmental Protection Agency suggested using simple substitution methods with data sets less than 15% censored (USEPA 2000). Since less than 15% of the data here was censored for the majority of constituents (except for TN and SRP at Black Fork), this method is likely adequate for our data set.

The database covers several decades where processing and analyses changes occurred for some constituents. Some data were combined to account for changing methods (e.g. switching from filtered to unfiltered samples or for gaps in data availability). At all sites, we combined the mean daily discharge (Q_d, P00060) with the instantaneous discharge (Q_i, P00061) to account for missing Q_i values (< 10 % of data). For the James Fork, we combined the filtered NN (p00631) with the unfiltered nitrate plus nitrite (p00630). There were a few sample dates with both filtered and unfiltered data. The values were within 10% of each other, so an average of the values was used. At the Poteau and Black Fork, full data sets were available for the filtered nitrate plus nitrite, so no combination was necessary.

Constituent concentrations were used to evaluate long-term water quality trends, using the following three-step procedure (White et al. 2004):

- Discharge and constituent concentrations were log transformed in order to reduce effects of outliers (Helsel and Hirsch 1991).
- Constituent concentrations were flow adjusted using a locally weighted regression (LOESS) smoothing technique. LOESS spans were manually inspected, in order to minimize error from the LOESS regression while maximizing the regression's predictive power (Simpson and Haggard 2018). A range of spans between 0.3 and 0.7 for all constituents was chosen, based on the root mean square errors (RMSE) and visual inspection of the LOESS fits.
- Residuals from the LOESS fit (i.e. the flow-adjusted concentrations, FACs) were analyzed over time in order to evaluate trends, changes in residuals represent a change in constituent concentration over time unrelated to flow. Monotonic trends were examined using linear regression and the nonparamtetric Seasonal Kendall Test (SKT) based on quarterly data or the

median FAC during that quarter. The slopes from these tests were used to estimate the magnitude (% yr^{-1}) of any trends (Sen 1968; Hirsch et al. 1982). Trends with p-values less than 0.05 were considered "extremely likely" to increase or decrease, p-values between 0.05 and 0.20 were considered "likely" to increase or decrease, and p-values greater than 0.20 were considered "likely not changing".

Trend analysis was then repeated by removing all censored values to see if the reporting limits influence our trends interpretation. The results from linear regression and the SKT were not different across most of the data, so the results section focuses on the linear model slopes and p-values.

A nonparametric change point analysis (nCPA) was implemented for all FACs over time, to detect any changes in the time series of data (King and Richardson 2003; Qian et al. 2003). If one or more change point was identified, then the three-step trend analysis was conducted on the time series to the left and right of the point. Additionally, for constituents with gaps in the data sets, a simple t-test or analysis of variance (ANOVA) was used to analyze the difference between means FACs across the groups of data. All data analysis was completed using R.

RESULTS

USGS 07249400- James Fork (Site 1)

Constituent Loads

The USGS gaging station on the James Fork (Figure 3) is near Hackett, Arkansas, and its watershed covers an area of 381 km^2 that is 50.3% forest, 4.8% urban and 40.8% agriculture. Flow measurements for the project period of October, 2017 through September, 2020 ranged from 0.0 and 11,400 cfs. A total of 114 water samples were collected during the project period, with 71 during baseflow conditions and 43 during storm flow. Water samples were collected across 99.9% of all flow measurements, with no flow measurements falling below where water samples were collected, and 0.1% of flow measurements falling above.

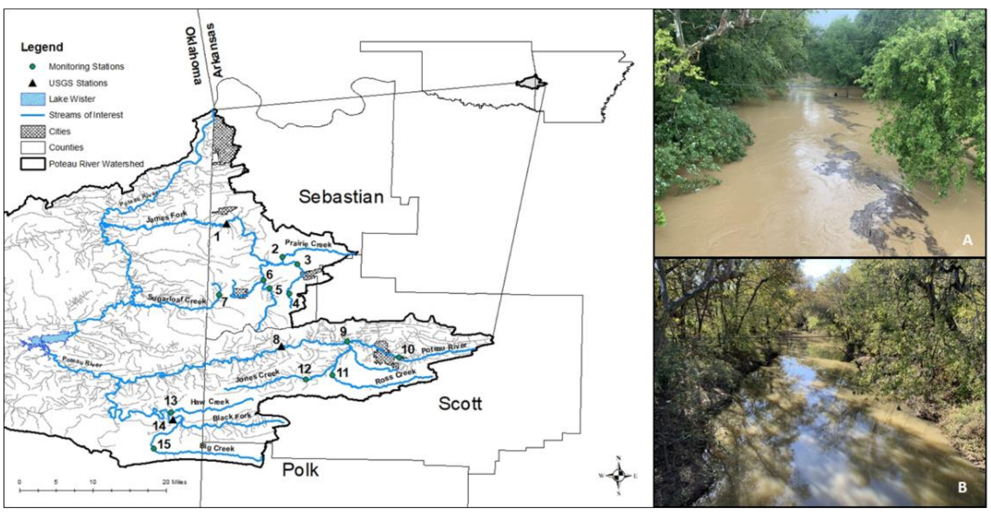


Figure 3: Upper Poteau River Watershed site map (left) and images of the James Fork (Site 1) during storm flow (A) and baseflow conditions (B).

Constituent concentrations were generally greater in the 2017 project year (i.e., October, 2017 – September, 2018) compared to 2018 and 2019 (Table 3), except for NN and Fl which were greatest in

2019. Additionally, constituent concentrations were generally greatest in the winter months (i.e., December, January, and February), and least in spring months (i.e., March, April and May).

Table 3: Project year (e.g., 2017 project year is October 1, 2017 through September 30, 2018) and seasonal mean concentrations for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), sulfate (SO_4^{2-}), turbidity and electrical conductivity (EC) at the James Fork (USGS 07249400, Site 1).

Project Year/ Season	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}	Turbidity	EC
	mg L^{-1}								NTU	µS cm^{-1}
2017	0.92	0.223	0.21	0.055	97.43	0.120	5.023	31.544	122.41	205.44
2018	0.76	0.236	0.14	0.035	62.22	0.115	3.952	24.795	77.15	141.29
2019	0.76	0.252	0.15	0.044	72.47	0.153	4.039	29.241	71.88	160.16
Fall	0.82	0.248	0.16	0.055	50.81	0.124	4.438	25.401	61.62	170.02
Winter	0.91	0.298	0.21	0.039	105.83	0.119	5.159	31.588	128.23	168.29
Spring	0.76	0.209	0.13	0.035	56.24	0.120	3.979	24.997	64.33	141.64
Summer	0.77	0.188	0.18	0.052	96.21	0.155	3.828	32.245	107.21	198.42

Measured concentrations were multiplied by instantaneous flow (Q_i) to estimate constituent loads (L_i). The R^2 and NSE values for each constituent's GAM were greater than 0.90, and all constituents but Fl were greater than 0.96 (Table 4). Daily constituent loads were then estimated by integrating L_i over time, and then daily loads were summed into monthly (Appendix A) and annual loads (Table 6). Nutrient and sediment loads were greater in the 2019 project year compared to 2017 and 2018, while anions (i.e., Fl, Cl and SO_4^{2-}) were greater in the 2018 project year. NN loads generally made up about 25% of TN loads, and SRP loads made about 23% of TP loads. Slightly higher percentages were observed for mean concentrations each year, with NN making up about 29% of TN concentrations and SRP making up about 26% of TP concentrations (Table 3).

Table 4: Generalized additive model (GAM) R^2 and Nash-Sutcliffe Efficiency (NSE), mean daily loads (kg day^{-1}) with 95% confidence intervals, and project year (e.g., 2017 project year is October 1, 2017 through September 30, 2018) annual loads (kg) for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), and sulfate (SO_4^{2-}) at the James Fork (USGS 07249400, Site 1). Additionally, the mean daily flow (Q_d) for each project year (cfs).

Constituent	R^2	NSE	Mean Daily Load	2017	2018	2019
Q_d	--	--	--	141	330	335
TN	0.993	0.993	648 (558-753)	45,931,200	105,979,000	106,952,000
NN	0.964	0.967	157 (98-254)	11,293,000	25,705,000	25,863,000
TP	0.981	0.983	164 (120-226)	12,547,000	25,502,000	27,557,000
SRP	0.962	0.964	38 (24-63)	2,940,000	5,851,000	6,485,000
TSS	0.980	0.982	75,690 (49,549-116,380)	6,571,877,000	10,775,740,000	12,903,722,000
Fl	0.910	0.917	66 (37-119)	4,372,000	11,062,000	10,770,000
Cl	0.994	0.994	2,100 (1,842-2,395)	142,180,000	355,076,000	342,004,000
SO_4^{2-}	0.983	0.984	11,984 (9,394-15,326)	831,340,000	2,004,536,000	1,953,638,000

Trend Analysis

Trend analysis was conducted using the over 40 years of available flow and water quality data from the USGS at the James Fork. Sediments, P and TN generally increased with discharge, while NN was more variable at higher flows. LOESS was fit to each concentration and discharge relationship with sampling proportions of 0.4 – 0.7 (Table 5), and LOESS RMSEs were relatively low (< 0.36).

The trends in flow-adjusted concentrations over time (i.e., 1995 – 2020) were variable across constituents. The specific changes include:

- TN likely increased ($0.05 < p < 0.20$) at 0.29 % yr^{-1}, with no change points identified (Figure 4, A); however, the average flow-adjusted TN was 20% greater between 1976 and 1981 compared to 1995 to 2020 ($p < 0.05$).
- NN extremely likely increased from 1995 to 2020 (where the data was completely filtered, Table 1) by 1.25 % yr^{-1} ($p < 0.05$); however, with the combined dataset of filtered and unfiltered NN,

the average flow adjusted NN was 34% greater from 1979 to 1981 compared to after 1995 ($p < 0.05$, Figure 4, B). One change point occurred for NN in April 1998, where flow-adjusted NN was 27% greater after 1998 compared to before.

- TP was likely not changing between 1995 and 2020 ($p = 0.28$); two significant change points occurred in the FACs, one in September 1996 and one in April 2008 (Figure 4, C), but no monotonic changes occurred before or after the change points.
- SRP likely increased ($0.05 < p < 0.20$) by a magnitude of 0.44 % yr^{-1}; two change points occurred in flow-adjusted SRP, one in June 2006 and the other in April 2011, and average SRP FACs were 21% greater after 2011 and 24% less before 2006 compared to between 2006 and 2011 (Figure 4, D).
- SS extremely likely decreased at a rate of 2.27% yr^{-1} ($p < 0.05$, Figure 4, E), but the average flow-adjusted SS after 1995 was not significantly different than the average flow adjusted SS before 1981 ($p > 0.05$); two change points were identified relatively close in time, one in June 2002 and the other in January 2005.

Table 5: Optimal LOESS Sampling Proportion, LOESS RMSE, Linear Model Slope, Linear Model p-Value, Seasonal Kendall's Test (SKT) Sen's Slope, and Seasonal Kendall's Test p-Value for Trends in Flow Adjusted Concentrations (FACS) for each Parameter the James Fork (USGS 07249400, Site 1).

Parameter	LOESS Sampling Proportion	LOESS RMSE	Linear Model Slope (%/yr)	Linear Model p-Value	SKT Sen's Slope (%/yr)	SKT p-Value
TN	0.40	0.16	0.29	0.15	0.28	0.12
NN	0.70	0.36	1.25	<0.01	0.99	<0.01
TP	0.70	0.26	0.12	0.28	0.04	0.55
SRP	0.70	0.25	0.44	0.15	0.12	0.42
SS	0.50	0.3	-2.27	<0.01	-2.18	<0.01

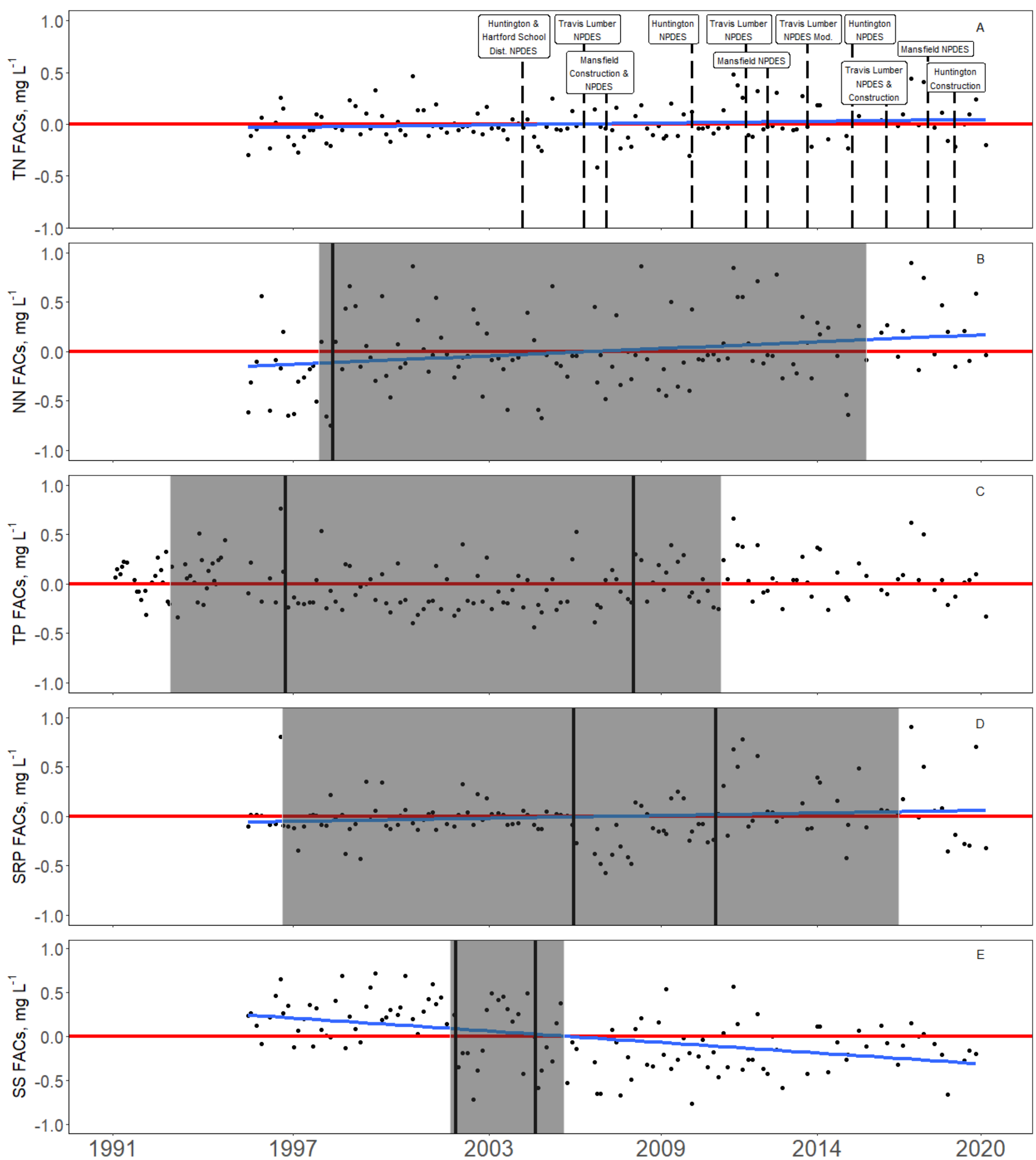


Figure 4: Trends in Flow Adjusted Concentrations (FACs) of Total Nitrogen (TN), Total Phosphorus (TP), Suspended Sediments (SS), Nitrate+Nitrite (NN), and Soluble Reactive Phosphorus (SRP) at the James Fork. The FACs were truncated from -1 to 1 for consistency. This may cause a few data points to be missing from the figure, but all data were included in trend analysis. Significant change points are identified by solid vertical lines, the grey areas are the 95% confidence intervals around the change points, and significant linear model slopes are identified by solid blue lines. A timeline of events related to Nonpoint Source Discharge Elimination System (NPDES) permits and other significant milestones for the point sources on the James Fork (Site 1) is shown in Figure 4,A.

Prairie Creek (Site 2)

The Prairie Creek monitoring site (Figure 5) is near Huntington, Arkansas, and its watershed covers an area of 70 km^2 that is 23.0% forest, 5.1% urban and 61.4% agriculture. A pressure transducer was installed at site 2 on December 21, 2017, and stage measurements throughout the study (January 2018 – December 2020) ranged between 0.05 and 13.6 ft. Due to equipment malfunction, stage measurements were not collected for 18 days in January 2019 (i.e., January 8 – 18, 2019). Baseflow discharge measurements were collected on 12 occasions throughout the project period, with baseflows ranging from 0.4 to 32.3 cfs. Due to time constraints, a SonTek-IQ was not deployed at this site.

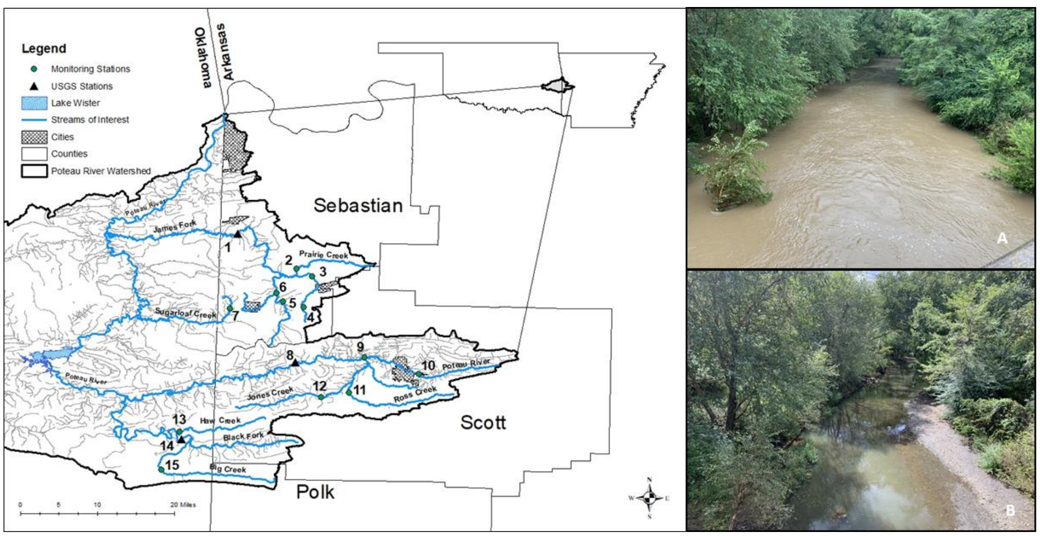


Figure 5: Upper Poteau River Watershed site map (left) and images of Prairie Creek (Site 2) during storm flow (A) and baseflow conditions (B).

A total of 65 water samples were collected from site 2, with 35 during baseflow conditions and 30 during storm flow between October 2017 and September 2020. Water samples were collected across 97.9% of all stage measurements, with less than 1% of stage measurements falling above where water samples were collected, and 2% of stage measurements falling below. Constituent concentrations were generally greater in the 2017 project year (i.e., October 2017 – September 2018) compared to 2018 and 2019 (Table 6). Additionally, constituent concentrations were generally greatest in the summer months (i.e., June, July, and August), and least in spring months (i.e., March, April, and May). However, NN, Cl and $SO_4^{2`}$ concentrations were greatest in the winter months (December, January, and February) and least in spring months.

Table 6: Project year (e.g., 2017 project year is October 1, 2017 through September 30, 2018) and seasonal mean concentrations for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), sulfate (SO_4^{2-}), turbidity and electrical conductivity (EC) at Prairie Creek (Site 2).

Project Year/ Season	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}	Turbidity	EC
	------------	------------	------------	------------	mg L^{-1}	------------	------------	------------	NTU	µS cm^{-1}
2017	0.99	0.277	0.24	0.119	54.84	0.123	5.502	20.102	82.18	133.73
2018	0.89	0.245	0.19	0.085	53.15	0.106	4.133	12.531	71.81	91.83
2019	0.94	0.283	0.22	0.117	53.13	0.134	4.397	13.642	59.29	99.71
Fall	0.97	0.304	0.22	0.146	36.48	0.120	5.121	15.465	53.57	107.97
Winter	0.98	0.338	0.19	0.082	39.24	0.088	5.534	16.348	65.94	111.33
Spring	0.77	0.128	0.14	0.056	35.01	0.104	3.983	12.584	48.13	96.03
Summer	1.03	0.302	0.29	0.130	95.16	0.161	3.986	15.682	105.73	109.54

Lower Cherokee Creek (Site 3)

The Lower Cherokee Creek monitoring site (Figure 6) is near Huntington, Arkansas, and its watershed covers an area of 80 km^2 that is 45.1% forest, 6.0% urban and 46.4% agriculture. A pressure transducer was installed at site 3 on December 21, 2017, but the pressure transducer was lost in a storm event on June 10, 2019. Stage measurements were not continued past this point, since this site was also too deep for manual discharge measurements and SonTek-IQ installation. From December 2017 to June 2019, stage measurements ranged between 0.0 and 7.9 ft.

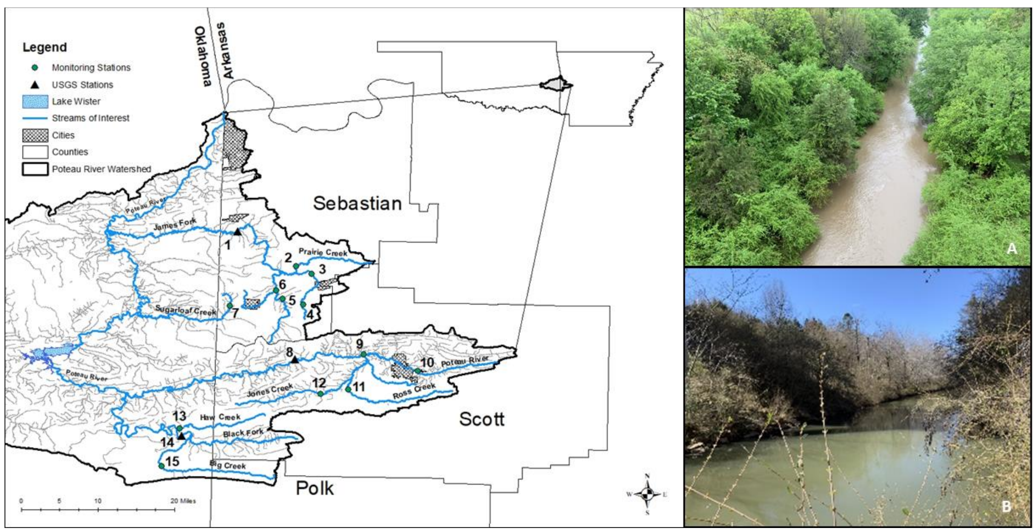


Figure 6: Upper Poteau River Watershed site map (left) and images of Lower Cherokee Creek (Site 3) during storm flow (A) and baseflow conditions (B).

A total of 41 water samples were collected from site 3, with 20 during baseflow conditions and 21 during storm flow between October 2017 and June 2019. Water samples were collected across 94.0% of all stage measurements, with less than 1% of stage measurements falling above where water samples were collected, and 5.9% of stage measurements falling below. Constituent concentrations were generally greater in the 2017 project year (i.e., October 2017 – September 2018) compared to 2018 (Table 7). Additionally, constituent concentrations were generally greatest in the summer months (i.e., June, July, and August), and least in spring months (i.e., March, April, and May), except TN and EC concentrations were greatest in the winter, and Cl and $SO_4^{2`}$ concentrations were greatest in the fall months (September, October, and November). However, only about a year and a half of water quality data is available for this site compared to 3 years at other sites.

Table 7: Project year (e.g., 2017 project year is October 1, 2017 through September 30, 2018) and seasonal mean concentrations for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), sulfate (SO_4^{2-}), turbidity and electrical conductivity (EC) at the Lower Cherokee Creek (Site 3).

Project Year/ Season	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}	Turbidity	EC
	------------	------------	------------	------------	mg L^{-1}	------------	------------	------------	NTU	µS cm^{-1}
2017	2.46	0.725	0.33	0.169	45.06	0.183	8.095	16.985	76.28	186.19
2018	0.84	0.227	0.14	0.053	26.37	0.096	3.466	10.211	44.55	74.88
2019	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fall	1.12	0.300	0.22	0.122	18.50	0.093	8.090	14.985	31.91	137.00
Winter	2.93	0.420	0.26	0.121	33.93	0.099	6.792	14.405	62.20	146.33
Spring	0.78	0.193	0.11	0.050	18.74	0.120	4.520	12.148	28.53	99.72
Summer	1.65	0.869	0.32	0.140	63.48	0.207	4.064	12.812	105.55	133.56

Cherokee Creek Headwaters (Site 4)

The Cherokee Creek Headwaters monitoring site (Figure 7) lies between Hartford and Mansfield, Arkansas, and its watershed covers an area of 14 km^2 that is 84.5% forest, 1.1% urban and 9.4% agriculture. A pressure transducer was installed at site 4 on December 19, 2017, and stage measurements throughout the study (January 2018 – December 2020) ranged between 0.1 and 7.6 ft. Due to equipment malfunction, stage measurements were not collected for 19 days in January 2019 (i.e., January 8 – 26 2019). Baseflow discharge measurements were collected on 19 occasions throughout the project period, with baseflows ranging from 0.0 to 18.6 cfs. A SonTek-IQ was deployed between December 2018, and April 2019, and again from October 2019, to June 2020. Flows captured by the SonTek-IQ, above 1.5 ft stage, ranged between 35 and 2,300 cfs. Between SonTek-IQ and manual discharge measurements, 98.7% of all stage measurements were captured by flow measurements, (i.e., less than 2% of all stage measurements fell outside the range of measured flow).

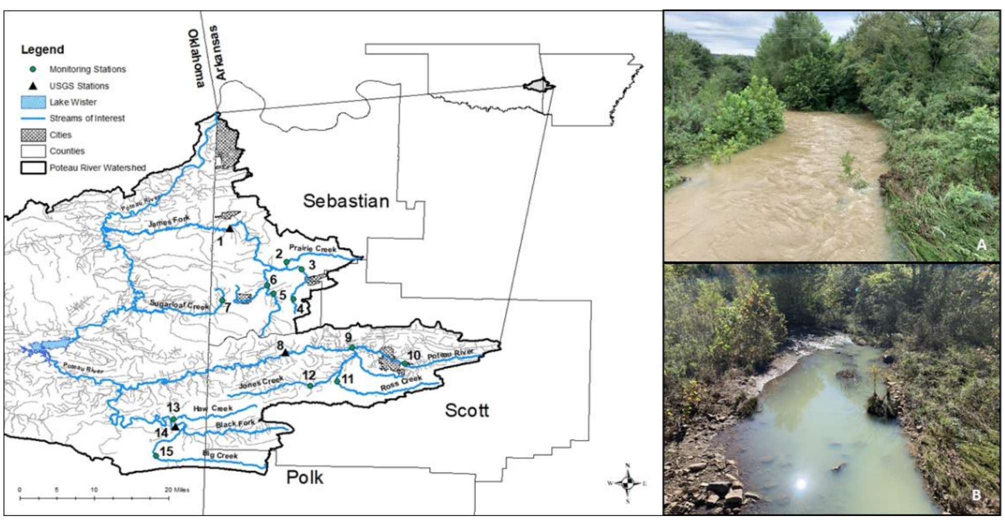


Figure 7: Upper Poteau River Watershed site map (left) and images of the Cherokee Creek Headwaters (Site 4) during storm flow (A) and baseflow conditions (B).

A total of 80 points were used from the SonTek-IQ data and combined with the baseflow discharge measurements to develop a rating curve. For the final rating curve (Figure 8), a two-point regression, with a slope of 0.04 ft^2/s, was used for stage values less than 1.31 ft. LOESS regression was used between 1.31 and 6.97 ft, where measured flow data exists, and Manning's equation was used to predict flows above 6.97 ft, with a Manning's n of 0.05. The rating curve was used to develop a continuous record of flow from January 2018 through December 2020 (except for the missing days of stage in January 2019).

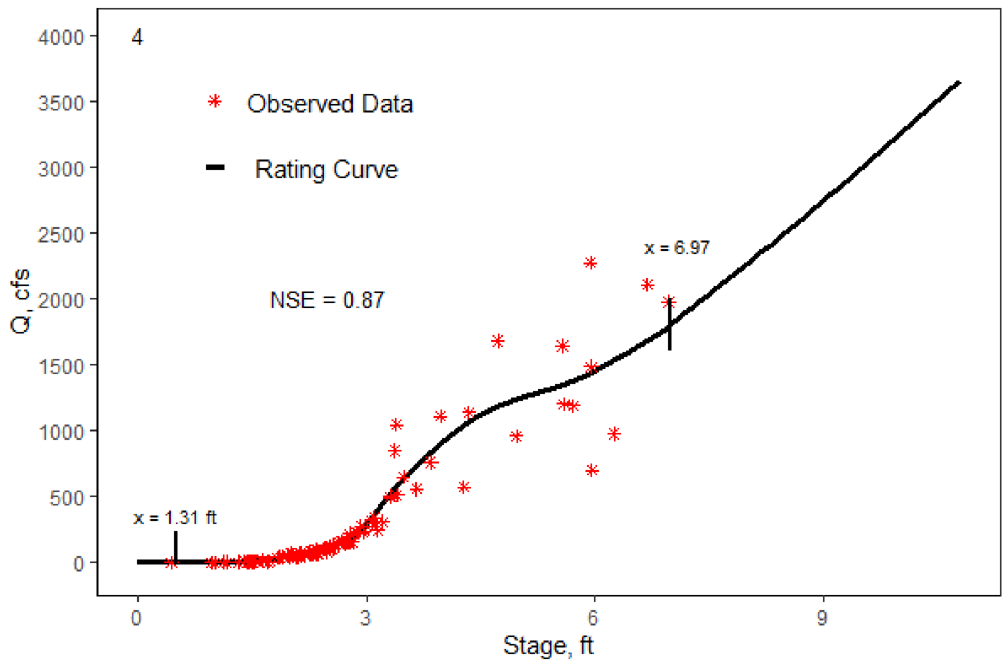


Figure 8: Rating curve for the Cherokee Creek Headwaters (Site 4). Two-point regression was used for stages below 1.31 ft, LOESS regression for stages between 1.31 and 6.97 ft, and Manning's equations for stages above 6.97 ft.

A total of 68 water samples were collected from site 4, with 36 during baseflow conditions and 32 during storm flow between October 2017 and September 2020. Water samples were collected across 97.6% of all stage measurements, with less than 1% of stage measurements falling above where water samples were collected, and 2.3% of stage measurements falling below. Constituent concentrations were generally greater in the 2017 project year (i.e., October 2017 – September 2018) compared to 2018 and 2019 (Table 8). Additionally, constituent concentrations were generally greatest in the summer months (i.e., June, July, and August), and least in spring months (i.e., March, April, and May). However, TSS, turbidity, and Fl concentrations were least and Cl concentrations were greatest in the winter months (i.e., December, January, and February).

Table 8: Project year (e.g., 2017 project year is October 1, 2017 through September 30, 2018) and seasonal mean concentrations for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), sulfate (SO_4^{2-}), turbidity and electrical conductivity (EC) at the Cherokee Creek Headwaters (Site 4).

Project Year/ Season	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}	Turbidity	EC
	mg L^{-1}								NTU	µS cm^{-1}
2017	0.73	0.235	0.16	0.087	18.05	0.088	7.969	14.684	48.39	94.24
2018	0.35	0.032	0.05	0.010	8.50	0.084	3.230	10.023	27.32	55.38
2019	0.41	0.081	0.06	0.026	8.03	0.096	4.083	12.168	25.44	68.79
Fall	0.49	0.097	0.09	0.045	9.10	0.091	5.129	11.658	27.61	74.16
Winter	0.42	0.088	0.06	0.017	6.22	0.060	6.135	12.848	25.54	73.52
Spring	0.38	0.052	0.05	0.012	7.53	0.080	3.539	10.879	27.13	59.13
Summer	0.59	0.174	0.13	0.066	19.53	0.121	4.687	12.975	47.06	76.22

Measured concentrations were multiplied by instantaneous flow (Q_i) to estimate constituent loads (L_i). The GAM for log transformed L_i, Q_i, and day of year (DOY) was used to develop a continuous record of constituent loads from January 2018 through December 2020 (except for the missing days of stage in January 2019). The R^2 and NSE values for each constituent's GAM were greater than 0.80, and all constituents but NN were greater than 0.90 (Table 9). Daily constituent loads were then estimated by integrating L_i over time, and then daily loads were summed into monthly (Appendix A) and annual loads (Table 9). Constituent loads in January 2019 may be underestimated due to 19 days of missing stage data. However, the USGS monitoring station in this watershed (James Fork- USGS 07249400) expressed mostly baseflow conditions during this time period, with two small storm event raising the stage by less than 5 ft each. Therefore, constituent loads during this time were likely small. Most constituent loads were greater in 2020 compared to 2018 and 2019, except for SRP and Cl, which were greatest in 2018. NN loads generally made up about 10% of TN loads, while SRP loads made up closer to

25% of TP loads. However, NN made up about 20% of TN concentrations and SRP made up about 38% of TP concentrations each year.

Table 9: Generalized additive model (GAM) R^2 and Nash-Sutcliffe Efficiency (NSE), mean daily loads (kg day^{-1}) with 95% confidence intervals, and calendar year annual loads (kg) for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), and sulfate (SO_4^{2-}) at the Cherokee Creek Headwaters (Site 4). Additionally, the mean daily flow (Q_d) for each calendar year (cfs).

Constituent	R^2	NSE	Mean Daily Load	2018	2019	2020
Q_d	--	--	--	9	13	13
TN	0.976	0.978	13 (8-23)	1,410,000	1,606,000	2,203,000
NN	0.873	0.882	1 (0-3)	129,000	146,000	179,000
TP	0.967	0.975	2 (1-4)	265,000	208,000	297,000
SRP	0.936	0.954	1 (0-2)	92,000	45,000	77,000
TSS	0.962	0.958	459 (157-1,421)	38,470,000	44,708,000	97,715,000
Fl	0.952	0.954	2 (1-3)	217,000	290,000	326,000
Cl	0.990	0.991	59 (48-75)	216,000	144,000	144,000
SO_4^{2-}	0.993	0.994	232 (191-285)	24,316,000	34,964,000	32,101,000

James Fork Headwaters (Site 5)

The James Fork Headwaters monitoring site (Figure 9) lies near Hartford, Arkansas, and its watershed covers an area of 39 km^2 that is 84.7% forest, 1.2% urban and 8.9% agriculture. A pressure transducer was installed at site 5 on December 19, 2017, and stage measurements throughout the study (January 2018 – December 2020) ranged between 0.0 and 9.3 ft. Due to equipment malfunction, stage measurements were not collected for 19 days in January 2019 (i.e., January 8 – 26 2019). Baseflow discharge measurements were collected on 15 occasions throughout the project period, with baseflows ranging from 0.2 to 63.6 cfs. A SonTek-IQ was deployed between January and June 2018, and flows captured by the SonTek-IQ, above 1.5 ft stage, ranged between 55 and 1,100 cfs. Between SonTek-IQ and manual discharge measurements, 92.9% of all stage measurements were captured by flow measurements, (i.e., less than 8% of all stage measurements fell outside the range of measured flow).

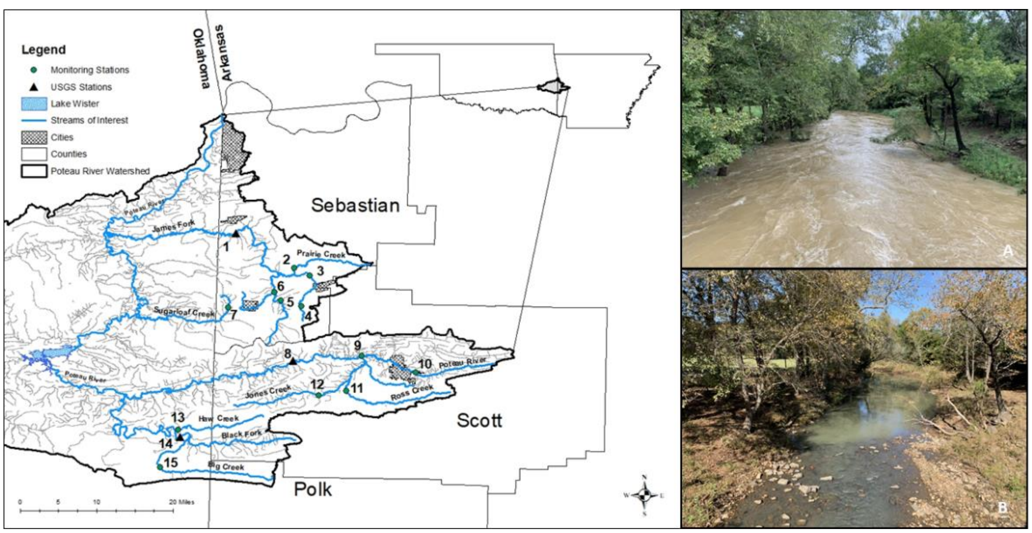


Figure 9: Upper Poteau River Watershed site map (left) and images of the James Fork Headwaters (Site 5) during storm flow (A) and baseflow conditions (B).

A total of 35 points were used from the SonTek-IQ data and combined with the baseflow discharge measurements to develop a rating curve. For the final rating curve (Figure 10), a two-point regression with a slope of 0.95 ft^2/s was used for stage values less than 1.15 ft. LOESS regression was used between 1.15 and 3.95 ft, where measured flow data exists, and Manning's equation was used to predict flows above 3.95 ft, with a Manning's n of 0.022. The rating curve was used to develop a continuous record of flow from January 2018 through December 2020 (except for the missing days of stage in January 2019).

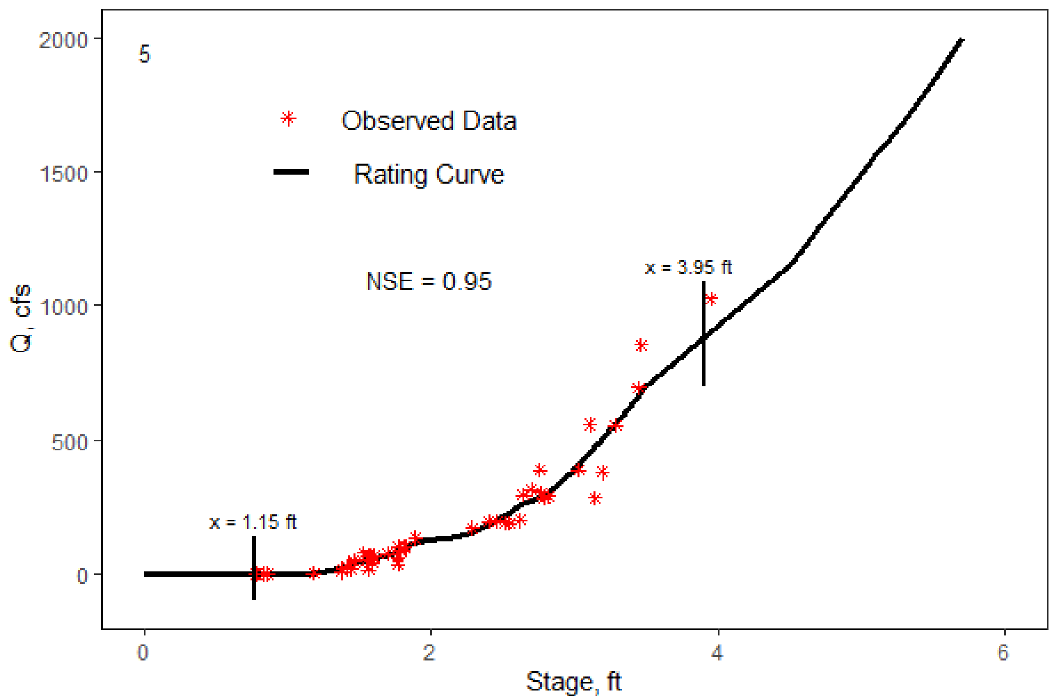


Figure 10: Rating curve for the James Fork Headwaters (Site 5). Two-point regression was used for stages below 1.15 ft, LOESS regression for stages between 1.15 and 3.95 ft, and Manning's equations for stages above 3.95 ft.

A total of 78 water samples were collected from site 5, with 38 during baseflow conditions and 40 during storm flow between October 2017 and September 2020. Water samples were collected across 98.3% of all stage measurements, with less than 1% of stage measurements falling above where water samples were collected, and 1.6% of stage measurements falling below. Constituent concentrations were generally greater in the 2017 project year (i.e., October 2017 – September 2018) compared to 2018 and 2019 (Table 10). Additionally, constituent concentrations were generally greatest in the summer months (i.e., June, July, and August), and least in spring months (i.e., March, April, and May). However, NN, SRP and Cl concentrations were greatest in the fall months (i.e., September, October, and November), and Fl and SO_4^{2-} were least in the winter months (i.e., December, January, and February).

Table 10: Project year (e.g., 2017 project year is October 1, 2017 through September 30, 2018) and seasonal mean concentrations for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), sulfate (SO_4^{2-}), turbidity and electrical conductivity (EC) at the James Fork Headwaters (Site 5).

Project Year/ Season	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}	Turbidity	EC
	------- mg L^{-1} -------								NTU	µS cm^{-1}
2017	0.76	0.173	0.20	0.081	43.69	0.054	4.031	38.998	42.78	151.33
2018	0.38	0.108	0.08	0.005	47.93	0.087	2.404	20.341	56.53	80.00
2019	0.44	0.105	0.09	0.038	25.58	0.090	3.157	24.911	33.46	105.91
Fall	0.60	0.180	0.15	0.091	32.03	0.074	3.944	31.803	32.48	132.92
Winter	0.55	0.144	0.12	0.034	30.19	0.063	3.366	20.611	43.71	88.94
Spring	0.27	0.066	0.03	0.004	13.16	0.069	2.628	24.080	21.60	93.53
Summer	0.63	0.113	0.17	0.035	75.68	0.100	2.841	37.172	73.16	138.23

Measured concentrations were multiplied by instantaneous flow (Q_i) to estimate constituent loads (L_i). The GAM for log transformed L_i, Q_i, and day of year (DOY) was used to develop a continuous record of constituent loads from January 2018 through December 2020 (except for the missing days of stage in January 2019). The R^2 and NSE values for each constituent's GAM were greater than 0.80, and all constituents but SRP were greater than 0.90 (Table 11). Daily constituent loads were then estimated by integrating L_i over time, and then daily loads were summed into monthly (Appendix A) and annual loads (Table 11). Constituent loads in January 2019 may be underestimated due to 19 days of missing stage data. However, the USGS monitoring station in this watershed (James Fork- USGS 07249400) expressed mostly baseflow conditions during this time period, with two small storm event raising the stage by less than 5 ft each. Therefore, constituent loads during this time were likely small. Most constituent loads were greatest in the 2020, except for NN and SRP, which were greatest in 2018, and Cl and SO_4^{2-}, which were greatest in 2019. NN loads generally made up about 16% of TN loads, while SRP loads made up about 11% of TP loads. However, NN made up about 15% of TN concentrations and SRP made up about 10% of TP concentrations each year.

Table 11: Generalized additive model (GAM) R^2 and Nash-Sutcliffe Efficiency (NSE), mean daily loads (kg day^{-1}) with 95% confidence intervals, and calendar year annual loads (kg) for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), and sulfate (SO_4^{2-}) at the James Fork Headwaters (Site 5). Additionally, the mean daily flow (Q_d) for each calendar year (cfs).

Constituent	R^2	NSE	Mean Daily Load	2018	2019	2020
Q_d	--	--	--	32	47	42
TN	0.964	0.969	47 (28-79)	5,794,000	5,790,000	6,888,000
NN	0.920	0.933	7 (3-14)	1,111,000	844,000	670,000
TP	0.937	0.944	14 (6-34)	1,273,000	1,356,000	3,008,000
SRP	0.897	0.929	1 (0-5)	204,000	103,000	122,000
TSS	0.964	0.971	6,355 (2,584-15,969)	416,350,000	874,984,000	1,211,851,000
Fl	0.941	0.944	7 (5-10)	708,000	956,000	999,000
Cl	0.990	0.994	199 (141-280)	25,243,000	29,274,000	23,687,000
SO_4^{2-}	0.963	0.966	1,019 (803-1,300)	123,177,000	152,960,000	125,570,000

Lower James Fork (Site 6)

The Lower James Fork monitoring site (Figure 11) lies near Hartford, Arkansas, and its watershed covers an area of 95 km^2 that is 69.9% forest, 3.5% urban and 18.3% agriculture. A pressure transducer was installed at site 6 on December 20, 2017, and stage measurements throughout the study (January 2018 – December 2020) ranged between 1.1 and 13.9 ft. Due to equipment malfunction, stage measurements were not collected for 19 days in January 2019 (i.e., January 8 – 26, 2019). Baseflow discharge measurements were collected on 12 occasions throughout the project period, with baseflows ranging from 0.0 to 29.4 cfs. A SonTek-IQ was deployed between February and June 2018, and flows captured by the SonTek-IQ, above 1.5 ft stage, ranged between 7.8 and 3,100 cfs. Between SonTek-IQ and manual discharge measurements, 95.6% of all stage measurements were captured by flow measurements, (i.e., less than 5% of all stage measurements fell outside the range of measured flow).

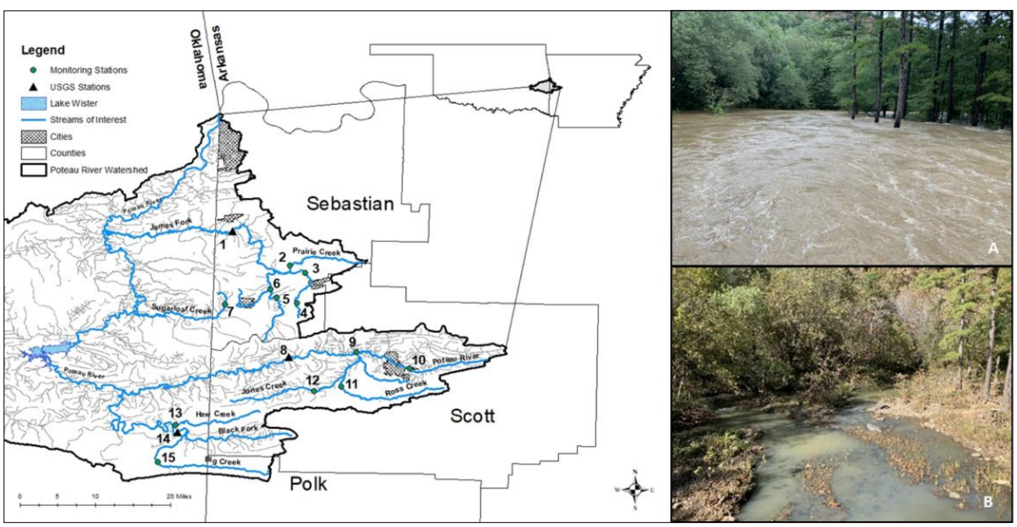


Figure 11: Upper Poteau River Watershed site map (left) and images of the Lower James Fork (Site 6) during storm flow (A) and baseflow conditions (B).

A total of 45 points were used from the SonTek-IQ data and combined with the baseflow discharge measurements to develop a rating curve. For the final rating curve (Figure 12), a two-point regression with a slope of 0.21 ft^2/s was used for stage values less than 1.69 ft. LOESS regression was

used between 1.69 and 9.06 ft, where measured flow data exists, and Manning's equation was used to predict flows above 9.06 ft, with a Manning's n of 0.03. The rating curve was used to develop a continuous record of flow from January 2018 through December 2020 (except for the missing days of stage in January 2019).

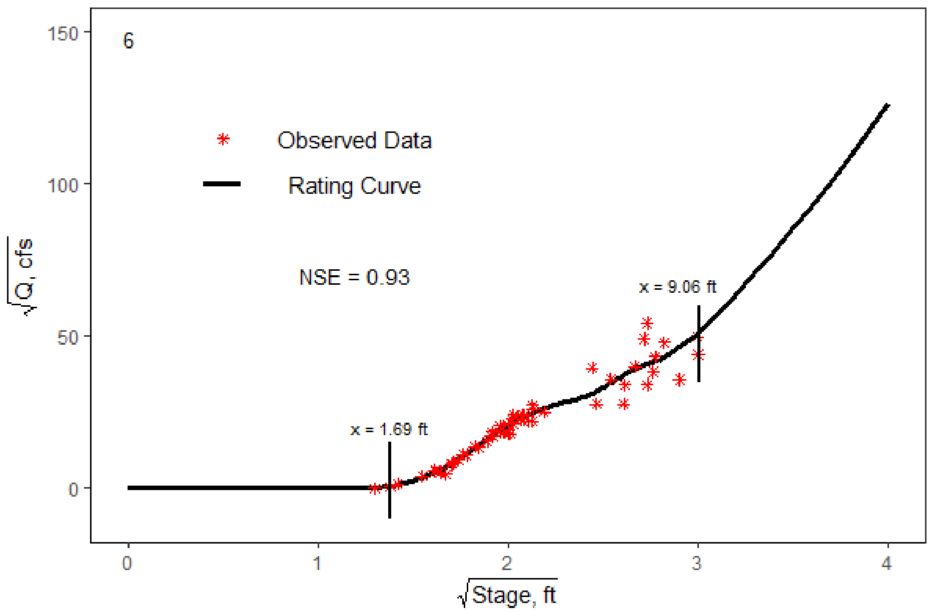


Figure 12: Rating curve for the Lower James Fork (Site 6). Two-point regression was used for stages below 1.69 ft, LOESS regression for stages between 1.69 and 9.06 ft, and Manning's equations for stages above 9.06 ft.

A total of 76 water samples were collected from site 6, with 37 during baseflow conditions and 39 during storm flow between October 2017 and September 2020. Water samples were collected across 98.3% of all stage measurements, with less than 1% of stage measurements falling above where water samples were collected, and 1.6% of stage measurements falling below. Constituent concentrations were generally greater in the 2017 project year (i.e., October 2017 – September 2018) compared to 2018 and 2019 (Table 12). Additionally, constituent concentrations were generally the least in spring months (i.e., March, April, and May), except for Fl which was the least in the winter (i.e., December, January, and February). The seasons with the greatest concentrations were more variable across constituents, with TN, NN, Cl and SO_4^{2-} being the greatest in the winter, TP, SRP, Fl and EC in the fall (i.e., September, October, and November), and TSS and turbidity in the summer (i.e., June, July and August).

Table 12: Project year (e.g., 2017 project year is October 1, 2017 through September 30, 2018) and seasonal mean concentrations for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), sulfate (SO_4^{2-}), turbidity and electrical conductivity (EC) at the Lower James Fork (Site 6).

Project Year/ Season	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}	Turbidity	EC
	------------------------------- mg L^{-1} -------------------------------								NTU	µS cm^{-1}
2017	0.99	0.258	0.26	0.115	113.02	0.082	3.827	32.725	117.50	140.03
2018	0.58	0.094	0.14	0.040	45.50	0.092	2.859	21.990	66.63	95.61
2019	0.71	0.178	0.22	0.125	57.90	0.117	3.394	25.595	60.09	112.49
Fall	0.81	0.202	0.27	0.187	44.46	0.118	4.044	28.068	52.67	124.09
Winter	0.92	0.246	0.25	0.098	61.64	0.068	4.092	29.255	100.03	122.94
Spring	0.52	0.070	0.10	0.031	26.64	0.085	2.721	23.323	40.22	97.46
Summer	0.78	0.191	0.20	0.069	141.55	0.116	2.793	27.345	123.18	121.50

Measured concentrations were multiplied by instantaneous flow (Q_i) to estimate constituent loads (L_i). The GAM for log transformed L_i, Q_i, and day of year (DOY) was used to develop a continuous record of constituent loads from January 2018 through December 2020 (except for the missing days of stage in January 2019). The R^2 and NSE values for each constituent's GAM were greater than 0.80, and all constituents but SRP were greater than 0.90 (Table 13). Daily constituent loads were then estimated by integrating L_i over time, and then daily loads were summed into monthly (Appendix A) and annual loads (Table 13). Constituent loads in January 2019 may be underestimated due to 19 days of missing stage data. However, the USGS monitoring station in this watershed (James Fork- USGS 07249400) expressed mostly baseflow conditions during this time period, with two small storm event raising the stage by less than 5 ft each. Therefore, constituent loads during this time were likely small. Constituent loads were greatest in 2020 compared to 2018 and 2019. NN loads generally made up about 17% of TN loads, while SRP loads made up about 33% of TP loads. However, NN made up about 23% of TN concentrations and SRP made up about 44% of TP concentrations each year.

Table 13: Generalized additive model (GAM) R^2 and Nash-Sutcliffe Efficiency (NSE), mean daily loads (kg day^{-1}) with 95% confidence intervals, and calendar year annual loads (kg) for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), and sulfate (SO_4^{2-}) at the Lower James Fork (Site 6). Additionally, the mean daily flow (Q_d) for each calendar year (cfs).

Constituent	R^2	NSE	Mean Daily Load	2018	2019	2020
Q_d	--	--	--	64	79	93
TN	0.978	0.980	158 (107-239)	17,317,000	19,076,000	25,963,000
NN	0.881	0.889	28 (13-65)	2,709,000	3,513,000	4,827,000
TP	0.966	0.969	52 (30-93)	4,836,000	5,957,000	9,876,000
SRP	0.929	0.937	19 (7-53)	1,938,000	1,650,000	3,832,000
TSS	0.974	0.978	17,578 (8,047-40,371)	1,455,028,000	2,185,492,000	3,282,371,000
Fl	0.980	0.983	16 (12-25)	1,929,000	2,117,000	2,595,000
Cl	0.994	0.996	474 (366-617)	59,666,000	59,915,000	67,247,000
SO_4^{2-}	0.993	0.995	3,266 (2,377-4,513)	410,050,000	410,849,000	465,393,000

Upper Sugar Loaf Creek (Site 7)

The Upper Sugar Loaf Creek monitoring site (Figure 13) is near Hartford, Arkansas, and its watershed covers an area of 7 km^2 that is 88.6% forest, 1.6% urban and 1.3% agriculture. A pressure transducer was installed at site 7 on December 20, 2017, and stage measurements throughout the study (January 2018 – December 2020) ranged between 0.0 and 5.8 ft. Due to equipment malfunction, stage measurements were not collected for 18 days in January 2019 (i.e., January 8 – 18 2019). Baseflow discharge measurements were collected on 12 occasions throughout the project period, with baseflows ranging from 0 to 6.0 cfs. Due to time constraints, a SonTek-IQ was not deployed at this site.

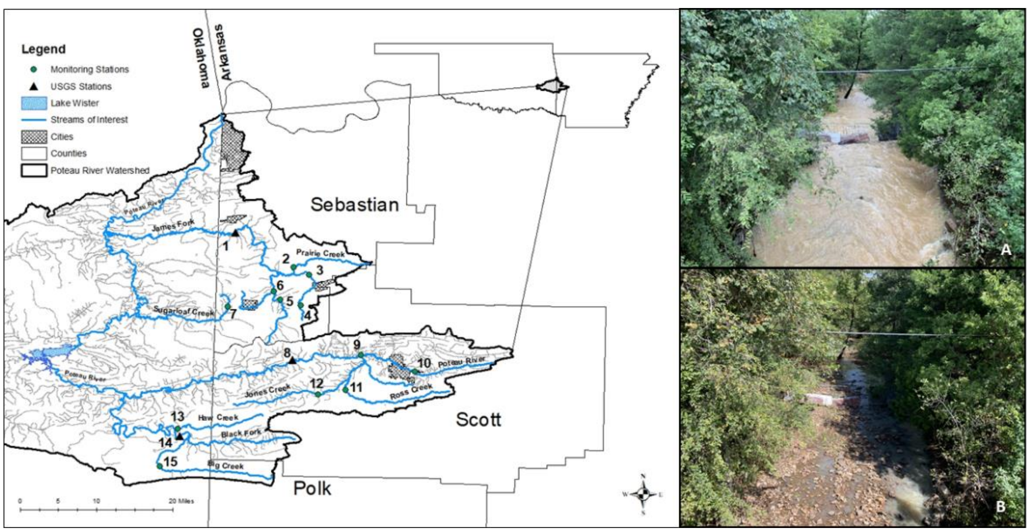


Figure 13: Upper Poteau River Watershed site map (left) and images of Upper Sugar Loaf Creek (Site 7) during storm flow (A) and baseflow conditions (B).

A total of 66 water samples were collected from site 2, with 35 during baseflow conditions and 31 during storm flow between October 2017 and September 2020. Water samples were collected across 97.0% of all stage measurements, with less than 1% of stage measurements falling above where water samples were collected, and 2.9% of stage measurements falling below. Constituent concentrations were generally greater in the 2017 project year (i.e., October 2017 – September 2018) compared to 2018 and 2019 (Table 14). TN, NN, Cl, and EC were greatest in the winter months (i.e., December, January, and February), and generally the least in the fall months (i.e., September, October, and November. However, TP, SRP, TSS, Fl and turbidity were greatest in the summer months (i.e., June, July, and August), and generally the least in the winter months.

Table 14: Project year (e.g., 2017 project year is October 1, 2017 through September 30, 2018) and seasonal mean concentrations for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), sulfate (SO_4^{2-}), turbidity and electrical conductivity (EC) at Upper Sugar Loaf Creek (Site 7).

Project Year/ Season	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}	Turbidity	EC
	----------	----------	----------	----------	mg L^{-1}	----------	----------	----------	NTU	µS cm^{-1}
2017	0.79	0.530	0.08	0.006	51.06	0.074	6.617	12.531	94.77	79.63
2018	0.30	0.082	0.06	0.004	13.98	0.097	4.115	12.904	59.48	63.78
2019	0.30	0.094	0.05	0.005	11.18	0.117	4.843	12.842	49.28	71.42
Fall	0.34	0.130	0.05	0.005	7.81	0.107	5.016	12.663	50.28	68.30
Winter	0.69	0.509	0.05	0.004	9.24	0.067	5.589	13.307	44.76	74.80
Spring	0.34	0.131	0.05	0.005	8.11	0.101	4.163	13.810	50.87	68.69
Summer	0.41	0.121	0.09	0.005	60.06	0.114	5.440	11.613	106.69	72.10

USGS 07247000- Poteau River (Site 8)

Constituent Loads

The USGS gaging station on the Poteau River (Figure 14) is near Cauthron, Arkansas, and its watershed covers an area of 527 km^2 that is 63.7% forest, 5.6% urban and 21.3% agriculture. Flow measurements for the project period of October, 2017 and September, 2020 ranged from 0.01 and 20,200 cfs. A total of 115 water samples were collected during the project period, with 75 during baseflow conditions and 40 during storm flow. Water samples were collected across 98.8% of all flow measurements, with 0.1% flow measurements falling above where water samples were collected, and 1.1% of flow measurements falling below.

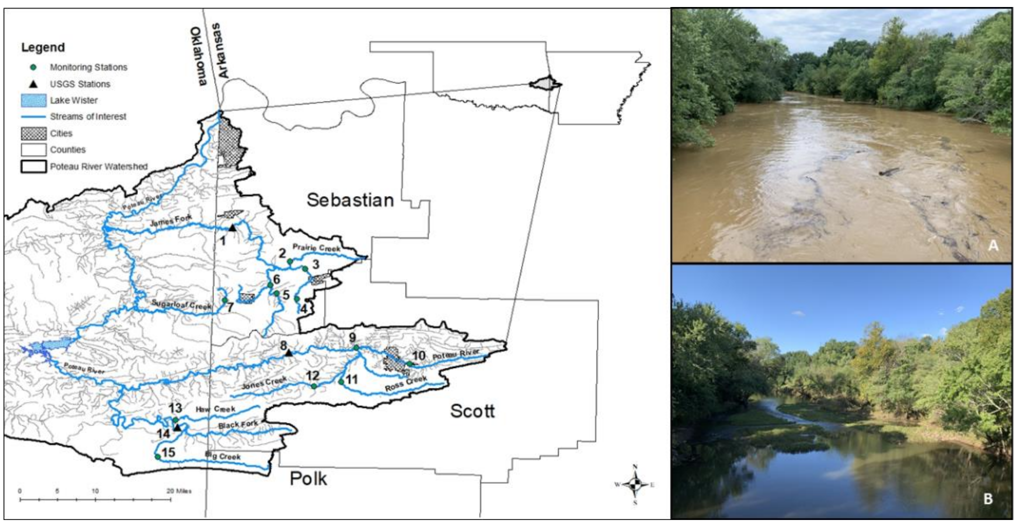


Figure 14: Upper Poteau River Watershed site map (left) and images of the Poteau River (Site 8) during storm flow (A) and baseflow conditions (B).

Constituent concentrations of TP, SRP, TSS, Fl and turbidity were greatest in the 2018 project year (i.e., October, 2018 – September, 2019), while TN and NN were greatest in the 2019 project year, and Cl SO_4^{2-}, and EC were greatest in the 2017 project year (Table 15). Additionally, constituent concentrations were generally greatest in the winter months (i.e., December, January and February), and least in spring months (i.e., March, April, and May).

Table 15: Project year (e.g., 2017 project year is October 1, 2017 through September 30, 2018) and seasonal mean concentrations for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), sulfate (SO_4^{2-}), turbidity and electrical conductivity (EC) at the Poteau River (USGS 07247000, Site 8).

Project Year/ Season	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}	Turbidity	EC
	----------	----------	----------	----------	mg L^{-1}	----------	----------	----------	NTU	µS cm^{-1}
2017	0.95	0.267	0.15	0.046	39.06	0.057	13.720	9.019	44.76	144.26
2018	0.88	0.243	0.17	0.054	43.87	0.076	5.596	7.265	53.93	71.98
2019	0.99	0.388	0.14	0.051	35.40	0.072	7.086	6.782	34.44	89.78
Fall	0.95	0.356	0.11	0.046	18.05	0.062	13.375	7.570	24.47	128.71
Winter	1.04	0.378	0.20	0.071	54.69	0.053	7.531	8.896	62.71	101.76
Spring	0.78	0.188	0.14	0.042	42.31	0.073	3.945	7.001	47.19	61.97
Summer	0.98	0.285	0.14	0.045	41.34	0.083	10.430	7.226	41.48	114.89

Measured concentrations were multiplied by instantaneous flow (Q_i) to estimate constituent loads (L_i). The R^2 and NSE values for each constituent's GAM were greater than 0.80, and all constituents but Fl were greater than 0.90 (Table 16). Daily constituent loads were then estimated by integrating L_i over time, and then daily loads were summed into monthly (Appendix A) and annual loads (Table 16). Constituent loads were greatest in the 2019 project year. NN loads generally made up about 26% of TN loads, while SRP loads made about 33% of TP loads. SRP concentrations also made up about 33% of TP concentrations each year, but NN made up about 32% of TN concentrations each year.

Table 16: Generalized additive model (GAM) R^2 and Nash-Sutcliffe Efficiency (NSE), mean daily loads (kg day^{-1}) with 95% confidence intervals, and project year (e.g., 2017 project year is October 1, 2017 through September 30, 2018) annual loads (kg) for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), and sulfate (SO_4^{2-}) at the Poteau River (USGS 07247000, Site 8). Additionally, the mean daily flow (Q_d) for each project year (cfs).

Constituent	R^2	NSE	Mean Daily Load	2017	2018	2019
Q_d	--	--	--	205	505	651
TN	0.986	0.987	953 (783-1,164)	58,865,000	129,420,000	193,480,000
NN	0.946	0.951	254 (123-537)	14,466,000	36,026,000	51,038,000
TP	0.961	0.964	202 (148-279)	12,811,000	25,274,000	42,968,000
SRP	0.939	0.949	71 (34-149)	3,907,000	8,040,000	16,362,000
TSS	0.970	0.973	59,810 (41,276-87,241)	3,658,104,000	7,072,929,000	13,217,249,000
Fl	0.877	0.892	66 (38-114)	3,257,000	9,253,000	13,808,000
Cl	0.992	0.993	3,056 (2,342-4,004)	185,338,000	445,563,000	592,901,000
SO_4^{2-}	0.981	0.983	6,944 (5,247-9,217)	407,296,000	1,018,190,000	1,354,743,000

Trend Analysis

Trend analysis at the Poteau River was conducted using over 20 years of available flow and water quality data from the USGS. Sediments, P and TN generally increased with discharge, while NN was more variable at higher flows. LOESS was fit to each concentration and discharge relationship with sampling proportions of 0.4 – 0.7 (Table 17), and LOESS had relatively low RMSEs (< 0.35).

Trends were identified in all flow-adjusted concentrations over time (i.e., 1995 – 2020), but the direction varied by constituent. The specific changes include:

- TN likely increased ($0.05 < p < 0.20$) at 0.44 % yr^{-1}, showing a change point in May 2007 (Figure 15, A); average TN FACs were 9% greater after 2007 compared to before 2007.
- NN extremely likely increased ($p < 0.05$, Figure 15, B) at a rate of 1.23 % yr^{-1}, but no change point in NN FACs occurred over time.
- TP extremely likely decreased ($p < 0.05$) at -1.53 % yr^{-1}, with a change point in August 2002, resulting in a 22% decrease in mean FACs (Figure 15, C).
- SRP extremely likely decreased ($p < 0.05$) with the greatest magnitude of change compared to other constituents (-2.55 % yr^{-1}), and one change point in SRP FACs occurred in October 2003 (Figure 15, D) where mean FACs were 32% less after 2003.
- SS extremely likely decreased ($p < 0.05$) at -2.15 % yr^{-1}, and one change point occurred in October 2002 (Figure 15, E) resulting in a 32% decrease in mean FACs.

Table 17: Optimal LOESS Sampling Proportion, LOESS RMSE, Linear Model Slope, Linear Model p-Value, Seasonal Kendall's Test (SKT) Sen's Slope, and Seasonal Kendall's Test p-Value for Trends in Flow Adjusted Concentrations (FACS) for each Parameter the Poteau River (USGS 07247000, Site 8).

Parameter	LOESS Sampling Proportion	LOESS RMSE	Linear Model Slope (%/yr)	Linear Model p-Value	SKT Sen's Slope (%/yr)	SKT p-Value
TN	0.7	0.14	0.44	0.019	0.30	0.010
NN	0.7	0.36	1.23	0.015	0.62	0.045
TP	0.5	0.28	-1.53	<0.01	-1.37	<0.01
SRP	0.5	0.46	-2.55	<0.01	-2.71	<0.01
SS	0.6	0.3	-2.15	<0.01	-2.16	<0.01

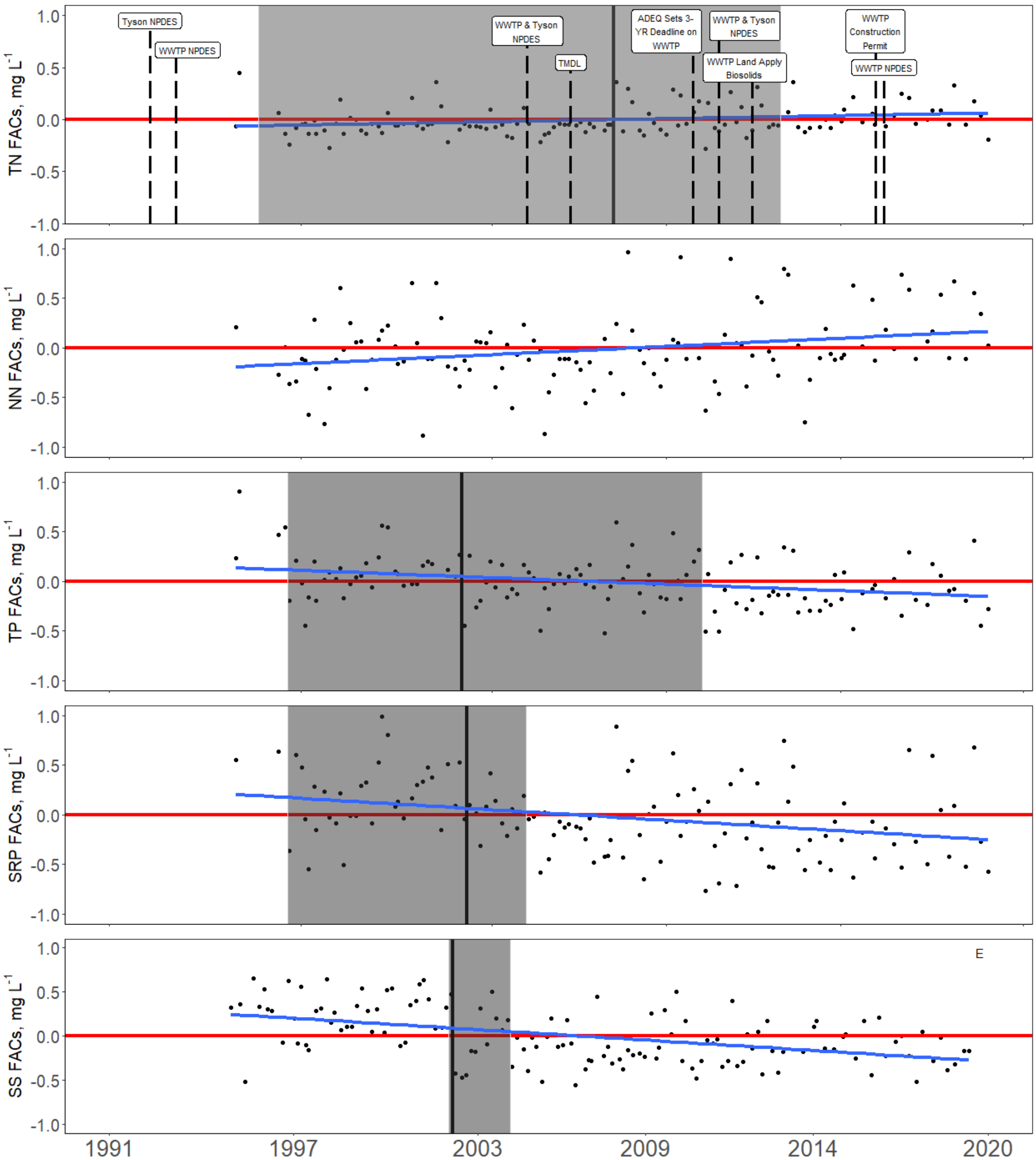


Figure 15: Trends in Flow Adjusted Concentrations (FACs) of Total Nitrogen (TN), Total Phosphorus (TP), Suspended Sediments (SS), Nitrate+Nitrite (NN), and Soluble Reactive Phosphorus (SRP) at the Poteau River. The FACs were truncated from -1 to 1 for consistency. This may cause a few data points to be missing from the figure, but all data were included in trend analysis. Significant change points are identified by solid vertical lines, the grey areas are the 95% confidence intervals around the change points, and significant linear model slopes are identified by solid blue lines. A timeline of events related to Nonpoint Source Discharge Elimination System (NPDES) permits and other significant milestones for the point sources on the Poteau River is shown in Figure A.

Lower Poteau River (Site 9)

The Lower Poteau River monitoring site (Figure 16) lies just downstream of Waldron, Arkansas, and its watershed covers an area of 193 km^2 that is 51.6% forest, 7.7% urban and 32.0% agriculture. A pressure transducer was installed at site 9 on December 19, 2017, and stage measurements throughout the study (January 2018 – December 2020) ranged between 1.3 and 22.9 ft. Baseflow discharge measurements were collected on 14 occasions throughout the project period, with baseflows ranging from 1.5 to 108.9 cfs. A SonTek-IQ was deployed between October 2019 and June 2020, and flows captured by the SonTek-IQ, above 1.5 ft stage, ranged between 200 and 7,500 cfs. Between SonTek-IQ and manual discharge measurements, 99.9% of all stage measurements were captured by flow measurements, (i.e., less than 1% of all stage measurements fell outside the range of measured flow).

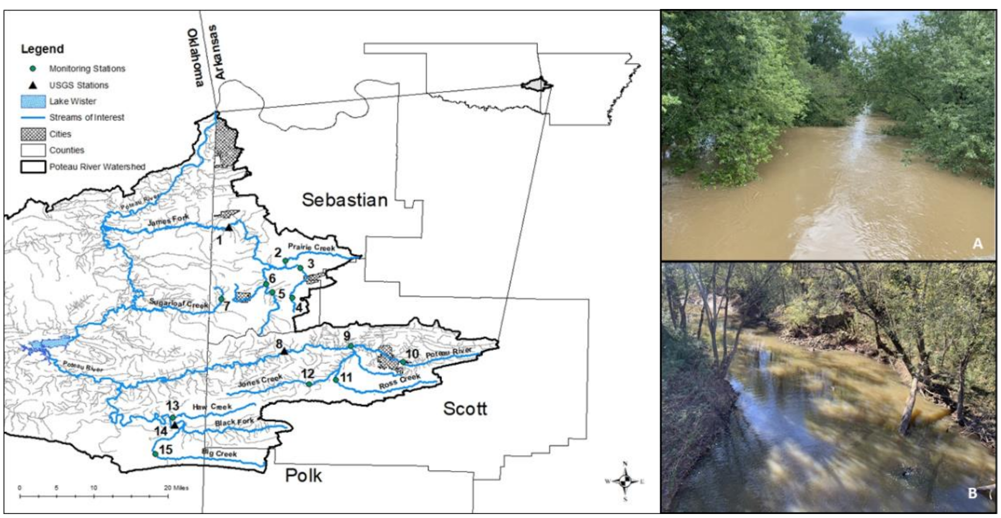


Figure 16: Upper Poteau River Watershed site map (left) and images of the Lower Poteau River (Site 9) during storm flow (A) and baseflow conditions (B).

A total of 132 points were used from the SonTek-IQ data and combined with the baseflow discharge measurements to develop a rating curve. For the final rating curve (Figure 17), a two-point regression with a slope of 0.31 ft^2/s for stage values less than 1.70 foot. LOESS regression was used between 1.70 and 21.72 ft, where measured flow data exists, and Manning's equation was used to predict flows above 21.72 ft, with a Manning's n of 0.07. The rating curve was used to develop a continuous record of flow from January 2018 through December 2020.

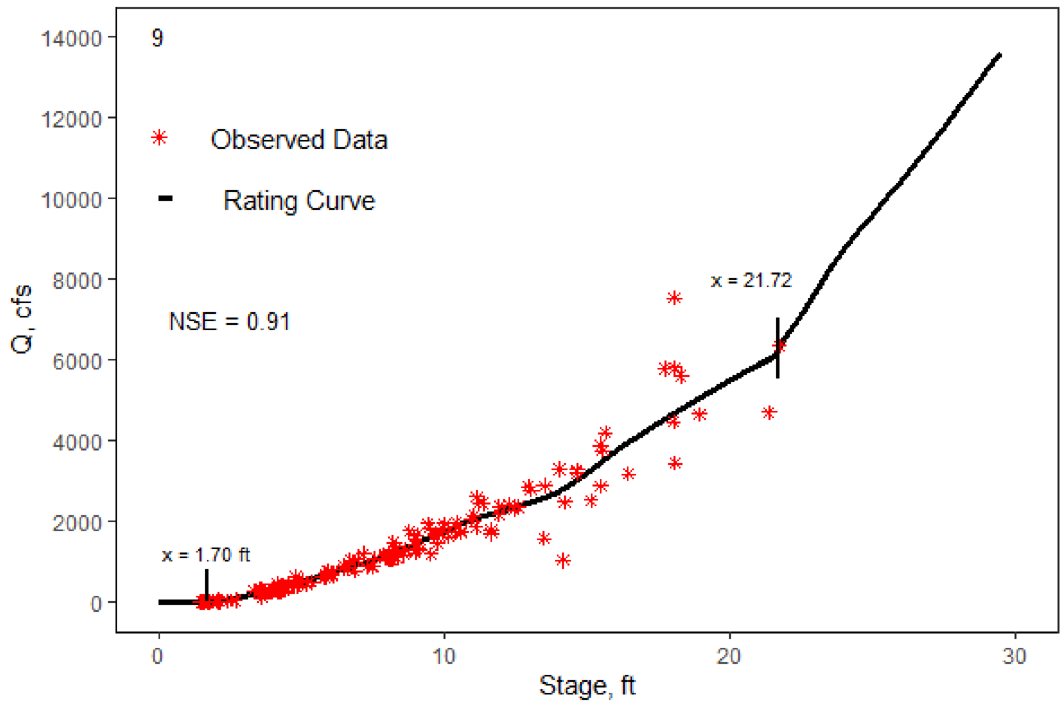


Figure 17: Rating curve for the Lower Poteau River (Site 9). Two-point regression was used for stages below 1.7 ft, LOESS regression for stages between 1.7 and 21.72 ft, and Manning's equations for stages above 21.72 ft.

A total of 72 water samples were collected from site 9, with 39 during baseflow conditions and 33 during storm flow between October 2017 and September 2020. Water samples were collected across 99.7% of all stage measurements, with less than 1% of stage measurements falling above and below where water samples were collected. Constituent concentrations were generally greater in the 2017 project year (i.e., October 2017 – September 2018) compared to 2018 and 2019 (Table 18), except for TN, NN and Fl, which were greatest in the 2019 project year. Additionally, constituent concentrations were generally greatest in the summer months (i.e., June, July, and August), and least in spring months (i.e., March, April, and May). However, Cl, EC and SO_4^{2-} concentrations were greatest in the fall months (i.e., September, October, and November) and least in spring months.

Table 18: Project year (e.g., 2017 project year is October 1, 2017 through September 30, 2018) and seasonal mean concentrations for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), sulfate (SO_4^{2-}), turbidity and electrical conductivity (EC) at the Lower Poteau River (Site 9).

Project Year/ Season	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}	Turbidity	EC
	---------------------------------- mg L^{-1}							----------------------------------	NTU	µS cm^{-1}
2017	2.50	1.533	0.39	0.230	71.93	0.070	35.879	17.829	75.61	300.21
2018	1.39	0.484	0.25	0.128	44.32	0.074	7.329	8.591	58.31	86.77
2019	3.14	2.356	0.33	0.210	48.56	0.079	12.535	9.986	46.03	168.45
Fall	2.57	1.580	0.31	0.207	28.33	0.069	26.532	15.453	34.01	270.68
Winter	1.97	1.123	0.27	0.141	44.94	0.062	15.543	12.778	58.48	154.61
Spring	1.04	0.256	0.22	0.102	42.14	0.072	5.724	8.066	53.20	79.96
Summer	3.38	2.489	0.42	0.264	87.58	0.091	18.640	10.290	78.33	185.37

Measured concentrations were multiplied by instantaneous flow (Q_i) to estimate constituent loads (L_i). The GAM for log transformed L_i, Q_i, and day of year (DOY) was used to develop a continuous record of constituent loads from January 2018 through December 2020. The R^2 and NSE values for each constituent's GAM were greater than 0.80, and all constituents but NN were greater than 0.90 (Table 19). Daily constituent loads were then estimated by integrating L_i over time, and then daily loads were summed into monthly (Appendix A) and annual loads (Table 19). Constituent loads were greater in 2020 compared to 2018 and 2019. NN loads generally made up about 28% of TN loads, while SRP loads made up closer to 43% of TP loads. However, NN and SRP made up about 57% of TN and TP concentrations each year.

Table 19: Generalized additive model (GAM) R^2 and Nash-Sutcliffe Efficiency (NSE), mean daily loads (kg day^{-1}) with 95% confidence intervals, and calendar year annual loads (kg) for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), and sulfate (SO_4^{2-}) at the Lower Poteau River (Site 9). Additionally, the mean daily flow (Q_d) for each calendar year (cfs).

Constituent	R^2	NSE	Mean Daily Load	2018	2019	2020
Q_d	--	--	--	162	206	310
TN	0.963	0.967	640 (462-889)	64,926,000	75,269,000	116,022,000
NN	0.891	0.907	180 (105-309)	19,004,000	21,320,000	31,720,000
TP	0.975	0.981	146 (91-236)	14,622,000	14,790,000	29,362,000
SRP	0.947	0.954	64 (37-111)	6,125,000	6,780,000	12,840,000
TSS	0.980	0.989	29,710 (12,180-74,315)	2,819,108,000	2,759,340,000	6,307,051,000
Fl	0.967	0.969	37 (27-51)	3,589,000	4,547,000	6,919,000
Cl	0.954	0.966	2,409 (1,560-3,743)	244,470,000	320,123,000	399,121,000
SO_4^{2-}	0.983	0.985	4,057 (3,173-5,199)	408,097,000	515,280,000	699,963,000

Poteau River Headwaters (Site 10)

The Poteau River Headwaters monitoring site (Figure 18) lies just upstream of Waldron, Arkansas, and its watershed covers an area of 39 km^2 that is 52.7% forest, 5.5% urban and 33.1% agriculture. A pressure transducer was installed at site 10 on December 20, 2017, and stage measurements throughout the study (January 2018 – December 2020) ranged between 0.3 and 12.1 ft. Due to equipment malfunction, stage measurements were not collected for 18 days in January 2019 (i.e., January 8 – 25 2019). Baseflow discharge measurements were collected on 16 occasions throughout the project period, with baseflows ranging from 0.0 to 26.2 cfs. A SonTek-IQ was deployed between December 2018, and March 2019, and again from October, 2019, to January, 2020. Flows captured by the SonTek-IQ, above 1.5 ft stage, ranged between 60 and 4,000 cfs. Between SonTek-IQ and manual discharge measurements, 99.5% of all stage measurements were captured by flow measurements, (i.e., less than 1% of all stage measurements fell outside the range of measured flow).

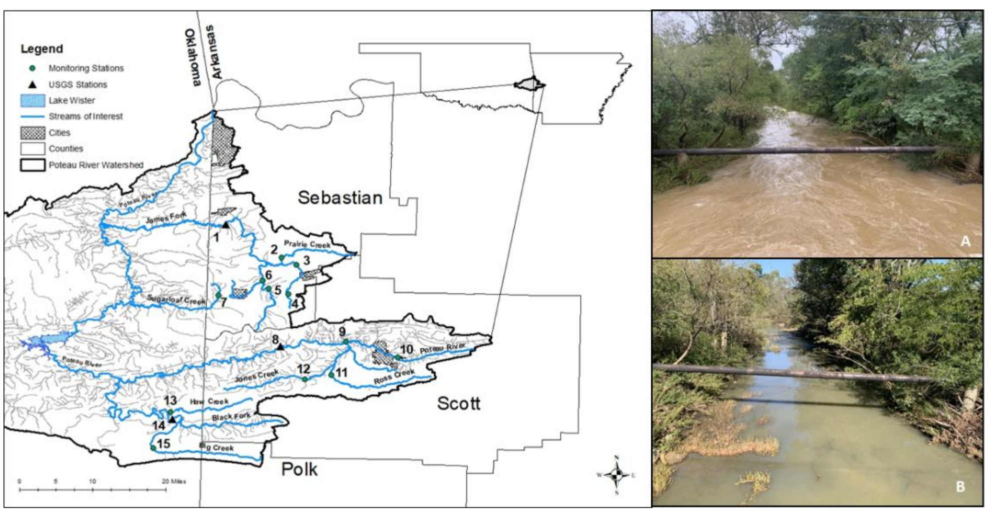


Figure 18: Upper Poteau River Watershed site map (left) and images of the Poteau River Headwaters (Site 10) during storm flow (A) and baseflow conditions (B).

A total of 96 points were used from the SonTek-IQ data and combined with the baseflow discharge measurements to develop a rating curve. The largest storm event captured by the SonTek-IQ occurred in January 2020, reaching a stage of 11.9 ft. Prior to this event, the maximum stage captured by the SonTek-IQ was 5 ft. Therefore, more data points were included from this event in January 2020, compared to other events in order to fill in the upper end of the rating curve. For the final rating curve (Figure 19), a two-point regression with a slope of 0.08 ft^2/s was used for stage values less than 1.0 ft. LOESS regression was used between 1 and 11.9 ft, where measured flow data exists, and Manning's equation was used to predict flows above 11.9 ft, with a Manning's n of 0.002. The rating curve was used to develop a continuous record of flow from January 2018 through December 2020 (except for the missing days of stage in January 2019).

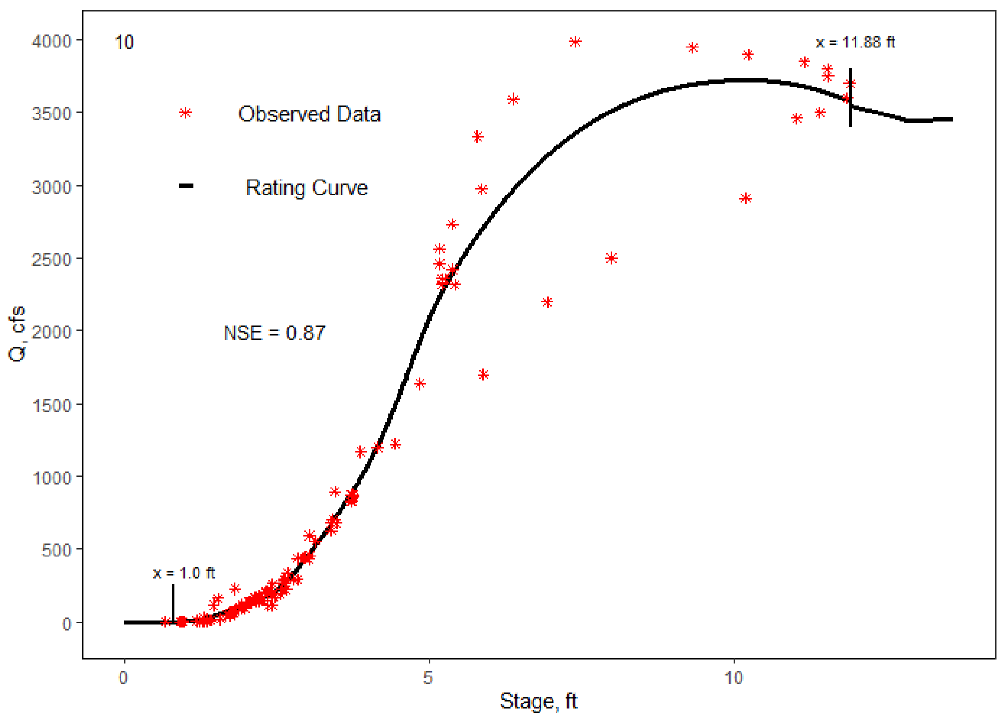


Figure 19: Rating curve for the Poteau River Headwaters (Site 10). Two-point regression was used for stages below 1 ft, LOESS regression for stages between 1 and 11.88 ft, and Manning's equations for stages above 11.88 ft.

A total of 71 water samples were collected from site 10, with 39 during baseflow conditions and 32 during storm flow between October 2017 and September 2020. Water samples were collected across 96.8% of all stage measurements, with less than 1% of stage measurements falling above where water samples were collected, and 3.1% of stage measurements falling below. Constituent concentrations were generally greater in the 2017 project year (i.e., October 2017 – September 2018) compared to 2018 and 2019 (Table 20). Additionally, constituent concentrations were generally greatest in the summer months (i.e., June, July, and August), and least in spring months (i.e., March, April, and May). However, NN, Cl and SO_4^{2-} concentrations were greatest in the winter months (i.e., December, January, and February) and least in spring months.

Table 20: Project year (e.g., 2017 project year is October 1, 2017 through September 30, 2018) and seasonal mean concentrations for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), sulfate (SO_4^{2-}), turbidity and electrical conductivity (EC) at the Poteau River Headwaters (Site 10).

Project Year/ Season	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}	Turbidity	EC
	----------	----------	----------	----------	mg L^{-1}	----------	----------	----------	NTU	µS cm^{-1}
2017	0.96	0.134	0.24	0.143	25.62	0.104	6.651	9.802	40.12	119.49
2018	0.75	0.110	0.16	0.080	23.71	0.089	3.595	8.340	41.92	68.49
2019	0.79	0.170	0.15	0.082	20.07	0.105	4.046	8.447	29.56	81.45
Fall	0.85	0.203	0.18	0.111	11.85	0.083	5.314	9.124	29.39	98.32
Winter	0.81	0.208	0.17	0.084	21.49	0.078	5.795	10.317	40.00	89.65
Spring	0.61	0.058	0.12	0.051	19.20	0.083	3.116	7.767	32.20	61.77
Summer	0.97	0.113	0.24	0.133	36.31	0.136	4.313	8.244	44.08	95.81

Measured concentrations were multiplied by instantaneous flow (Q_i) to estimate constituent loads (L_i). The GAM for log transformed L_i, Q_i, and day of year (DOY) was used to develop a continuous record of constituent loads from January 2018 through December 2020 (except for the missing days of stage in January 2019). The R^2 and NSE values for each constituent's GAM were greater than 0.90 (Table 21). Daily constituent loads were then estimated by integrating L_i over time, and then daily loads were summed into monthly (Appendix A) and annual loads (Table 21). Constituent loads in January 2019 may be underestimated due to 18 days of missing stage data. However, the USGS monitoring station in this watershed (Black Fork- USGS 07294000) expressed mostly baseflow conditions during this time period, with one small storm event raising the stage by about 2 ft. Therefore, constituent loads during this time were likely small. Constituent loads were greatest in 2020 compared to 2018 and 2019. NN loads generally made up about 15% of TN loads, while SRP loads made up closer to 50% of TP loads, and similar trends occurred for mean concentrations each year.

Table 21: Generalized additive model (GAM) R^2 and Nash-Sutcliffe Efficiency (NSE), mean daily loads (kg day^{-1}) with 95% confidence intervals, and calendar year annual loads (kg) for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), and sulfate (SO_4^{2-}) at the Poteau River Headwaters (Site 10). Additionally, the mean daily flow (Q_d) for each calendar year (cfs).

Constituent	R^2	NSE	Mean Daily Load	2018	2019	2020
Q_d	--	--	--	42.2	44.2	56.8
TN	0.987	0.988	91 (67-127)	10,682,000	9,694,000	15,698,000
NN	0.924	0.934	15 (6-39)	2,100,000	1,436,000	2,194,000
TP	0.980	0.983	23 (14-37)	2,425,000	2,215,000	4,381,000
SRP	0.963	0.966	11 (5-23)	1,213,000	991,000	2,113,000
TSS	0.970	0.975	4,778 (2,558-9,151)	363,325,000	462,791,000	1,055,892,000
Fl	0.978	0.982	8 (6-11)	910,000	991,000	1,404,000
Cl	0.990	0.992	357 (276-464)	47,367,000	41,894,000	51,669,000
SO_4^{2-}	0.989	0.992	834 (684-1,021)	104,207,000	99,123,000	125,442,000

Ross Creek (Site 11)

The Ross Creek monitoring site (Figure 20) lies just south of Waldron, Arkansas, and its watershed covers an area of 77 km^2 that is 71.8% forest, 4.6% urban and 13.9% agriculture. A pressure transducer was installed at site 11 on December 20, 2017, and stage measurements throughout the study (January 2018 – December 2020) ranged between 0.1 and 14.9 ft. Due to equipment malfunction, stage measurements were not collected for 13 days in 2020 (i.e., May 23 – June 4, 2020). Baseflow discharge measurements were collected on 18 occasions throughout the project period, with baseflows ranging from 0.0 to 39.9 cfs. A SonTek-IQ was deployed between March and December 2020, and flows captured by the SonTek-IQ, above 1.5 ft stage, ranged between 100 and 6,400 cfs. Between SonTek-IQ and manual discharge measurements, 96.5% of all stage measurements were captured by flow measurements, (i.e., less than 4% of all stage measurements fell outside the range of measured flow).

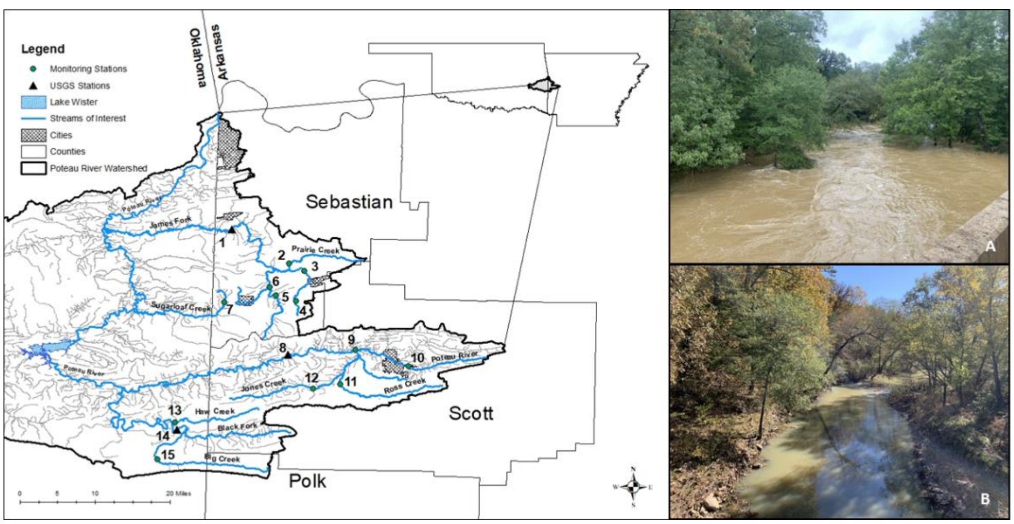


Figure 20: Upper Poteau River Watershed site map (left) and images of Ross Creek (Site 11) during storm flow (A) and baseflow conditions (B).

A total of 108 points were used from the SonTek-IQ data and combined with the baseflow discharge measurements to develop a rating curve. For the final rating curve (Figure 21), a two-point regression with a slope of 2.37 ft^2/s was used for stage values less than 0.78 ft. LOESS regression was

used between 0.78 and 12.4 ft, where measured flow data exists, and Manning's equation was used to predict flows above 12.4 ft, with a Manning's n of 0.022. The rating curve was used to develop a continuous record of flow from January 2018 through December 2020 (except for the missing days of stage in May and June 2020).

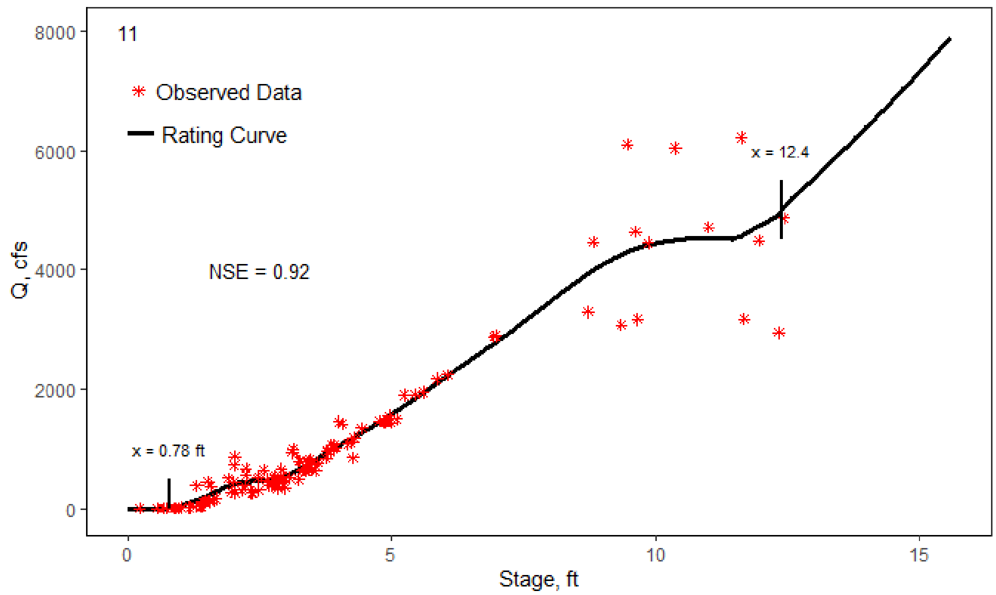


Figure 21: Rating curve for Ross Creek (Site 11). Two-point regression was used for stages below 0.78 ft, LOESS regression for stages between 0.78 and 12.4 ft, and Manning's equations for stages above 12.4 ft.

A total of 64 water samples were collected from site 11, with 36 during baseflow conditions and 28 during storm flow between October 2017 and September 2020. Water samples were collected across 96.2% of all stage measurements, with less than 1% of stage measurements falling above where water samples were collected, and 3.7% of stage measurements falling below. Cl and EC concentrations were greatest in the 2017 project year (i.e., October 2017 – September 2018), while TN, TP, SRP, TSS, and turbidity were greatest in the 2018 project year, and NN, Fl and SO_4^{2-} were greatest in the 2019 project year (Table 22). Additionally, constituent concentrations were generally greatest in the winter months (i.e., December, January, and February), except SO_4^{2-} and EC were greatest in the fall (i.e., September, October, and November), and TN and Fl were greatest in the summer (i.e., June, July, and August).

Table 22: Project year (e.g., 2017 project year is October 1, 2017 through September 30, 2018) and seasonal mean concentrations for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), sulfate (SO_4^{2-}), turbidity and electrical conductivity (EC) at Ross Creek (Site 11).

Project Year/ Season	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}	Turbidity	EC
	------------------------------------- mg L^{-1} -------------------------------------								NTU	µS cm^{-1}
2017	0.52	0.118	0.05	0.016	9.77	0.061	4.101	6.061	15.62	72.15
2018	0.62	0.154	0.12	0.032	38.54	0.074	2.579	7.015	55.82	47.37
2019	0.62	0.168	0.10	0.027	37.26	0.079	2.602	8.478	40.82	55.64
Fall	0.57	0.178	0.07	0.024	13.29	0.069	3.647	9.519	19.43	72.09
Winter	0.61	0.194	0.12	0.031	41.64	0.054	3.694	8.428	57.61	56.55
Spring	0.53	0.110	0.10	0.025	28.14	0.066	2.178	6.293	42.33	42.02
Summer	0.66	0.133	0.11	0.025	38.97	0.097	2.668	5.635	40.46	59.63

Measured concentrations were multiplied by instantaneous flow (Q_i) to estimate constituent loads (L_i). The GAM for log transformed L_i, Q_i, and day of year (DOY) was used to develop a continuous record of constituent loads from January 2018 through December 2020 (except for the missing days of stage in May and June 2020. The R^2 and NSE values for each constituent's GAM were greater than 0.90 (Table 23). Daily constituent loads were then estimated by integrating L_i over time, and then daily loads were summed into monthly (Appendix A) and annual loads (Table 23). Constituent loads in May and June 2020 may be underestimated due to 13 days of missing stage data. The USGS monitoring station in this watershed (Poteau River- USGS 07247000) expressed two storm events in the May portion of this timespan, where stage raised about 10 ft each. Therefore, constituent loads during this time may be underestimated. Constituent loads were greatest in 2020, except for NN and Fl which was greatest in 2019. NN and SRP loads generally made up about 26% of TN and TP loads, respectively, and similar trends occurred for mean concentrations each year.

Table 23: Generalized additive model (GAM) R^2 and Nash-Sutcliffe Efficiency (NSE), mean daily loads (kg day^{-1}) with 95% confidence intervals, and calendar year annual loads (kg) for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), and sulfate (SO_4^{2-}) at Ross Creek (Site 11). Additionally, the mean daily flow (Q_d) for each calendar year (cfs).

Constituent	R^2	NSE	Mean Daily Load	2018	2019	2020
Q_d	--	--	--	105	168	203
TN	0.990	0.991	223 (182-275)	20,134,000	31,224,000	37,262,000
NN	0.962	0.967	59 (37-96)	5,656,000	9,037,000	8,765,000
TP	0.977	0.979	38 (26-54)	3,208,000	4,924,000	6,818,000
SRP	0.971	0.975	10 (6-16)	851,000	1,301,000	1,697,000
TSS	0.987	0.992	10,967 (5,846-20,933)	1,148,235,000	1,204,205,000	1,990,781,000
Fl	0.960	0.977	28 (12-68)	2,736,000	4,272,000	4,091,000
Cl	0.989	0.990	931 (788-1,102)	85,914,000	137,773,000	145,310,000
SO_4^{2-}	0.982	0.983	2,629 (2,110-3,284)	242,561,000	386,955,000	411,874,000

Upper Jones Creek (Site 12)

The Upper Jones Creek monitoring site (Figure 22) is south of Waldron, Arkansas, just downstream of the Lake Hinkle Dam, and its watershed covers an area of 73 km^2 that is 84.8% forest, 2.7% urban and 2.2% agriculture. A pressure transducer was installed at site 11 on December 20, 2017, and stage measurements throughout the study (January 2018 – December 2020) ranged between 0.0 and 4.69 ft. Baseflow discharge measurements were collected on 13 occasions throughout the project period, with baseflows ranging from 0.0 to 40.9 cfs. A SonTek-IQ was deployed between January and November 2018, and flows captured by the SonTek-IQ, above 1.5 ft stage, ranged between 20 and 575 cfs. Between SonTek-IQ and manual discharge measurements, 96.0% of all stage measurements were captured by flow measurements, (i.e., only 4% of all stage measurements fell outside the range of measured flow).

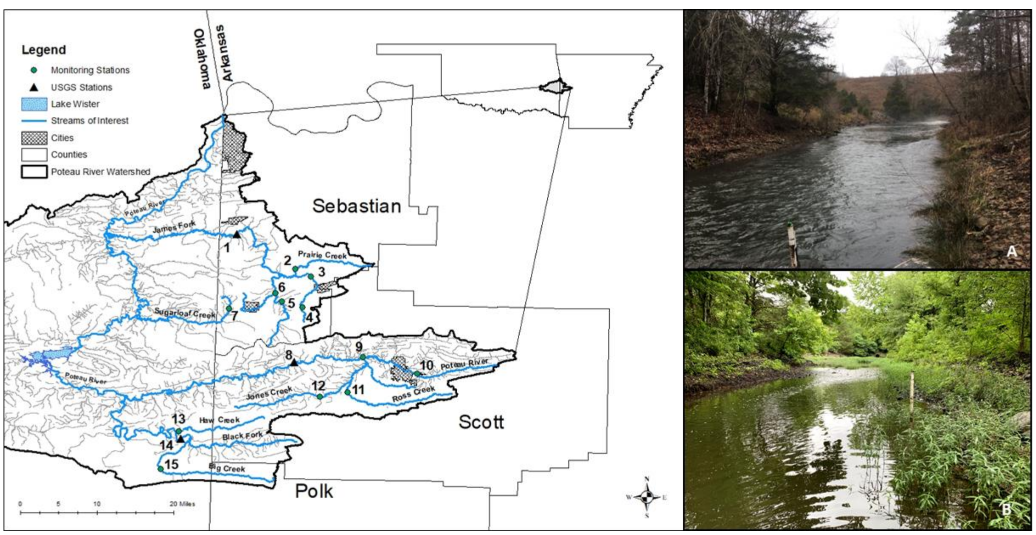


Figure 22: Upper Poteau River Watershed site map (left) and images of Upper Jones Creek (Site 12) during storm flow (A) and baseflow conditions (B).

A total of 56 points were used from the SonTek-IQ data and combined with the baseflow discharge measurements to develop a rating curve. For the final rating curve (Figure 23), a two-point regression with a slope of 0.12 ft^2/s was used for stage values less than 0.59 ft. LOESS regression was used between 0.59 and 4.43 ft, where measured flow data exists, and Manning's equation was used to predict flows above 4.43 ft, with a Manning's n of 0.036. The rating curve was used to develop a continuous record of flow from January 2018 through December 2020.

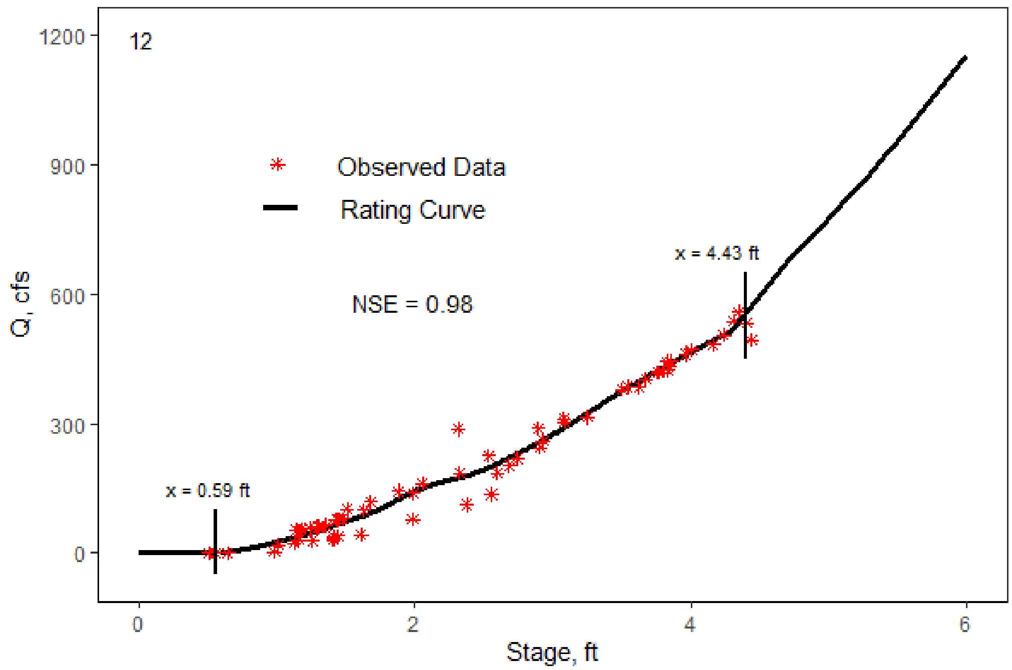


Figure 23: Rating curve for Upper Jones Creek (Site 12). Two-point regression was used for stages below 0.59 ft, LOESS regression for stages between 0.59 and 4.43 ft, and Manning's equations for stages above 4.43 ft.

A total of 92 water samples were collected from site 12, with 67 during baseflow conditions and 25 during storm flow between October 2017 and September 2020. Water samples were collected across 97.1% of all stage measurements, with less than 1% of stage measurements falling above where water samples were collected, and 2.9% of stage measurements falling below. Constituent concentrations were generally greater in the 2017 project year (i.e., October 2017 – September 2018) compared to 2018 and 2019 (Table 20). TN, NN, Cl and turbidity were greatest in the winter months (i.e., December, January, and February), TP, SRP, TSS, and Fl were greatest in the summer months (i.e., June, July, and August), SO_4^{2-} was greatest in the spring months (i.e., March, April, and May), and EC was greatest in the fall months (i.e., September, August, November).

Table 24: Project year (e.g., 2017 project year is October 1, 2017 through September 30, 2018) and seasonal mean concentrations for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), sulfate (SO_4^{2-}), turbidity and electrical conductivity (EC) at Upper Jones Creek (Site 12).

Project Year/ Season	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}	Turbidity	EC
	-----------------				mg L^{-1}			-----------------	NTU	µS cm^{-1}
2017	0.59	0.104	0.03	0.003	6.50	0.039	2.049	3.235	6.09	45.53
2018	0.51	0.072	0.02	0.002	4.31	0.066	1.926	4.113	5.82	40.63
2019	0.51	0.089	0.02	0.003	3.82	0.063	1.625	3.425	5.23	34.11
Fall	0.54	0.057	0.02	0.004	3.93	0.053	1.871	3.153	5.00	43.28
Winter	0.59	0.169	0.02	0.002	5.20	0.052	2.048	3.478	6.83	41.16
Spring	0.44	0.090	0.02	0.002	4.00	0.051	1.878	3.911	5.38	37.32
Summer	0.58	0.043	0.03	0.004	6.10	0.069	1.677	3.763	5.68	38.75

Measured concentrations were multiplied by instantaneous flow (Q_i) to estimate constituent loads (L_i). The GAM for log transformed L_i, Q_i, and day of year (DOY) was used to develop a continuous record of constituent loads from January 2018 through December 2020. The R^2 and NSE values for each constituent's GAM were greater than 0.90 (Table 23). Daily constituent loads were then estimated by integrating L_i over time, and then daily loads were summed into monthly (Appendix A) and annual loads (Table 25). Constituent loads were greatest in 2020, except for TN was greatest in 2019 and NN was greatest in 2018. NN loads generally made up about 22% of TN loads, while SRP loads made up about 10% of TP loads. However, NN concentrations made up about 16% of TN concentrations each year, and SRP concentrations made up about 11% of TP concentrations.

Table 25: Generalized additive model (GAM) R^2 and Nash-Sutcliffe Efficiency (NSE), mean daily loads (kg day^{-1}) with 95% confidence intervals, and calendar year annual loads (kg) for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), and sulfate (SO_4^{2-}) at Upper Jones Creek (Site 12). Additionally, the mean daily flow (Q_d) for each calendar year (cfs).

Constituent	R^2	NSE	Mean Daily Load	2018	2019	2020
Q_d	--	--	--	46	74	78
TN	0.998	0.999	77 (68-88)	7,462,000	11,653,000	11,367,000
NN	0.970	0.976	15 (8-27)	2,048,000	1,905,000	1,937,000
TP	0.982	0.983	3 (2-4)	269,000	467,000	521,000
SRP	0.967	0.970	0.3 (0-1)	27,000	41,000	49,000
TSS	0.979	0.982	686 (477-992)	58,317,000	104,779,000	107,865,000
Fl	0.916	0.918	8 (6-12)	733,000	1,187,000	1,283,000
Cl	0.998	0.998	288 (259-321)	26,942,000	42,614,000	44,401,000
SO_4^{2-}	0.992	0.992	553 (496-616)	48,048,000	83,175,000	87,051,000

Haw Creek (Site 13)

The Haw Creek monitoring site (Figure 24) is south of Waldron, Arkansas, and its watershed covers an area of 62 km^2 that is 90.3% forest, 1.8% urban and 1.1% agriculture. A pressure transducer was installed at site 2 on December 20, 2017, and stage measurements throughout the study (January 2018 – December 2020) ranged between 0.99 and 12.4 ft. This site was too deep for manual discharge measurements and SonTek-IQ installation, therefore no flow measurements were collected at this site.

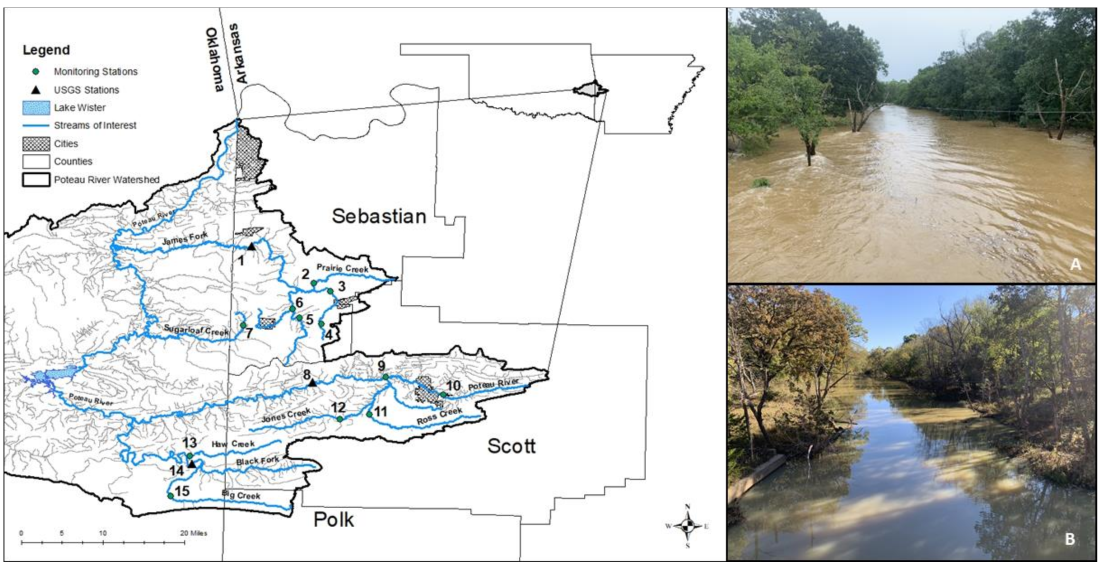


Figure 24: Upper Poteau River Watershed site map (left) and images of Haw Creek (Site 13) during storm flow (A) and baseflow conditions (B).

A total of 60 water samples were collected from site 13, with 35 during baseflow conditions and 25 during storm flow between October 2017 and September 2020. Water samples were collected across 95.8% of all stage measurements, with less than 1% of stage measurements falling above where water samples were collected, and 4.1% of stage measurements falling below. Constituent concentrations were generally greater in the 2017 project year (i.e., October 2017 – September 2018) compared to 2018 and 2019 (Table 26). Cl was greatest in the fall months (i.e., September, October, and November), TP, SRP, TSS, and turbidity were greatest in the winter months (i.e., December, January, and

February), NN and SO_4^{2-} were greatest in the spring months (i.e., March, April, and May), and TN, Cl, and EC were greatest in the summer months (i.e., June, July, and August).

Table 26: Project year (e.g., 2017 project year is October 1, 2017 through September 30, 2018) and seasonal mean concentrations for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), sulfate (SO_4^{2-}), turbidity and electrical conductivity (EC) at Haw Creek (Site 13).

Project Year/ Season	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}	Turbidity	EC
	----------	----------	----------	----------	mg L^{-1}	----------	----------	----------	NTU	µS cm^{-1}
2017	0.44	0.070	0.04	0.002	14.30	0.041	2.540	3.182	24.54	45.78
2018	0.30	0.040	0.04	0.003	12.62	0.063	1.947	4.858	32.01	30.64
2019	0.26	0.061	0.03	0.003	7.60	0.084	2.080	4.497	21.02	32.66
Fall	0.34	0.066	0.04	0.003	9.35	0.070	2.484	4.347	22.63	38.62
Winter	0.32	0.057	0.05	0.003	21.10	0.047	2.198	4.135	40.04	30.39
Spring	0.28	0.066	0.03	0.003	7.89	0.053	1.763	4.438	24.85	29.29
Summer	0.37	0.034	0.04	0.002	6.71	0.090	2.220	4.053	15.67	47.03

USGS 07294000- Black Fork (Site 14)

Constituent Loads

The USGS gaging station on the Black Fork (Figure 25) is near Page, Oklahoma, and its watershed covers an area of 245 km^2 that is 88.3% forest, 3.5% urban and 9.8% agriculture. Flow measurements for the project period of October, 2017 and September, 2020 ranged from 0.02 and 23,100 cfs. A total of 107 water samples were collected during the project period, with 75 during baseflow conditions and 32 during storm flow. Water samples were collected across 98.8% of all flow measurements, with no flow measurements falling above where water samples were collected, and 1.2% of flow measurements falling below.

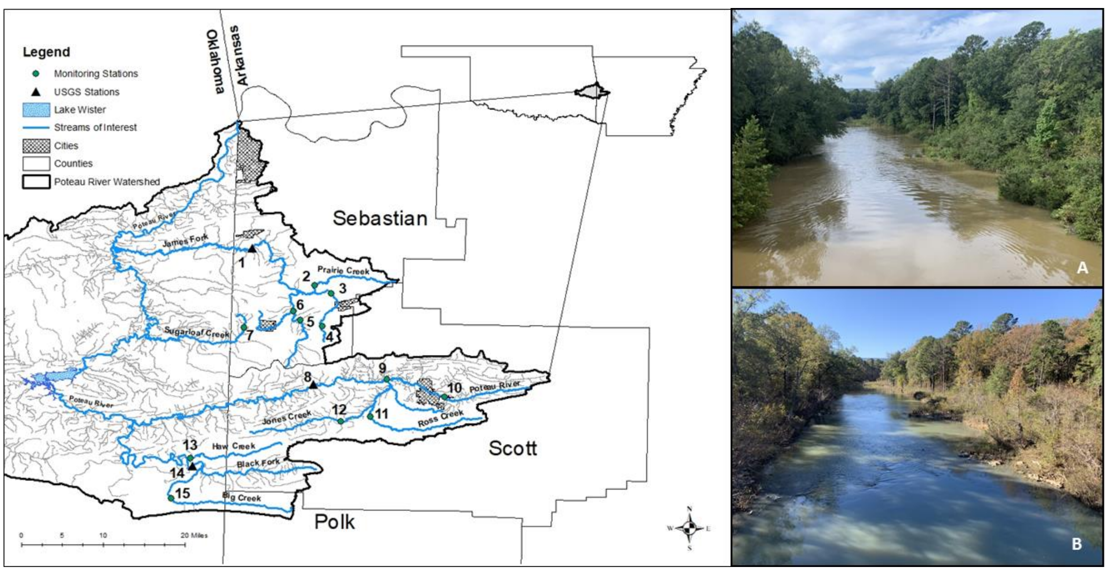


Figure 25: Upper Poteau River Watershed site map (left) and images of the Black Fork (Site 14) during storm flow (A) and baseflow conditions (B).

Constituent concentrations were generally greater in the 2018 project year (i.e., October, 2018 – September, 2019) compared to 2017 and 2019 (Table 27), except for NN and Fl which were greatest in 2019 and Cl which was greatest in 2017. Additionally, constituent concentrations were generally greatest in the spring months (i.e., March, April, and May), and least in summer months (i.e., June, July, and August).

Table 27: Project year (e.g., 2017 project year is October 1, 2017 through September 30, 2018) and seasonal mean concentrations for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), sulfate (SO_4^{2-}), turbidity and electrical conductivity (EC) at the Black Fork (USGS 07294000, Site 14).

Project Year/ Season	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}	Turbidity	EC
	--------	--------	--------	--------	mg L^{-1}	--------	--------	--------	NTU	µS cm^{-1}
2017	0.34	0.081	0.04	0.007	12.83	0.031	2.272	3.161	20.55	32.24
2018	0.38	0.100	0.06	0.014	29.35	0.064	2.119	5.964	37.26	38.63
2019	0.31	0.124	0.03	0.005	11.73	0.069	1.659	3.523	18.45	25.36
Fall	0.33	0.095	0.04	0.005	9.82	0.052	2.197	3.730	15.74	32.08
Winter	0.37	0.146	0.04	0.006	21.14	0.040	2.060	3.583	33.58	26.45
Spring	0.38	0.106	0.06	0.014	32.17	0.070	2.012	5.941	39.07	36.71
Summer	0.30	0.055	0.04	0.008	6.17	0.059	1.773	3.517	11.54	33.11

Measured concentrations were multiplied by instantaneous flow (Q_i) to estimate constituent loads (L_i). The R^2 and NSE values for each constituent's GAM were greater than 0.80 (Table 28). Daily constituent loads were then estimated by integrating L_i over time, and then daily loads were summed into monthly (Appendix A) and annual loads (Table 27). Constituent loads were greatest in the 2019 project year. NN loads generally made up about 28% of TN loads, while SRP loads made about 13% of TP loads, and similar trends occurred for mean concentrations each year.

Table 28: Generalized additive model (GAM) R^2 and Nash-Sutcliffe Efficiency (NSE), mean daily loads (kg day^{-1}) with 95% confidence intervals, and project year (e.g., 2017 project year is October 1, 2017 through September 30, 2018) annual loads (kg) for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), and sulfate (SO_4^{2-}) at the Black Fork (USGS 07294000, Site 14). Additionally, the mean daily flow (Q_d) for each project year (cfs).

Constituent	R^2	NSE	Mean Daily Load	2017	2018	2019
Q_d	--	--	--	118	256	338
TN	0.986	0.987	128 (101-163)	7,906,000	17,497,000	25,921,000
NN	0.946	0.951	35 (20-64)	2,311,000	5,122,000	6,786,000
TP	0.961	0.964	18 (12-19)	928,000	2,283,000	4,358,000
SRP	0.939	0.949	2 (1-5)	110,000	355,000	532,000
TSS	0.970	0.973	10,855 (6,166-19,824)	526,581,000	1,280,827,00	2,535,218,000
Fl	0.877	0.892	15 (6-40)	614,000	2,292,000	3,208,000
Cl	0.992	0.993	482 (412-565)	31,437,000	72,501,000	88,944,000
SO_4^{2-}	0.981	0.983	1,208 (880-1,668)	66,675,000	187,081,000	229,592,000

Trend Analysis

Trend analysis was conducted using the 27 years of available flow and water quality data from the USGS. All constituents at the Black Fork generally increased in concentration with increasing discharge. LOESS was fit to each concentration and discharge relationship with sampling proportions of 0.4 – 0.7 (Table 29). All LOESS fits for the constituents had relatively low RMSEs (< 0.35).

The flow-adjusted concentrations were either extremely likely decreasing or likely not changing over time (i.e., 1991 – 2018). The specific changes include:

- TN decreased ($p < 0.05$) at -0.60 % yr^{-1}, showing a change point in March 2002 (Figure 26, A); FACs to the right or left of the change were likely not changing over time ($p > 0.20$).
- NN was likely not changing over time ($p = 0.97$, Figure 26, B), and no change point in NN FACs occurred over time.
- TP decreased ($p < 0.05$) with the greatest magnitude of change compared to other constituents (-1.04 % yr^{-1}); two change points occurred in TP FACs, one in November 1998 and one in January 2003 (Figure 26, C).

- No monotonic changes occurred after the change point in 2003, but there was an extremely likely increase in TP FACs between 1991 and 2003 ($p = 0.03$); average TP FACs between 1998 and 2003 were 23% greater than between 1991 and 2003 and 19% greater than after 2003.

- SRP decreased ($p < 0.05$) by a magnitude of -0.90 % yr^{-1}, but nearly 40% of the data are censored; one change point in SRP FACs occurred in May 2000 (Figure 26, D), but no monotonic changes occurred before or after ($p > 0.20$).

- SS was likely not changing between 1991 and 2018 ($p = 0.52$), and no significant change point occurred in the FACs (Figure 26, E).

Table 29: Optimal LOESS Sampling Proportion, LOESS RMSE, Linear Model Slope, Linear Model p-Value, Seasonal Kendall's Test (SKT) Sen's Slope, and Seasonal Kendall's Test p-Value for Trends in Flow Adjusted Concentrations (FACS) for each Parameter the Black Fork (USGS 07294000, Site 14).

Parameter	LOESS Sampling Proportion	LOESS RMSE	Linear Model Slope (%/yr)	Linear Model p-Value	SKT Sen's Slope (%/yr)	SKT p-Value
TN	0.4	0.16	-0.60	<0.01	-0.66	<0.01
NN	0.4	0.26	-0.01	0.97	-0.01	0.94
TP	0.6	0.25	-1.04	<0.01	-1.07	<0.01
SRP	0.4	0.22	-0.90	<0.01	-0.40	<0.01
SS	0.4	0.32	-0.19	0.52	-0.25	0.28

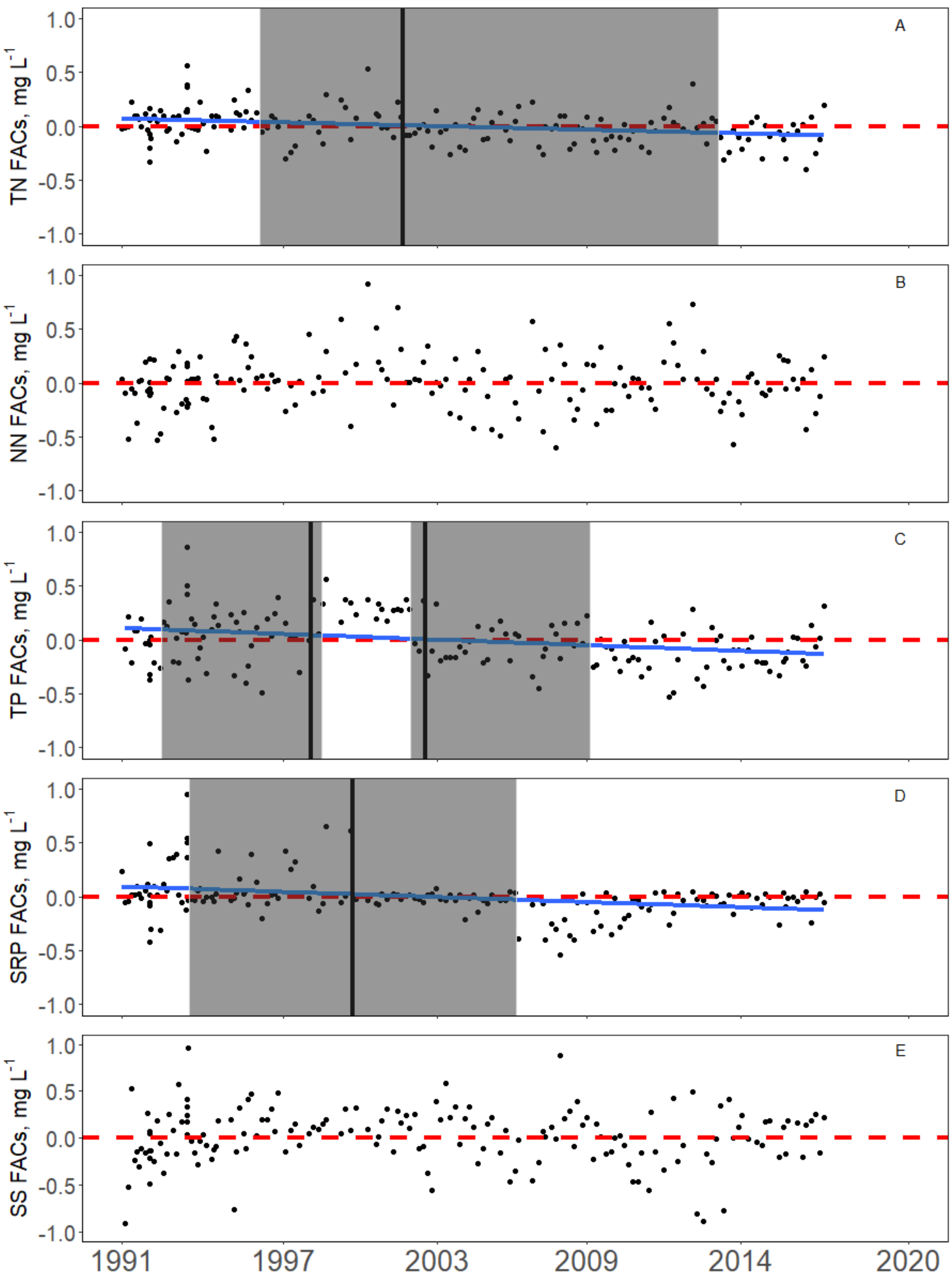


Figure 26: Trends in Flow Adjusted Concentrations (FACs) of Total Nitrogen (TN), Total Phosphorus (TP), Suspended Sediments (SS), Nitrate+Nitrite (NN), and Soluble Reactive Phosphorus (SRP) at the Black Fork. The FACs were truncated from -1 to 1 for consistency. This may cause a few data points to be missing from the figure, but all data were included in trend analysis. Significant change points are identified by solid vertical lines, the grey areas are the 95% confidence intervals around the change points, and significant linear model slopes are identified by solid blue lines.

Big Creek (Site 15)

The Big Creek monitoring site (Figure 27) is near Page, Oklahoma, and its watershed covers an area of 60 km^2 that is 92.3% forest, 6.2% urban and 0.0% agriculture. A pressure transducer was installed at site 15 on December 20, 2017, and stage measurements throughout the study (January 2018 – December 2020) ranged between 0.0 and 9.40 ft. Baseflow discharge measurements were collected on 17 occasions throughout the project period, with baseflows ranging from 0.0 to 77.5 cfs. A SonTek-IQ was deployed between October 2019 and January 2020, and again between March and May 2020. Flows captured by the SonTek-IQ, above 1.5 ft stage, ranged between 15 and 2,700 cfs. Between SonTek-IQ and manual discharge measurements, 89.0% of all stage measurements were captured by flow measurements, (i.e., less than 1% of all stage measurements fell above the range of measured flow, and 11% fell below the range of measured flow).

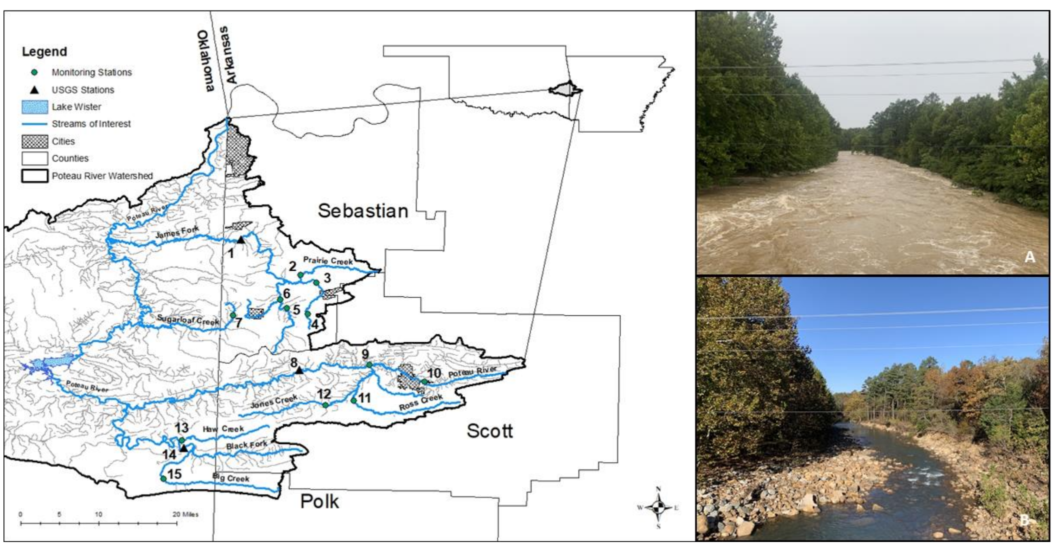


Figure 27: Upper Poteau River Watershed site map (left) and images of Big Creek (Site 15) during storm flow (A) and baseflow conditions (B).

A total of 68 points were used from the SonTek-IQ data and combined with the baseflow discharge measurements to develop a rating curve. For the final rating curve (Figure 28), a two-point regression with a slope of 6.21 ft^2/s was used for stage values less than 0.21 ft. LOESS regression was

used between 0.21 and 4.43 ft, where measured flow data exists, and Manning's equation was used to predict flows above 4.43 ft, with a Manning's n of 0.025. The rating curve was used to develop a continuous record of flow from January 2018 through December 2020.

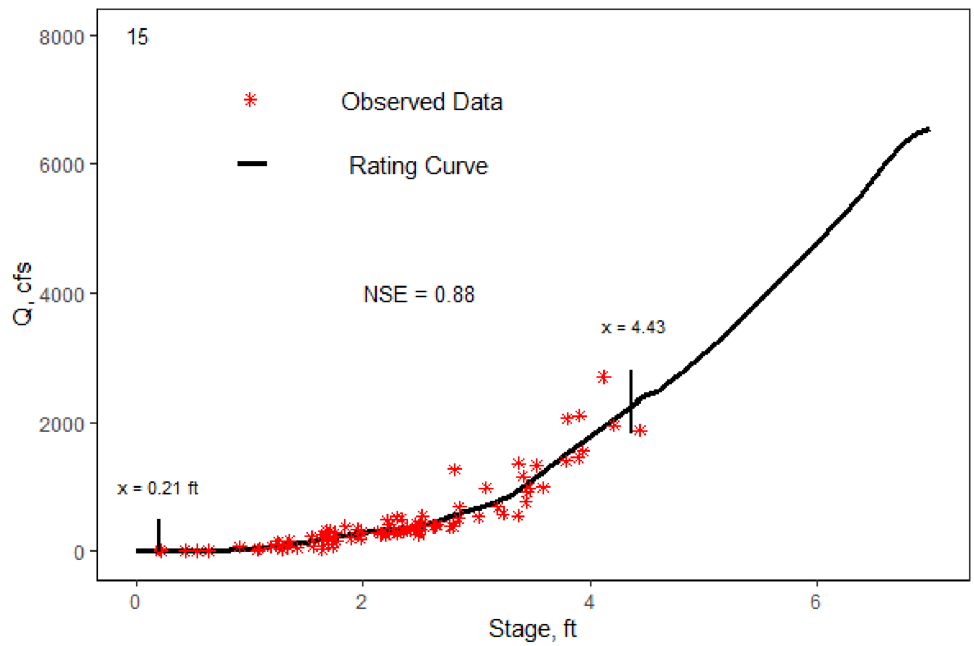


Figure 28: Rating curve for Big Creek (Site 15). Two-point regression was used for stages below 0.21 ft, LOESS regression for stages between 0.59 and 4.43 ft, and Manning's equations for stages above 4.43 ft.

A total of 61 water samples were collected from site 15, with 36 during baseflow conditions and 25 during storm flow between October 2017 and September 2020. Water samples were collected across 96.2% of all stage measurements, with less than 1% of stage measurements falling above where water samples were collected, and 3.7% of stage measurements falling below. Constituent concentrations were generally greater in the 2019 project year (i.e., October 2019 – September 2020) compared to 2017 and 2018 (Table 30). NN and Cl were greatest in the winter months (i.e., December, January, and February), SRP, Fl, and EC were greatest in the summer months (i.e., June, July, and August), and TN, TP, TSS, SO_4^{2-}, and turbidity were greatest in the fall months (i.e., September, August, November).

Table 30: Project year (e.g., 2017 project year is October 1, 2017 through September 30, 2018) and seasonal mean concentrations for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), sulfate (SO_4^{2-}), turbidity and electrical conductivity (EC) at Big Creek (Site 15).

Project Year/ Season	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}	Turbidity	EC
	----------	----------	----------	----------	mg L^{-1}	----------	----------	----------	NTU	µS cm^{-1}
2017	0.30	0.151	0.02	0.003	7.52	0.035	1.868	3.054	13.91	25.23
2018	0.28	0.137	0.02	0.002	8.13	0.054	1.638	3.536	15.14	20.05
2019	0.38	0.241	0.02	0.002	13.39	0.068	1.398	2.783	16.14	19.60
Fall	0.36	0.194	0.03	0.002	17.27	0.057	1.692	3.502	19.77	23.27
Winter	0.34	0.195	0.02	0.002	9.13	0.039	1.740	2.711	16.06	20.28
Spring	0.31	0.170	0.01	0.002	8.47	0.049	1.394	3.156	14.67	18.06
Summer	0.28	0.146	0.01	0.003	3.94	0.073	1.663	3.233	9.68	24.23

Measured concentrations were multiplied by instantaneous flow (Q_i) to estimate constituent loads (L_i). The GAM for log transformed L_i, Q_i, and day of year (DOY) was used to develop a continuous record of constituent loads from January 2018 through December 2020. The R^2 and NSE values for each constituent's GAM were greater than 0.80 (Table 31). Daily constituent loads were then estimated by integrating L_i over time, and then daily loads were summed into monthly (Appendix A) and annual loads (Table 31). Constituent loads were generally greatest in 2018, except TP and TSS were greatest in 2020. NN loads generally made up about 50% of TN loads, while SRP loads made up about 12% of TP loads, and similar trends occurred in mean concentrations each year.

Table 31: Generalized additive model (GAM) R^2 and Nash-Sutcliffe Efficiency (NSE), mean daily loads (kg day^{-1}) with 95% confidence intervals, and calendar year annual loads (kg) for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), and sulfate (SO_4^{2-}) at Big Creek (Site 15). Additionally, the mean daily flow (Q_d) for each calendar year (cfs).

Constituent	R^2	NSE	Mean Daily Load	2018	2019	2020
Q_d	--	--	--	157	135	72
TN	0.986	0.988	103 (78-137)	18,443,000	13,742,000	9,056,000
NN	0.961	0.967	53 (34-85)	9,545,000	7,522,000	3,994,000
TP	0.938	0.948	5 (2-16)	783,000	524,000	837,000
SRP	0.955	0.970	1 (0-2)	94,700	84,000	47,000
TSS	0.849	0.860	3,990 (1,062-20,101)	567,773,000	234,963,000	793,745,000
Fl	0.886	0.900	13 (6-28)	2,236,000	1,917,000	981,000
Cl	0.995	0.996	421 (372-477)	72,295,000	64,683,000	31,448,000
SO_4^{2-}	0.988	0.989	899 (784-1,033)	156,537,000	131,719,000	71,650,000

Constituent Concentrations and Land Use

The human development index (HDI, % urban plus % agriculture land use) ranges from 2.9 to 66.5% across sites in the UPRW. The majority of human development is represented by agricultural land use, since urban areas make up less than 8% of land use across all subwatersheds (Table 1). When comparing constituent concentrations and HDI, site 3 was removed since only 1.5 years of concentration data was available compared to 3 years of data for the remaining sites. Across the 3 year monitoring period, arithmetic mean concentrations under baseflow conditions generally increased with increasing HDI (Figure 29). For regression analyses, site 9 was also removed since it lies just downstream of the waste water treatment plant in Waldron, Arkansas. Significant increases in TN, TP, SRP, TSS, and Fl occurred with increasing HDI ($p < 0.05$), while no significant change occurred in NN, turbidity, Cl and SO_4^{2-} ($p > 0.05$). Similar trends occurred with baseflow geometric means, arithmetic and geometric means of all flow conditions, and flow-weighted mean concentrations (FWMC) and HDI across sites (Appendix B).

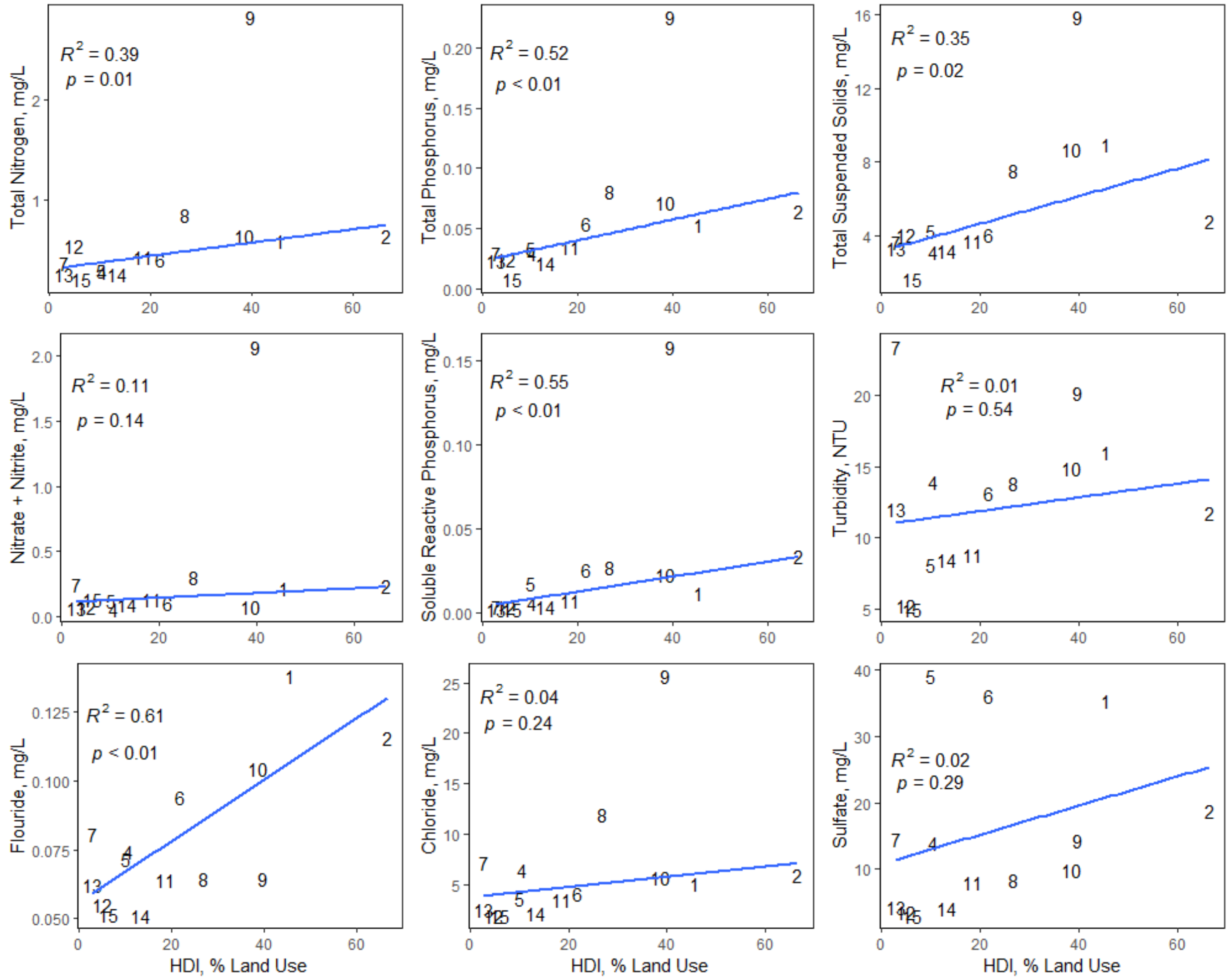


Figure 29: Arithmetic mean concentrations under baseflow conditions from October 1, 2017 through September 30, 2020 versus human development index (HDI, % urban area plus % agriculture land use). Data points are represented by site numbers, which correspond to Table 1, and blue lines indicate slopes of simple linear regression. Site 9 was removed from regression analyses due to its location directly downstream from the waste water treatment plant in Waldron, Arkansas.

Summary and Conclusions

The UPRW has been listed as a priority watershed in Arkansas since 1998 due to nutrient and sediment enrichment. According to the NPS pollution plan, the goals for the UPRW is to reduce pollutant levels that will restore designated uses and target subwatersheds where implementation of management practices can have the greatest impact. This study successfully monitored 15 sites within the UPRW, three of these existing at USGS monitoring sites, and the remaining 12 on the HUC-12 subwatershed scale, for three years. Specifically, this project:

- Collected water quality samples across a range of flows at all 15 sites
- Collected stage and discharge measurements at 8 of the 12 subwatershed sites
- Developed rating curves for subwatersheds with stage and discharge measurements
- Estimated monthly and annual constituent loads for the 3 USGS sites and the 8 subwatershed sites
- Conducted water quality trend analyses at the 3 USGS sites, and
- Analyzed nutrient concentrations in relationship to land use and human development.

The major findings from the three USGS sites in the UPRW include:

- Constituent concentrations were generally greatest in the winter and lowest in the spring at the James Fork (Site 1) and Poteau River (Site 8), but at the Black Fork (Site 14) constituent concentrations were generally greatest in the spring and least in the summer.
- Constituent loads were generally greatest in the 2019 project year at all three sites, as well as mean daily flow.
- At the Black Fork, the relatively undisturbed watershed within the UPRW, slight decreases or no changes occurred in flow-adjusted constituents over the 27 years of available data.

- At the Poteau River, which is impacted by both point and nonpoint sources, flow-adjusted N is increasing while flow-adjusted P and sediments are decreasing.
- At the James Fork, which has the largest percentage of agriculture land use in the watershed, flow-adjusted N and SRP are increasing, while sediments are decreasing.
- Decreasing sediments and P and on the James Fork and Poteau river are likely due to restrictions and improvements in point source outputs, as well as other 319(h) efforts implemented in the watershed.
- The magnitude of decreasing flow-adjusted concentrations were generally greater than increasing flow-adjusted concentrations, suggesting water quality is improving at a faster rate than it may be worsening.
- Continued monitoring will be important to insure increasing trends do not lead to more excessive nutrient concentrations.

The major findings from the HUC-12 subwatersheds in the UPRW include:

- The magnitude of constituent concentrations were variable across sites and seasons, but were most commonly greatest in the summer months and least in the spring.
- In general, constituent loads were greatest in 2020 compared to 2018 and 2019.
- The largest magnitude of constituent loads occurred at the Lower Poteau River (Site 9), which lies just downstream of the waste water treatment plant in Waldron, Arkansas, and has a watershed that is 33% agricultural land use.
- The smallest magnitude of constituent loads occurred at the Cherokee Creek Headwaters (Site 4), which has a watershed area of 14 km^2 that is predominately forested.

Lastly, average and flow-weighted concentrations increased with increasing human development index across sites (with the exclusion of sites 3 and 9). The majority of human development in the UPRW is represented by agricultural land use, since urban areas make up less than 8% of land use. Ultimately, the data collected in this project is important for understanding small-watershed pollutant sources and long-term trends in water quality at the UPRW.

Appendix A: Summary of monthly loads (kg) for total nitrogen (TN), nitrate plus nitrite (NN), total phosphorus (TP), soluble reactive phosphorus (SRP), total suspended solids (TSS), fluoride (Fl), chloride (Cl), and sulfate (SO_4^{2-}) for monitoring sites with flow records.

James Fork (USGS 07249400, Site 1)

Project Year	Month	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}
2017	Oct	4,900	860	410	40	68,100	590	49,100	256,400
	Nov	1,100	50	90	7	12,900	100	11,100	45,200
	Dec	5,800	1,200	360	40	47,900	1,000	65,900	388,000
	Jan	57,900	21,400	8,700	1,200	2,912,400	7,300	394,500	2,672,900
	Feb	1,330,200	272,000	355,900	58,900	174,266,300	75,100	3,736,300	18,654,100
	Mar	329,900	101,800	52,700	9,700	15,969,800	33,400	1,628,000	9,141,400
	Apr	415,600	122,500	73,500	16,100	26,333,600	50,600	1,780,000	9,903,100
	May	46,100	16,800	4,300	880	830,600	9,800	319,500	2,146,700
	Jun	67,400	20,700	14,300	4,100	5,681,300	13,200	239,900	1,732,900
	Jul	3,800	430	350	40	80,800	1,000	32,800	254,400
	Aug	907,900	213,400	321,700	93,400	209,844,000	115,100	1,946,100	14,666,000
	Sep	667,600	172,400	216,100	61,400	113,109,100	58,100	1,677,700	9,607,000
2018	Oct	510,900	159,500	109,900	29,600	34,999,300	44,300	1,955,400	9,597,500
	Nov	857,400	195,100	230,800	58,200	83,554,500	54,700	2,617,700	11,796,700
	Dec	1,361,300	243,800	294,300	61,700	97,503,500	118,500	4,601,200	22,936,300
	Jan	911,400	305,100	172,100	22,100	69,754,500	117,300	4,601,200	29,874,100
	Feb	844,700	245,000	172,100	27,200	73,723,500	66,100	3,586,700	19,888,000
	Mar	228,400	84,400	27,600	5,000	6,630,600	28,300	1,392,900	8,166,100
	Apr	1,064,300	250,500	252,600	57,800	115,079,900	104,300	3,217,100	16,728,100
	May	1,574,000	339,500	409,600	100,500	187,309,300	171,800	4,014,800	22,080,400
	Jun	1,295,100	251,400	420,400	115,100	212,095,900	174,500	2,680,900	17,942,100
	Jul	47,300	21,200	4,100	810	858,900	16,100	345,700	3,138,500
	Aug	149,800	49,300	36,500	10,700	18,703,300	26,200	553,700	4,528,500
	Sep	11,300	3,200	1,000	130	225,300	2,400	103,300	826,100
2019	Oct	205,400	67,800	34,700	9,200	7,414,800	19,100	906,700	4,456,700
	Nov	822,400	202,400	181,300	43,700	57,956,400	59,300	2,989,100	13,478,600
	Dec	317,900	83,300	46,900	10,200	11,638,000	37,200	1,726,300	9,345,500
	Jan	970,000	275,500	213,600	27,300	94,273,600	101,400	4,218,800	26,796,700
	Feb	836,900	251,800	163,900	25,200	68,254,700	69,000	3,717,700	21,013,000
	Mar	733,400	184,500	154,700	31,100	60,752,100	63,100	2,631,500	13,648,600
	Apr	1,113,000	277,400	241,500	54,200	98,646,200	112,700	3,621,900	18,811,500
	May	2,198,900	426,000	665,200	172,000	345,408,800	235,900	4,665,900	26,332,800
	Jun	39,200	16,500	3,500	770	640,700	11,100	259,000	2,005,400
	Jul	14,300	4,900	1,200	200	283,300	4,600	114,700	1,032,100
	Aug	314,500	87,600	97,900	28,700	59,568,000	43,200	854,900	6,498,400
	Sep	1,369,800	282,900	498,000	139,400	273,396,300	143,000	2,857,700	19,730,800

Cherokee Creek Headwaters (Site 4)

Calendar Year	Month	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}
2018	Jan	370	80	40	8	3,500	40	4,500	12,500
	Feb	19,200	1,800	3,200	990	416,900	2,000	88,900	327,600
	Mar	6,400	630	910	180	85,400	1,000	56,800	190,200
	Apr	4,000	340	660	100	52,600	870	42,100	145,600
	May	240	20	30	4	2,800	70	3,500	11,700
	Jun	40	4	3	0.4	370	10	760	2,000
	Jul	20	3	2	0.2	190	7	540	1,300
	Aug	6,800	750	2,500	1,600	338,300	1,100	24,400	97,100
	Sep	18,200	1,600	4,500	2,500	704,400	2,400	43,000	185,200
	Oct	17,100	1,700	3,100	520	354,600	2,900	75,300	277,100
	Nov	18,200	1,600	2,800	930	382,900	3,000	75,700	281,100
	Dec	27,400	2,300	4,400	750	872,700	4,900	143,500	500,600
2019	Jan	11,400	2,700	980	110	141,500	1,200	97,700	302,600
	Feb	15,000	1,900	2,700	770	198,200	1,800	119,100	384,700
	Mar	4,300	470	540	80	48,900	740	48,700	153,900
	Apr	25,800	1,700	3,900	660	557,600	5,000	164,300	644,500
	May	22,600	1,500	2,900	570	509,300	5,200	147,900	603,300
	Jun	50,700	3,300	5,600	1,300	2,220,000	9,400	142,700	719,000
	Jul	50	7	4	1	390	20	860	2,400
	Aug	140	20	40	20	2,900	30	1,200	3,800
	Sep	20	3	2	0.4	230	4	450	910
	Oct	20	4	3	0.4	270	6	550	1,100
	Nov	3,400	350	490	190	42,300	690	23,500	78,400
	Dec	900	100	160	20	14,300	210	9,000	27,200
2020	Jan	14,200	2,600	1,300	260	278,100	1,300	88,600	294,300
	Feb	9,500	1,300	1,700	470	129,400	1,100	76,400	243,200
	Mar	11,000	900	1,400	310	190,000	1,700	80,600	285,500
	Apr	7,600	600	1,200	200	117,200	1,600	68,700	247,000
	May	67,600	3,700	9,500	2,400	3,776,000	12,800	193,900	1,017,100
	Jun	170	20	20	3	1,900	60	2,700	8,800
	Jul	30	4	2	0.3	230	7	570	1,400
	Aug	12,300	990	1,800	620	582,200	1,400	17,200	88,300
	Sep	55,600	4,200	7,000	2,000	3,003,000	6,000	60,300	343,400
	Oct	2,300	220	360	80	37,000	400	10,900	39,000
	Nov	430	60	70	30	3,800	110	4,500	13,500
	Dec	3,300	370	490	70	46,400	780	32,900	100,900

James Fork Headwaters (Site 5)

Calendar Year	Month	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}
2018	Jan	910	420	90	30	12,400	130	15,700	103,600
	Feb	73,200	11,300	16,100	3,000	6,141,900	5,700	315,200	1,100,800
	Mar	54,500	10,300	9,700	580	2,576,700	5,500	230,500	1,250,300
	Apr	20,300	4,300	2,600	310	372,200	4,100	163,100	962,400
	May	8,800	1,700	1,000	110	165,700	2,200	70,900	535,300
	Jun	330	120	10	2	3,900	130	5,600	83,600
	Jul	390	110	10	3	5,400	130	4,300	85,800
	Aug	20,000	3,500	4,000	840	1,315,200	2,400	75,700	514,200
	Sep	21,900	3,500	5,900	5,800	592,200	2,200	76,500	444,300
	Oct	48,400	9,100	10,500	840	2,273,600	5,200	203,500	990,500
	Nov	115,200	17,100	32,400	4,300	8,161,800	13,200	468,400	1,802,800
	Dec	120,200	31,300	24,200	1,200	13,169,900	18,400	479,900	2,419,300
2019	Jan	42,300	12,700	9,000	230	1,689,900	5,100	199,900	1,457,100
	Feb	95,500	16,400	18,700	2,700	5,531,400	7,400	525,700	1,800,300
	Mar	25,700	5,500	3,700	230	530,200	3,400	155,500	895,500
	Apr	76,700	9,600	16,600	1,500	4,573,000	14,600	482,800	2,127,500
	May	100,100	13,900	18,200	1,700	5,231,300	21,100	550,000	3,157,000
	Jun	134,600	9,600	46,100	1,900	55,378,900	26,600	451,100	2,709,100
	Jul	360	90	10	3	4,900	120	4,000	81,100
	Aug	910	200	80	20	25,000	180	8,700	96,500
	Sep	500	120	30	30	2,100	110	4,900	71,900
	Oct	560	180	30	7	4,800	120	7,600	74,800
	Nov	5,000	1,500	700	280	112,200	730	41,100	188,900
	Dec	1,500	880	120	10	31,400	330	14,900	121,900
2020	Jan	29,200	5,300	7,700	470	2,066,900	3,200	206,500	850,900
	Feb	35,500	7,700	6,200	710	1,472,500	2,800	196,200	788,100
	Mar	36,800	7,300	6,400	400	968,500	4,800	198,600	997,000
	Apr	30,700	6,100	4,700	510	762,200	5,700	209,100	1,167,000
	May	158,100	9,800	46,800	3,800	28,842,100	34,100	702,300	3,375,600
	Jun	400	100	20	3	5,300	150	5,700	82,400
	Jul	270	40	9	2	3,300	90	3,200	65,400
	Aug	42,600	1,800	21,300	760	6,358,100	4,700	73,500	494,000
	Sep	226,400	12,600	156,100	3,300	60,362,900	25,500	292,000	2,020,500
	Oct	7,500	1,700	1,300	120	207,600	930	32,600	229,800
	Nov	460	190	20	20	2,600	120	10,300	69,100
	Dec	7,400	3,400	770	60	212,300	1,400	49,200	353,100

Lower James Fork (Site 6)

Calendar Year	Month	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}
2018	Jan	25,400	7,600	5,700	2,000	1,080,700	1,800	127,200	944,000
	Feb	325,100	52,600	94,300	34,200	35,889,800	22,100	951,000	7,438,300
	Mar	108,000	15,700	21,700	6,200	4,816,900	13,400	487,300	3,292,200
	Apr	66,500	7,700	11,800	2,600	2,664,400	11,800	372,200	2,514,500
	May	10,000	1,300	1,500	290	375,500	2,300	67,300	505,600
	Jun	810	180	90	10	10,800	230	6,200	60,100
	Jul	70	10	3	0.4	480	20	570	8,000
	Aug	120,300	24,200	34,800	12,100	14,240,500	14,100	302,100	2,846,600
	Sep	142,700	22,600	44,000	24,900	11,998,700	14,800	301,400	2,703,200
	Oct	123,700	18,400	32,600	20,000	5,775,000	17,100	460,100	2,656,800
	Nov	199,800	28,100	68,500	43,300	19,212,300	21,900	690,800	3,934,100
	Dec	324,700	47,900	89,000	16,400	25,519,500	41,600	1,219,600	7,361,100
2019	Jan	205,100	74,200	52,900	15,900	14,874,000	11,100	543,600	3,003,300
	Feb	225,500	45,100	52,100	18,600	12,274,800	18,900	991,600	6,420,600
	Mar	52,600	8,000	9,200	2,200	1,589,000	8,300	292,100	2,432,700
	Apr	236,100	24,200	54,100	13,300	23,341,600	30,100	880,700	5,617,700
	May	238,100	26,700	57,600	14,200	29,424,800	33,200	782,000	5,471,300
	Jun	503,400	94,300	241,000	61,900	95,739,700	53,900	758,300	6,510,900
	Jul	2,600	600	230	30	38,000	710	21,300	249,000
	Aug	6,000	1,500	950	230	123,700	1,300	34,800	311,600
	Sep	420	70	30	9	2,100	100	3,600	38,100
	Oct	7,300	1,400	1,400	620	80,900	1,500	49,600	333,900
	Nov	92,800	13,200	23,800	10,100	4,496,200	12,800	472,300	2,764,300
	Dec	24,200	4,200	4,500	700	638,500	5,000	176,600	1,177,900
2020	Jan	257,700	87,000	90,300	32,400	29,590,600	12,500	720,600	5,507,000
	Feb	163,300	35,400	37,900	13,700	8,807,800	13,300	736,800	4,318,800
	Mar	162,100	19,300	34,000	8,900	9,194,300	20,300	635,900	4,687,700
	Apr	125,200	13,800	23,700	5,400	6,303,900	20,500	606,800	4,011,900
	May	652,900	83,700	215,100	55,500	108,624,400	72,800	1,398,800	10,081,500
	Jun	4,200	800	540	80	47,600	1,200	29,300	273,000
	Jul	170	30	10	1	1,200	50	1,500	19,800
	Aug	152,500	30,600	69,100	31,200	24,917,600	13,000	229,300	1,738,200
	Sep	537,700	114,800	327,100	160,400	81,100,400	44,800	622,800	4,197,900
	Oct	48,300	6,600	15,200	9,800	3,934,300	4,900	143,600	794,900
	Nov	12,200	2,400	1,800	530	114,300	3,200	146,600	1,031,900
	Dec	53,400	9,000	10,600	2,200	1,643,900	10,400	347,400	2,226,400

Poteau River (USGS 07247000, Site 8)

Project Year	Month	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}
2017	Oct	6,500	350	510	100	44,200	300	102,200	58,300
	Nov	4,700	110	300	40	25,300	180	93,000	60,400
	Dec	31,800	5,500	2,600	600	259,600	1,800	338,300	498,100
	Jan	29,100	9,900	2,300	590	189,200	730	268,600	308,000
	Feb	2,512,700	581,700	671,900	224,800	195,754,400	101,300	5,285,100	13,836,700
	Mar	1,024,500	298,600	175,900	46,100	45,553,200	59,700	3,610,500	8,597,200
	Apr	655,200	136,900	109,400	25,600	33,117,700	49,000	2,577,400	5,929,400
	May	87,100	14,400	7,500	2,000	886,100	5,700	665,700	826,700
	Jun	11,300	420	920	130	86,600	630	133,500	106,400
	Jul	13,100	1,000	1,100	90	123,000	750	143,000	115,000
	Aug	452,800	122,000	86,900	22,200	27,906,100	44,000	1,689,900	3,096,500
	Sep	90,200	37,900	11,200	4,200	1,731,800	8,100	579,900	601,500
2018	Oct	360,100	160,100	50,800	22,000	8,985,900	31,400	1,914,000	2,582,700
	Nov	1,114,100	363,200	218,000	94,800	45,797,200	82,500	4,135,500	7,520,600
	Dec	1,089,700	212,000	185,200	57,600	56,194,400	73,400	4,533,600	12,670,000
	Jan	1,087,400	757,000	174,100	78,400	31,470,100	43,000	4,384,000	10,305,700
	Feb	1,456,200	535,700	275,100	103,000	68,501,800	64,900	4,520,600	11,438,700
	Mar	260,900	90,200	27,300	5,500	3,800,800	18,200	1,603,200	2,752,800
	Apr	1,811,900	310,700	375,900	100,000	128,943,900	135,200	5,220,300	14,524,700
	May	1,373,900	235,400	262,900	83,400	87,160,300	117,500	4,404,200	10,473,600
	Jun	1,995,800	282,200	512,400	123,600	155,898,600	176,400	4,851,400	10,733,800
	Jul	232,900	59,500	27,200	3,000	3,935,100	28,700	1,318,200	1,819,300
	Aug	20,100	3,600	2,000	340	241,000	1,400	195,300	168,800
	Sep	11,400	770	1,000	200	96,600	570	151,900	90,800
2019	Oct	38,700	13,800	3,600	1,100	312,900	2,800	351,800	331,300
	Nov	682,500	194,400	108,300	43,600	20,869,900	48,400	2,979,200	5,983,000
	Dec	535,900	146,500	67,000	23,500	11,312,900	39,900	3,095,600	6,205,000
	Jan	1,933,000	1,035,100	412,500	200,600	87,283,600	70,400	5,979,300	15,312,100
	Feb	1,214,600	526,300	198,400	71,100	44,498,100	60,200	4,660,600	10,686,300
	Mar	1,345,900	324,100	228,500	47,400	66,573,900	87,400	4,569,800	11,677,000
	Apr	1,907,500	373,200	330,100	78,800	105,284,100	147,200	6,160,800	17,113,600
	May	3,964,900	512,800	1,026,500	448,100	355,571,600	310,900	8,919,100	22,412,300
	Jun	286,700	64,100	32,300	9,000	5,366,200	32,800	1,552,600	2,303,200
	Jul	17,600	950	1,500	110	151,400	990	193,100	158,700
	Aug	946,000	227,300	259,400	85,000	91,517,600	76,000	2,775,400	4,711,300
	Sep	3,289,900	844,900	922,000	358,700	315,674,000	276,500	8,271,500	16,283,700

Lower Poteau River (Site 9)

Calendar Year	Month	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}
2018	Jan	32,600	26,700	2,100	1,200	65,800	630	354,900	256,400
	Feb	1,286,400	245,800	439,700	145,700	118,153,500	66,500	3,282,100	7,705,100
	Mar	618,600	160,300	130,100	46,300	15,077,100	36,700	2,472,800	4,874,300
	Apr	560,000	123,500	81,500	36,700	16,359,700	35,500	2,041,700	4,211,700
	May	180,400	74,100	12,600	6,900	670,200	5,500	1,192,500	1,104,600
	Jun	7,000	4,000	450	380	7,200	150	75,600	39,000
	Jul	30,800	20,300	3,000	2,100	84,900	990	379,300	150,700
	Aug	331,600	130,200	118,200	45,300	24,490,100	22,300	1,041,900	1,695,100
	Sep	159,800	97,400	22,600	12,900	1,961,400	7,900	908,900	812,200
	Oct	398,900	172,600	61,600	35,800	8,598,700	24,600	1,860,700	2,255,800
	Nov	890,400	282,500	159,500	95,100	17,344,400	50,000	3,167,500	4,671,600
	Dec	928,800	250,500	190,500	83,400	32,756,400	49,100	3,650,500	6,324,500
2019	Jan	555,900	252,700	83,500	40,400	11,704,100	32,100	3,437,800	5,821,500
	Feb	831,300	240,400	218,900	73,100	57,678,400	47,700	3,503,600	6,865,100
	Mar	280,200	113,100	28,000	11,700	2,091,800	15,800	1,803,500	2,618,700
	Apr	970,800	165,600	176,500	77,000	39,062,100	61,600	2,618,400	6,283,300
	May	856,600	164,900	164,200	67,400	42,942,000	58,100	2,699,800	5,773,200
	Jun	1,388,600	291,500	351,500	184,800	64,665,400	92,300	4,555,400	6,841,700
	Jul	206,300	109,700	22,600	13,900	1,657,600	12,400	2,429,900	1,351,600
	Aug	26,700	17,100	4,700	2,300	161,800	1,100	137,100	126,500
	Sep	7,900	6,300	680	580	10,200	160	65,800	34,100
	Oct	89,600	57,300	7,200	5,200	292,100	3,400	623,900	479,200
	Nov	554,300	165,400	106,500	55,800	6,512,100	29,100	2,019,500	3,118,200
	Dec	521,300	197,500	71,600	34,200	3,797,200	26,200	2,855,400	3,744,500
2020	Jan	901,100	337,100	173,200	80,200	31,858,600	49,900	4,268,000	7,861,200
	Feb	683,800	215,100	166,600	55,300	40,248,700	41,700	3,186,400	6,086,400
	Mar	835,300	185,000	143,200	61,800	24,859,400	50,200	2,800,300	6,124,500
	Apr	1,186,100	192,500	207,600	89,800	46,546,200	80,200	3,165,900	8,431,900
	May	2,244,600	332,400	634,900	254,600	121,209,400	144,200	4,968,500	11,671,400
	Jun	323,500	130,000	38,900	19,300	5,193,800	20,000	2,171,700	2,216,100
	Jul	103,800	67,400	7,000	6,100	218,200	2,200	1,450,500	476,700
	Aug	671,200	217,200	280,400	123,700	71,467,500	39,100	1,519,900	2,593,300
	Sep	1,683,900	471,600	679,800	311,800	174,938,000	108,300	3,591,500	6,673,600
	Oct	296,100	134,200	43,800	28,900	4,043,300	12,800	1,450,000	1,358,100
	Nov	302,300	179,100	20,000	14,500	643,500	8,300	1,999,600	1,554,100
	Dec	463,200	189,000	58,100	26,900	5,801,000	21,400	2,778,900	3,442,700

Poteau River Headwaters (Site 10)

Calendar Year	Month	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}
2018	Jan	21,600	860	2,400	830	130,200	4,100	357,200	610,600
	Feb	279,400	23,500	68,400	31,000	14,474,700	20,900	1,100,500	2,317,700
	Mar	73,400	8,300	14,300	6,700	1,772,400	7,700	416,600	944,300
	Apr	71,800	9,500	14,700	6,300	3,258,100	9,000	315,700	892,300
	May	8,300	980	1,100	390	93,900	2,000	59,600	181,800
	Jun	240	6	30	5	2,700	70	2,100	4,600
	Jul	1,800	160	310	110	24,500	390	11,800	25,400
	Aug	68,100	11,200	22,600	13,000	2,341,900	5,900	149,700	376,900
	Sep	8,800	1,400	1,500	730	80,900	1,200	45,200	109,900
	Oct	58,200	14,600	12,800	7,600	989,900	4,700	239,400	516,300
	Nov	136,900	37,700	31,900	18,300	3,760,700	9,200	534,900	1,102,700
	Dec	164,000	67,300	32,700	16,400	3,430,400	11,000	725,500	1,625,300
2019	Jan	75,600	6,800	15,300	8,300	1,262,900	6,700	512,200	913,400
	Feb	120,800	11,900	24,100	11,600	2,613,600	11,100	714,800	1,466,800
	Mar	28,300	2,900	3,700	1,500	293,300	4,800	273,300	616,000
	Apr	160,700	21,900	36,700	15,700	9,970,300	17,100	530,900	1,555,700
	May	135,000	19,500	32,000	13,800	7,497,100	15,100	368,700	1,205,100
	Jun	162,200	20,300	51,500	20,600	15,586,400	15,800	310,800	903,700
	Jul	2,100	150	320	100	26,500	490	14,200	32,300
	Aug	160	2	20	3	1,600	40	1,300	2,200
	Sep	110	1	10	1	880	20	830	1,300
	Oct	23,300	4,200	3,300	1,500	165,000	2,900	163,600	338,100
	Nov	73,500	23,500	14,200	8,000	1,047,700	5,700	378,500	770,200
	Dec	28,300	8,900	3,900	1,800	206,400	3,100	231,500	478,100
2020	Jan	149,700	9,700	33,800	15,600	6,869,700	13,100	905,700	1,613,400
	Feb	110,600	9,700	22,500	10,600	2,780,000	10,300	670,400	1,357,700
	Mar	91,000	12,600	17,500	8,100	2,176,200	9,900	474,000	1,156,500
	Apr	165,900	25,500	35,700	16,600	5,692,900	17,700	578,600	1,714,400
	May	294,100	40,900	80,700	32,500	27,995,600	29,800	603,100	1,978,700
	Jun	7,900	820	1,200	390	105,700	1,800	47,300	136,200
	Jul	1,400	190	270	110	23,200	220	6,200	14,500
	Aug	142,900	19,400	56,700	29,800	15,141,400	9,600	195,600	520,000
	Sep	263,200	39,200	100,100	53,500	25,252,700	18,000	388,600	1,052,900
	Oct	40,200	9,300	11,000	6,200	1,808,000	2,300	113,000	237,000
	Nov	4,900	560	540	200	27,800	770	57,200	106,500
	Dec	39,900	15,300	6,200	3,000	359,000	3,800	278,000	594,400

Ross Creek (Site 11)

Calendar Year	Month	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}
2018	Jan	2,800	1,100	140	30	24,300	140	43,400	77,400
	Feb	523,000	106,200	111,300	29,100	55,553,900	41,700	1,672,000	5,084,200
	Mar	197,400	49,300	27,900	7,600	6,151,500	28,600	938,800	2,687,500
	Apr	214,200	45,700	32,800	8,900	9,742,300	41,600	952,500	2,852,600
	May	28,100	7,600	2,700	580	259,000	4,000	163,200	456,500
	Jun	610	100	40	6	4,600	80	5,200	8,100
	Jul	540	80	40	4	7,700	100	4,200	6,100
	Aug	58,700	12,100	6,800	1,500	1,431,100	14,100	212,400	581,500
	Sep	26,300	5,800	2,400	500	150,500	4,300	127,700	320,600
	Oct	96,000	31,600	9,800	2,400	791,200	30,600	461,400	1,192,600
	Nov	238,800	84,800	35,500	9,700	8,281,700	19,000	933,400	2,533,900
	Dec	295,800	128,200	38,600	10,900	13,550,700	44,300	1,665,000	4,467,700
2019	Jan	273,800	108,000	27,000	6,500	3,768,500	16,300	1,967,400	4,885,700
	Feb	291,900	88,900	35,900	9,300	14,339,700	31,600	1,646,200	4,423,300
	Mar	125,100	37,100	12,300	2,800	1,400,200	19,500	827,500	2,248,200
	Apr	419,900	79,100	78,800	20,800	25,991,500	66,200	1,512,900	4,740,300
	May	331,400	67,800	57,900	16,200	13,252,900	39,100	1,136,900	3,596,200
	Jun	555,800	111,000	133,400	35,900	32,884,400	82,500	1,242,700	4,066,600
	Jul	50,700	15,200	5,000	1,100	505,100	12,600	228,300	624,900
	Aug	670	80	50	6	14,800	100	5,200	7,400
	Sep	860	100	50	8	4,400	70	7,200	10,400
	Oct	68,900	25,100	7,000	1,700	642,200	12,100	327,500	854,700
	Nov	366,700	159,000	42,500	11,600	6,425,200	55,600	1,730,200	4,660,600
	Dec	123,400	63,900	11,400	2,800	1,396,400	21,400	880,600	2,216,500
2020	Jan	389,500	122,200	61,700	13,500	18,044,700	12,200	2,078,400	5,408,500
	Feb	298,400	92,100	37,300	9,500	15,607,500	31,600	1,710,600	4,569,600
	Mar	299,400	71,400	41,500	11,600	8,394,100	38,800	1,409,600	4,114,300
	Apr	485,900	95,800	79,100	22,900	20,168,500	76,000	1,818,500	5,690,600
	May	334,900	60,100	83,900	20,600	36,253,600	38,400	885,100	2,898,000
	Jun	51,400	16,300	5,100	1,100	393,500	11,200	246,600	695,000
	Jul	6,300	1,900	460	100	61,800	1,100	39,300	91,300
	Aug	282,800	39,000	68,700	15,700	21,374,000	39,700	617,300	1,841,500
	Sep	599,900	73,400	151,400	36,200	38,990,000	43,900	1,199,500	3,640,400
	Oct	133,700	40,600	20,400	5,900	4,485,700	12,400	504,400	1,347,200
	Nov	62,500	33,700	4,400	830	418,200	8,500	468,400	1,129,900
	Dec	169,000	85,900	15,800	3,900	2,161,100	28,300	1,164,700	2,990,600

Upper Jones Creek (Site 12)

Calendar Year	Month	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}
2018	Jan	11,500	3,400	310	30	68,000	560	37,900	67,200
	Feb	151,600	56,000	5,200	530	1,203,300	11,400	518,900	912,900
	Mar	181,200	69,400	7,400	710	1,523,500	15,800	686,200	1,250,100
	Apr	48,700	9,800	2,400	190	408,700	4,800	212,200	405,100
	May	15,100	340	750	50	146,600	1,400	62,700	121,500
	Jun	4,600	190	160	20	39,700	250	13,000	24,500
	Jul	270	20	10	1	2,400	10	710	1,400
	Aug	3,500	160	190	20	35,400	280	10,700	22,100
	Sep	5,500	230	290	30	40,600	510	18,900	37,100
	Oct	16,300	510	610	60	89,800	1,800	55,400	104,200
	Nov	102,000	8,700	3,000	350	652,000	13,100	340,300	600,500
	Dec	83,200	22,300	2,100	220	663,200	11,200	294,500	468,500
2019	Jan	148,100	41,600	4,000	430	1,045,100	11,100	554,700	1,055,600
	Feb	156,900	48,000	5,300	480	981,800	11,100	527,800	975,500
	Mar	61,900	17,300	2,700	210	419,700	4,900	235,000	447,700
	Apr	101,500	20,300	5,200	490	1,074,900	11,900	470,400	878,300
	May	113,400	5,100	6,500	560	1,343,700	15,400	552,000	1,077,700
	Jun	168,400	2,900	7,300	580	1,936,500	18,900	514,300	1,140,400
	Jul	90,400	2,000	4,400	300	989,500	10,200	266,200	630,400
	Aug	8,900	420	470	40	94,000	730	26,500	56,200
	Sep	560	50	30	5	4,000	40	1,900	3,500
	Oct	800	130	20	4	4,500	50	2,500	4,000
	Nov	48,300	5,500	1,300	130	297,200	5,400	154,500	264,200
	Dec	74,600	15,800	1,900	200	564,500	9,500	255,100	416,700
2020	Jan	129,200	37,200	3,600	390	917,400	9,500	478,900	902,000
	Feb	116,500	32,600	4,000	340	668,300	7,900	388,300	726,900
	Mar	104,200	37,400	4,800	440	896,500	9,900	427,300	802,000
	Apr	142,300	37,500	7,200	680	1,445,100	16,300	648,200	1,218,100
	May	179,100	4,100	9,200	860	2,430,500	24,100	784,000	1,533,200
	Jun	61,300	800	2,700	210	605,400	6,600	204,100	437,600
	Jul	50	5	2	0.4	390	2	140	280
	Aug	17,500	340	1,100	80	171,300	2,200	57,800	136,300
	Sep	137,000	2,400	9,000	930	1,480,600	23,800	515,500	1,167,800
	Oct	16,000	840	600	70	95,400	2,000	55,800	104,500
	Nov	22,800	2,800	640	70	132,300	2,400	72,400	124,700
	Dec	23,800	5,800	550	50	170,000	2,400	77,700	120,600

Black Fork (USGS 07247250, Site 14)

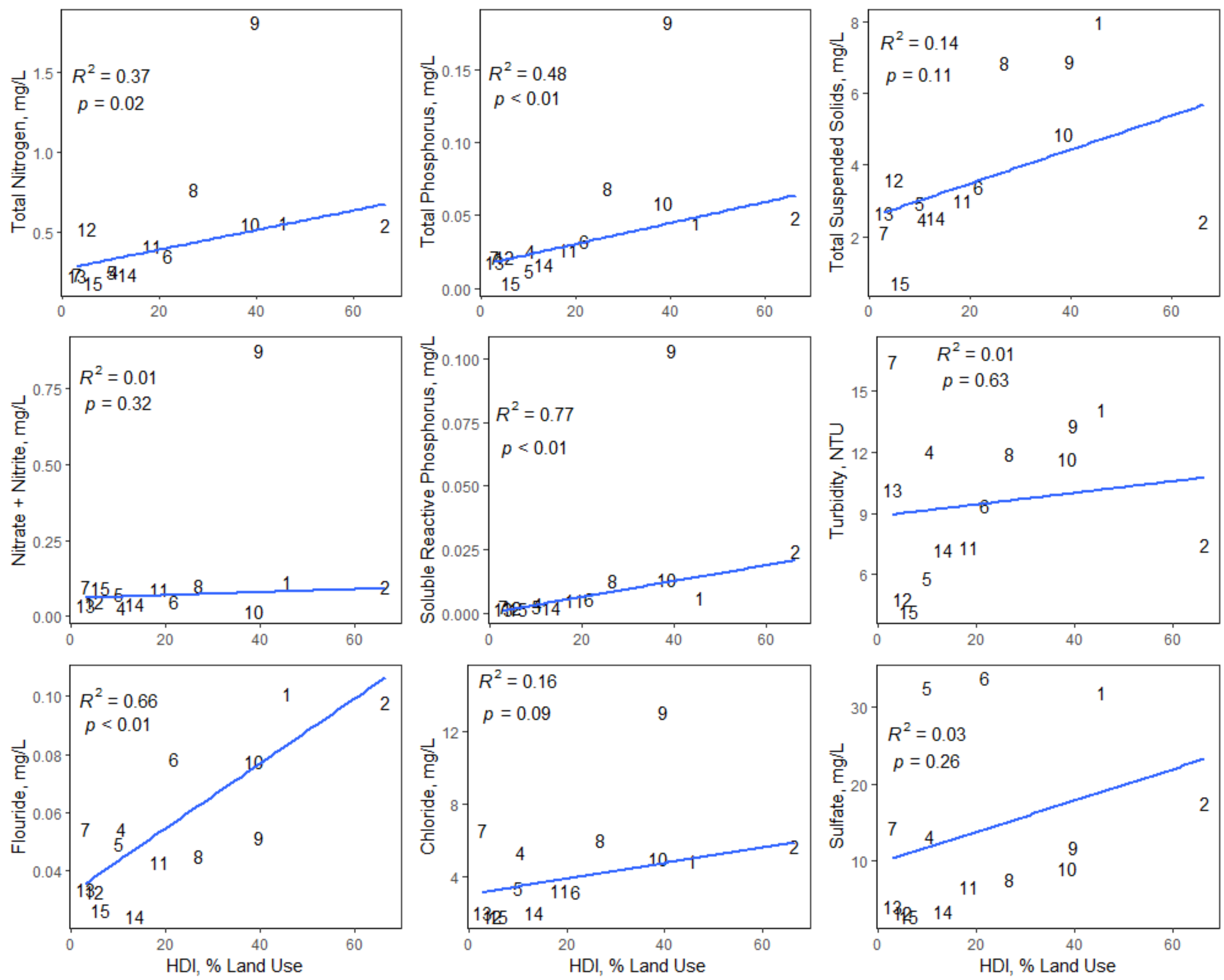
Project Year	Month	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}
2017	Oct	460	20	30	3	4,100	20	4,700	5,400
	Nov	170	5	9	1	1,500	3	2,100	2,100
	Dec	3,700	1,600	220	50	45,900	620	38,400	79,200
	Jan	15,600	12,100	940	220	179,500	860	122,400	203,300
	Feb	443,000	118,000	58,200	6,200	37,909,500	23,500	1,221,800	2,611,500
	Mar	92,800	31,800	8,300	1,300	3,081,800	7,500	537,900	1,049,800
	Apr	63,500	19,400	5,800	650	2,113,900	9,100	413,800	1,024,700
	May	16,700	4,800	1,300	370	299,400	2,500	134,400	309,600
	Jun	1,800	140	130	20	26,300	160	13,800	23,300
	Jul	1,300	120	110	10	16,900	150	8,700	12,900
	Aug	11,800	2,700	1,500	290	197,200	4,600	62,300	129,300
	Sep	9,900	2,500	1,000	150	126,200	2,300	66,700	120,400
2018	Oct	64,300	17,400	7,500	1,000	1,981,300	10,200	317,100	696,600
	Nov	128,100	32,300	16,300	1,200	6,710,500	14,500	507,800	1,199,500
	Dec	180,700	56,500	19,100	3,200	11,597,100	25,900	816,000	2,308,900
	Jan	137,300	104,100	10,200	1,700	3,401,800	5,500	645,700	1,405,500
	Feb	113,800	54,900	8,800	1,900	2,703,500	6,900	747,300	1,266,000
	Mar	42,200	19,700	2,900	420	513,000	6,000	375,700	713,900
	Apr	196,800	43,200	24,300	2,400	15,151,300	25,000	814,800	2,347,100
	May	250,000	46,900	33,500	7,700	21,335,900	34,400	937,800	2,934,400
	Jun	321,600	47,000	64,900	9,700	43,046,600	55,300	756,200	2,461,900
	Jul	25,000	5,900	3,000	410	561,100	7,500	123,100	275,800
	Aug	1,600	70	140	20	19,800	260	11,700	16,800
	Sep	590	30	50	4	6,100	60	5,000	6,400
2019	Oct	34,000	10,100	3,300	430	648,200	4,100	196,100	421,900
	Nov	124,900	37,800	12,500	1,200	4,554,900	15,200	622,800	1,529,700
	Dec	76,400	29,000	6,500	1,100	2,358,500	10,800	489,500	1,196,300
	Jan	281,100	150,600	33,600	3,200	22,840,100	7,900	763,700	1,858,200
	Feb	163,700	74,400	13,600	2,800	4,840,100	9,500	951,300	1,672,400
	Mar	213,900	60,500	21,700	2,800	9,972,500	19,600	1,020,000	2,323,000
	Apr	205,400	50,300	21,500	2,700	9,972,600	24,300	1,013,200	2,794,000
	May	429,500	63,500	79,300	19,800	70,497,000	49,600	1,079,700	3,755,000
	Jun	11,300	2,900	970	290	167,200	2,300	79,800	174,100
	Jul	6,500	1,300	660	80	92,800	1,800	38,600	74,300
	Aug	152,500	23,900	31,800	3,600	10,967,800	46,900	379,700	1,011,500
	Sep	465,500	62,200	138,900	6,300	74,924,200	75,800	788,800	2,358,300

Big Creek (Site 15)

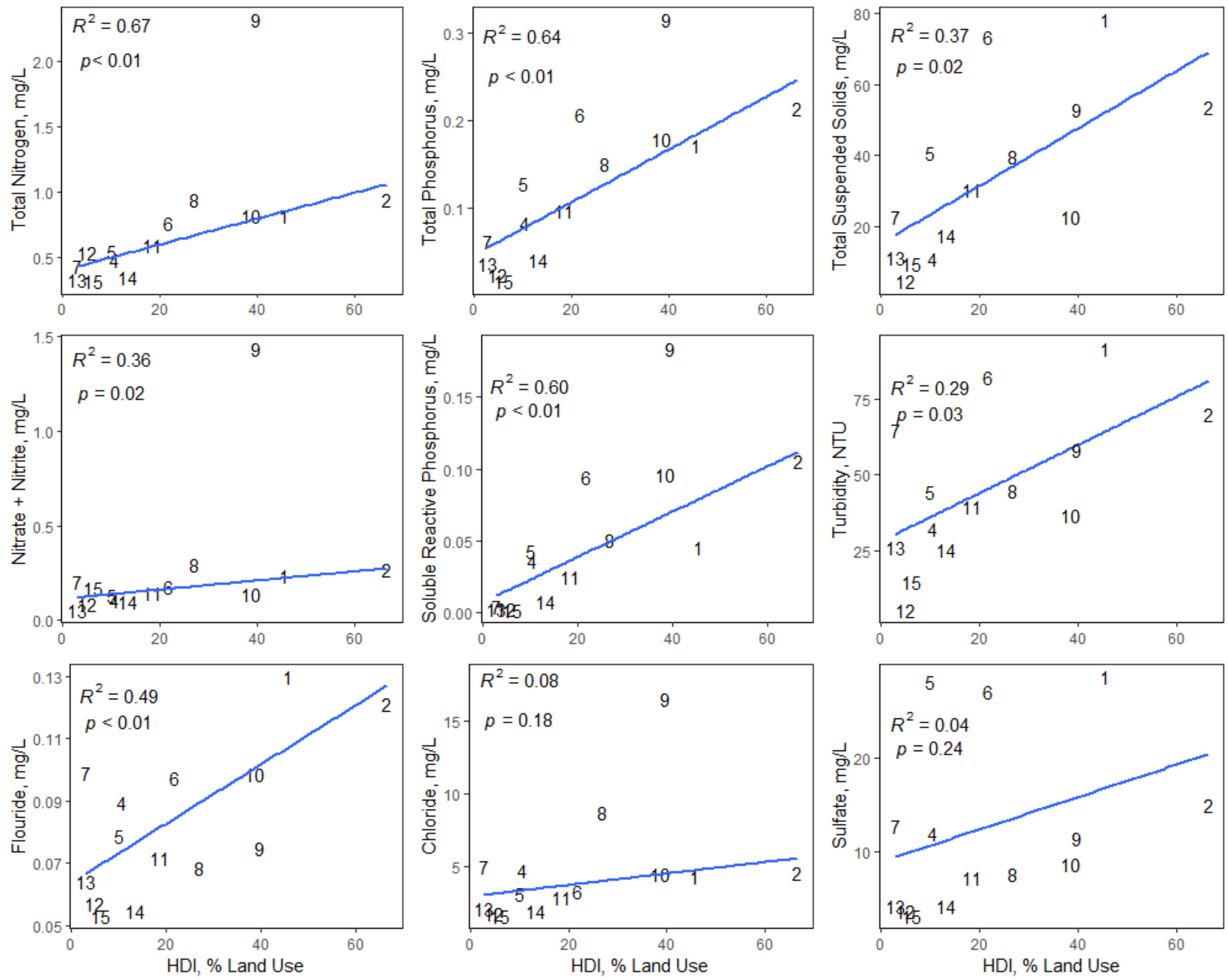
Calendar Year	Month	TN	NN	TP	SRP	TSS	Fl	Cl	SO_4^{2-}
2018	Jan	70,400	44,400	2,000	780	502,900	6,400	578,200	801,100
	Feb	461,600	216,800	25,500	1,600	22,766,700	24,100	1,341,900	3,093,100
	Mar	184,800	96,900	7,000	1,000	3,436,900	14,900	777,000	1,567,300
	Apr	164,100	95,300	5,500	1,300	2,462,500	18,700	715,100	1,523,700
	May	35,100	19,400	720	200	221,200	5,400	281,200	532,000
	Jun	3,500	2,100	70	40	9,000	770	30,800	49,900
	Jul	3,400	2,100	70	30	7,300	870	30,400	47,800
	Aug	13,000	7,400	490	230	105,500	2,800	82,000	156,900
	Sep	15,900	9,000	620	110	148,300	3,700	96,900	185,300
	Oct	133,100	71,600	5,800	890	2,792,500	25,600	564,100	1,261,000
	Nov	183,700	92,500	8,400	710	5,916,400	32,300	670,300	1,602,200
	Dec	272,500	140,100	9,400	930	9,074,900	51,200	873,200	2,260,300
2019	Jan	112,200	66,900	3,900	900	1,135,500	8,900	754,400	1,094,800
	Feb	75,000	46,600	2,100	430	579,400	7,400	541,700	840,000
	Mar	49,000	28,700	1,100	500	324,300	5,800	401,800	666,900
	Apr	203,200	109,700	7,900	1,500	4,789,000	20,300	765,100	1,739,000
	May	193,800	104,600	7,600	690	3,278,200	23,300	733,500	1,710,800
	Jun	186,800	95,000	9,200	1,300	4,286,800	23,800	663,300	1,615,500
	Jul	24,800	13,300	850	160	198,800	4,700	170,100	328,800
	Aug	2,300	1,400	50	40	4,700	630	19,900	30,300
	Sep	3,600	2,200	80	30	8,500	1,100	33,100	50,900
	Oct	73,800	39,300	3,200	480	1,096,400	15,500	345,200	735,800
	Nov	160,500	86,300	6,000	680	3,040,200	33,800	658,200	1,499,900
	Dec	63,300	34,400	1,900	310	892,200	15,000	318,800	693,900
2020	Jan	97,500	41,700	8,000	590	7,738,700	4,500	330,500	646,700
	Feb	24,300	15,200	620	170	148,100	2,600	215,900	300,600
	Mar	99,200	57,200	3,300	780	1,225,200	10,400	504,900	954,900
	Apr	84,800	49,400	2,600	720	817,600	10,600	452,800	899,100
	May	132,700	45,600	16,800	360	18,995,100	10,500	245,300	813,200
	Jun	960	580	20	10	1,900	210	8,300	13,000
	Jul	170	90	3	1	310	30	1,200	1,700
	Aug	54,200	24,800	3,900	410	2,688,100	6,400	141,100	391,800
	Sep	194,100	61,200	33,000	510	33,936,200	19,100	285,200	1,098,000
	Oct	14,000	7,500	550	80	227,100	3,000	69,800	138,100
	Nov	11,800	6,500	200	90	60,100	3,500	112,100	192,800
	Dec	42,900	23,800	1,000	230	488,400	11,200	260,800	537,400

Appendix B: Concentrations from October 1, 2017 through September 30, 2020 versus human development index (HDI, % urban area plus % agriculture land use). Data points are represented by site numbers, which correspond to Table 1, and blue lines indicate slopes of simple linear regression. Site 9 was removed from regression analyses due to its location directly downstream from the waste water treatment plant in Waldron, Arkansas.

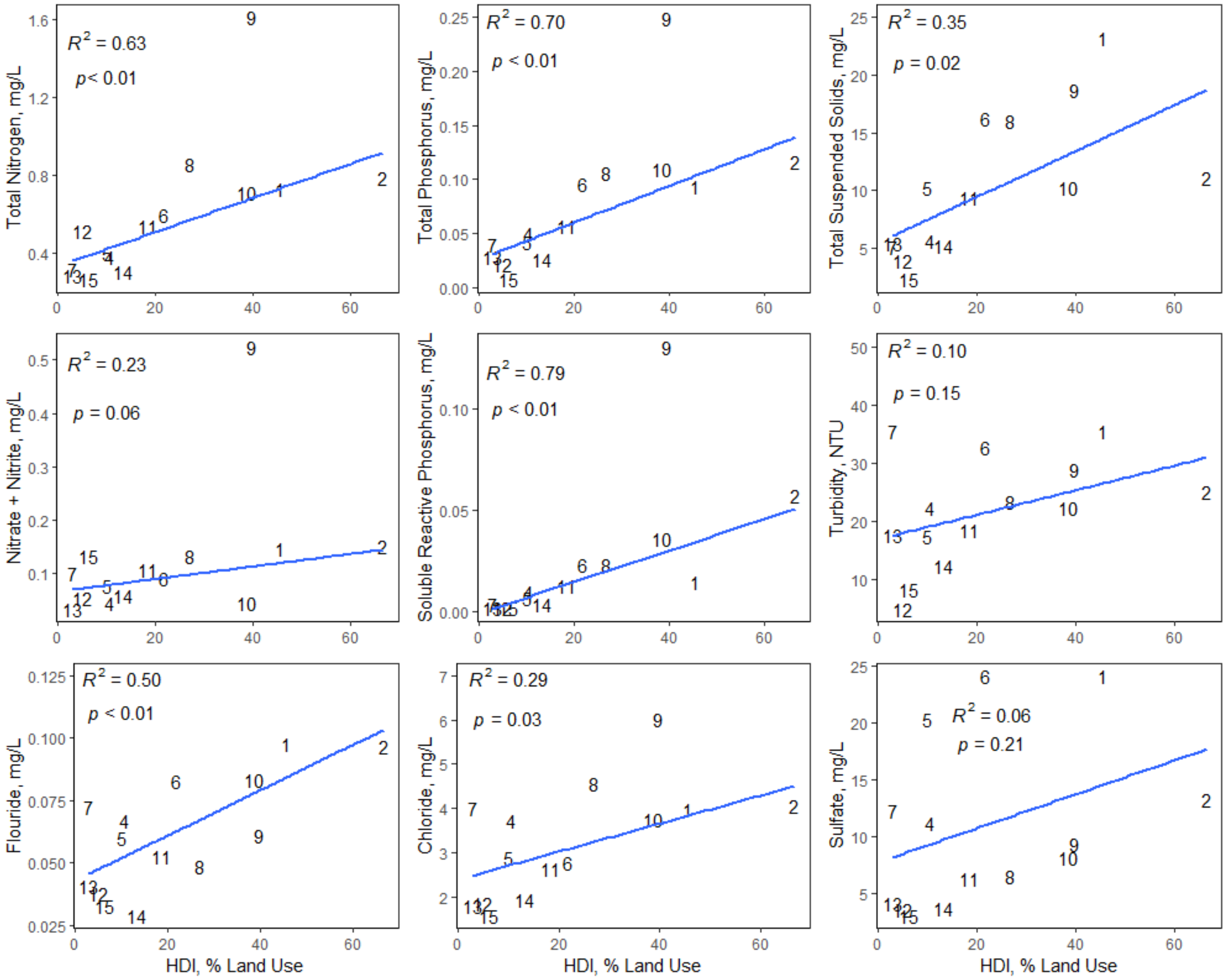
Geometric mean concentrations under baseflow conditions



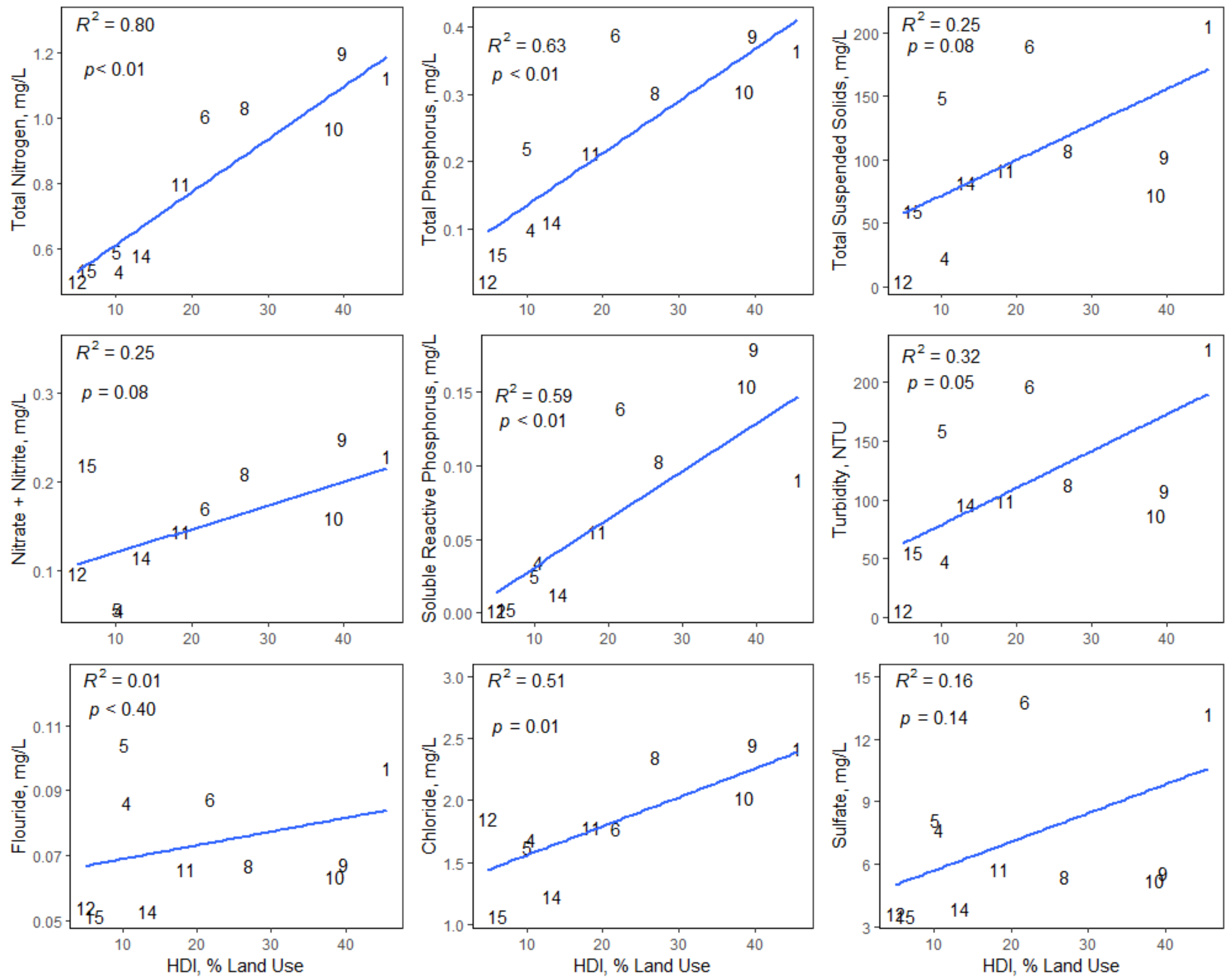
Arithmetic mean concentrations under all flow conditions



Geometric mean concentrations under all flow conditions



Flow-weighted mean concentrations



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