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WATERSHED INVESTIGATIVE SUPPORT TO THE POTEAU VALLEY IMPROVEMENT AUTHORITY

STREAM WATER QUALITY TO SUPPORT HUC 12 PRIORITIZATION IN THE LAKE WISTER WATERSHED, OKLAHOMA:
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Stream Water Quality to Support HUC 12 Prioritization in the Lake Wister Watershed, Oklahoma: August 2017 through May 2019

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INTRODUCTION

Nonpoint source pollution associated with human land use (agriculture and urbanization) is one of the leading causes of impairment to waterways in the United States (EPA 2000). The primary pollutants associated with agricultural and urban land use are sediment and nutrients which enter nearby streams during rain events and are then carried downstream. These sediments and nutrients may result in water quality issues in the downstream water bodies like increased algal growth or decreased water clarity (e.g. Smith et al., 1999).

Best management practices (BMPs) are often used to mitigate the effects of nonpoint source pollution in the watershed. Practices such as riparian buffers installed along the edge of field and conservation tillage (e.g., no-till, spring-till, and cover crops) slow overland flow, reducing erosion and nutrient loss from the landscape (Schoumans et al. 2014). Installing BMPs throughout the entire watershed would have the greatest effect at reducing nonpoint source pollution; however, this is not socially or economically feasible. Targeting critical source areas or priority watersheds for BMPs installation, optimizes the benefits while reducing the overall (Sharpley et al. 2000).

One way of targeting priority watersheds for implementing BMPs is through water quality monitoring during base flow (McCarty and Haggard 2016, Austin, Patterson, et al. 2018, McCarty et al. 2018). The premise is that stream water quality during base flow conditions reflects the influence of nonpoint source pollution across the watershed. Stream nutrient concentrations generally increase with the proportion of agricultural and urban land use in the watershed (Haggard et al. 2003, Giovannetti et al. 2013, Cox et al. 2013, Austin, Patterson, et al. 2018). Thus, stream water quality can be related to human development (i.e., percent urban and agriculture land cover) across a target watershed and this relationship can be used to highlight priority subwatersheds.

Lake Wister is on Oklahoma's 303(d) list for impaired water quality, including excessive algal biomass, pH, total phosphorus (TP), and turbidity (ODEQ, 2014). To address these water quality issues, the Poteau Valley Improvement Authority (PVIA) released its "Strategic Plan to Improve Water Quality and Enhance the Lake Ecosystem" in 2009. The strategic plan breaks down the restoration efforts into three zones of action to focus on the watershed, the full lake, and Quarry Island Cove. This study is a continuation of the study completed in June of 2017 (Austin, Smith, et al. 2018). The purpose of this project was to monitor stream water quality during base flow conditions at or near the outlets of the subwatersheds, in the Oklahoma portion of the Lake Wister Watershed (LWW). The Oklahoma Nonpoint Source Management Program Plan suggests that monitoring and assessment at the HUC 12 subwatershed scale is the most effective means to identify water quality problems associated with nonpoint source pollution (NPS Management Program Plan, 2014). The primary goal of this monitoring was to assist PVIA and other stakeholders in identifying the HUC 12 subwatersheds where implementation of BMPs could be prioritized to address sediment and nutrient transport from the landscape.

STUDY SITE DESCRIPTION

The LWW covers an area of 2,580 km² (~640,000 acres) and makes up the southern half (52%) of the entire Poteau River sub-basin (HUC 11110105; Figure 1). The LWW is divided into 10-digit hydrologic unit code or HUC 10 watersheds. The headwaters of the Poteau River watershed is entirely within Arkansas and was not part of this study. The Black Fork Poteau River and the Poteau River watersheds traverse the state line between Oklahoma and Arkansas, and the Middle Poteau River and Fourche Maline watersheds are entirely within Oklahoma. The HUC 10 watersheds that make up the LWW range in size from 377 to 675 km² (93,300 to 166,800 acres). The primary land use and land cover

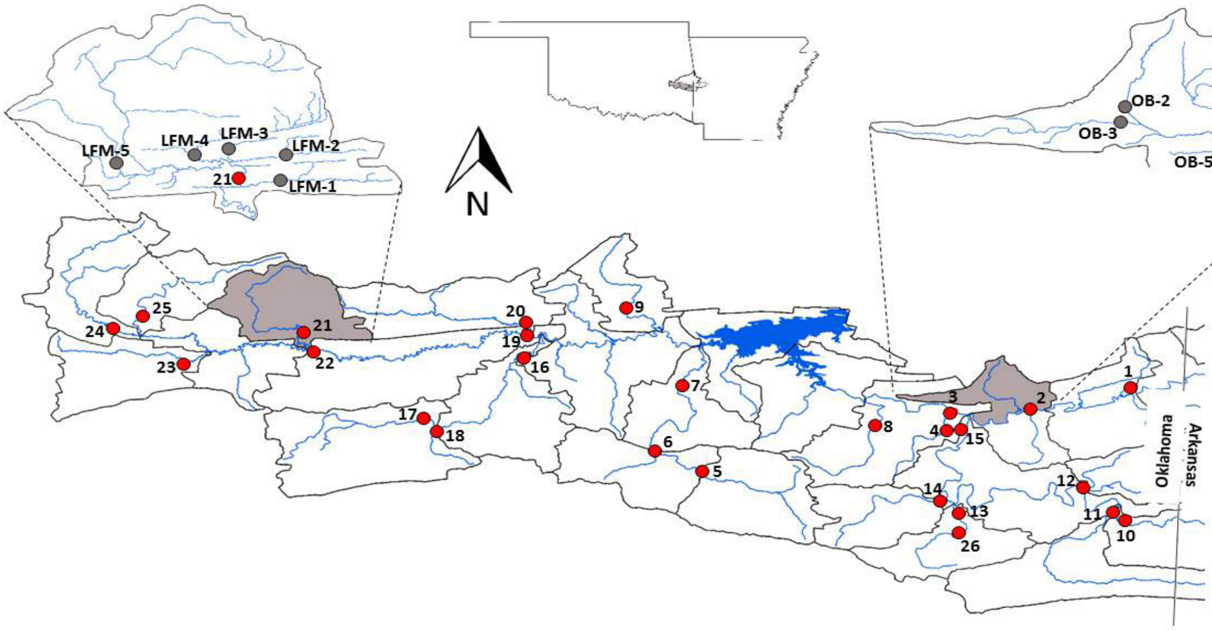

Figure 1: Sampling sites for the routine monitoring (red symbols) and special studies (gray symbols) across the Oklahoma portion of the Lake Wister Watershed.

(LULC) across the Oklahoma portion of the LWW is 72% forest, 19% agriculture, and 4% urban; the LULC for the 845 km² (~209,000 acres) portion of the LWW in Arkansas is similar with 71% forest, 20% agriculture, and 5% urban.

Within the Oklahoma portion of the LWW there are 26 HUC 12 subwatersheds that range in size from 42 to 125 km² (10,300 to 30,800 acres; Table 1). Forest is the dominant LULC across the HUC 12s, ranging from 45 to 95% of the watershed. The proportion of human development (i.e., agriculture plus urban) was less than half of the LULC across the HUC 12s (4–48%; Table 1). Additionally, across the LWW there are 7 EPA national pollutant discharge elimination system (NPDES) permitted point sources, including waste water treatment plants (WWTPs), sewage systems, and a poultry processing plant (Table 2).

For this study we selected 26 sampling sites near the outflow of 23 of the HUC 12's in the Oklahoma portion of the LWW (Figure 1; Table 3). The LULC for the catchments upstream of the 26 sample sites ranged from 49−95% forest, <1−37% agriculture, and <1−10% urban. While these sampling sites are located near the outflow of many of the HUC 12s within the Oklahoma portion of the LWW, they represent the catchment area upstream of them and not specifically the HUC 12s.

METHODS

Sample Collection and Analysis

Water samples were collected at the 26 sites at approximately monthly intervals during base flow conditions from August 2017 through May 2019 (following the approved quality assurance project plan). Water samples were not collected in January 2018 because several stream reaches were dry. The samples were collected from the vertical centroid of flow where the water is actively moving either by hand or with an Alpha style horizontal sampler lowered from the bridge. Water samples were split, filtered, and acidified in the field based on the specific storage needs for each analyte. Field duplicate water samples were collected at 10% of the sites within each monthly sampling event; these field duplicates were collected in the same fashion as the original water sample. Additionally, a field blank was collected during each sampling event. A summary of field quality assurance and quality control (QA/QC) data can be found in Appendix 1. All samples were stored on ice until delivered to the Arkansas Water Resources Center certified Water Quality Labs (AWRC WQL).

In addition to the routine monthly sampling, water samples were collected within select HUC 12 sub-

Table 1: Hydrologic unit code (HUC) 12 subwatersheds in the Oklahoma portion of the Lake Wister Watershed and corresponding LULC data, organized at the HUC 10 watershed scale.

HUC 12	Huc 12 Name	Area (km^2)	% F[1]	% AG[2]	% U[3]	%HDI[4]
HUC 10-1111010502: Black Fork Poteau River						
111101050201	Big Creek	111.7	90	4	5	9
111101050202	Upper Black Fork	124.5	87	7	2	9
111101050203	Haws Creek	73.5	91	3	2	5
111101050204	Shawnee Creek	50.2	87	2	6	9
111101050205	Cedar Creek	49.8	95	1	3	4
111101050206	Lower Black Fork	100.4	81	14	3	17
HUC 10-1111010503: Poteau River						
111101050303	Cane Creek	70.4	68	20	4	24
111101050304	Sugar Creek	71.3	68	27	3	30
111101050305	Hontubby Creek	55.5	63	25	9	34
HUC 10-1111010504: Fourche Maline						
111101050401	Cunneo Creek-Fourche Maline	55.5	83	13	1	14
111101050402	Coon Creek-Fourche Maline	74.4	80	13	4	17
111101050403	Bandy Creek	61.6	48	38	10	48
111101050404	Little Fourche Maline	61.8	68	25	3	28
111101050405	Clear Creek-Fourche Maline	56.1	53	40	4	44
111101050406	Red Oak Creek	73.2	54	37	6	42
111101050407	Upper Long Creek	103.8	83	12	2	13
111101050408	Lower Long Creek	78.2	77	16	1	17
111101050409	Pigeon Creek-Fourche Maline	110.5	53	35	2	37
HUC 10-1111010505: Middle Poteau River						
111101050501	Coal Creek- Poteau River	83	74	19	4	23
111101050502	Upper Holson Creek	77.7	60	25	3	28
111101050503	Coal Creek- Fourche Maline	41.6	68	19	4	22
111101050504	Middle Holson Creek	73	94	3	2	5
111101050505	Lower Holson Creek	59.1	89	5	4	9
111101050506	Cedar Creek-Fourche Maline	59.5	82	12	3	14
111101050507	Baker Branch-Fourche Maline	97.6	65	23	5	28
111101050508	Wister Lake Dam	75.5	45	16	3	19

[1] % Forest, includes deciduous, evergreen and mixed forest; [2] % Agriculture, includes crops, grassland, and pasture/hay; [3] % Urban, includes barren, developed-open space, low, medium, and high intensity development; [4] % Human Development Index is the sum of % Agriculture and % Urban.

watersheds to further understand the spatial variability in water quality and potential sources of nutrients within them. Additional sites were sampled within the Little Fourche Maline HUC 12 subwatershed and the Oil Branch subwatershed, tributary of the Poteau River (Figure 1). The sites were sampled a total of three times during the monthly routine samplings in January, February, and March of 2019. All samples were collected and processed in the same manner as routine monthly samples.

All water samples, field duplicates, and field blanks were analyzed for anions (Cl and SO_4), ammonia-nitrogen (NH_4-N), nitrate-N plus nitrite-N (hereinafter, NO_3-N), total N (TN), soluble reactive phosphorus (SRP), total P (TP), turbidity, total suspended solids (TSS) and sestonic chlorophyll-a (chl-a) following standard methods (Table 4). The analytical techniques, reporting limits and method detection limits are provided (Table 4), and additional information about the certified labs are available at: https://arkansas-water-center.uark.edu/water-quality-lab.php (date acquired 9/22/2019).

Data Analysis

All LULC data for the LWW, HUC 12s within the LWW, and catchments upstream of each sampling location were compiled using GeodataCrawler http://www.geodatacrawler.com/ (Leasure 2013) and Model My Watershed https://app.wikiwatershed.org/ (date acquired 1/31/2018). Within this LULC data, forest is defined as the sum of deciduous, evergreen, and mixed forest, agriculture is the sum of pasture/hay, row crop, and grassland, and urban is the sum of barren, developed open, and low, medium, and high intensity development. Previous, studies from northwest Arkansas have found stream nutrient concentrations to increase with increasing percent agriculture and urban area upstream (Haggard et al. 2003, Giovannetti et al. 2013). Because of this, a simple human development index (HDI) was calculated as the total percent agriculture and urban land use for the catchment upstream of each sample site and for each subwatershed (Tables 1 & 3).

All water quality data collected from August 2017 through May 2019 can be found in the data report "DR-WQ-MSC389" (last accessed). For the purpose of

Table 2: National Pollution Discharge Elimination System (NPDES) permitted sites within the Lake Wister Watershed in Arkansas and Oklahoma.

NPDES Code	Location	Source
OK0038407	Heavener, OK	WWTP[1]
OK0031828	U.S. Forest Service - Cedar Lake, near Hodgen, OK	Sewage systems
OK0022951	Jim E. Hamilton Correctional Center, near Hodgen, OK	WWTP
OK0021881	Wilburton, OK	WWTP
OK0031631	Red Oak Public Works Authority, Red Oak, OK	Sewage systems
AR0038482	Tyson Poultry, Waldron, AR	Poultry Processing
AR0035769	Waldron, AR	WWTP

[1] WWTP = Waste water treatment plant

analysis in this report, each parameter's MDL was substituted for measured values below the MDL and each parameters RL was substituted for all measured values greater than the MDL but less than the RL, with the exception of turbidity, TSS, CHL a, where all measured values were left uncensored

The geometric mean (hereinafter geomean) of constituent concentrations at each site was used in the data analysis, because it is less sensitive to extreme low and high values than arithmetic means. The geomean is typically a good estimate of the central tendency or middle of the data. Seasonal, annual, and overall project (all three years) geomeans were calculated for the water quality parameters at each site. Parameter geomeans and ranges at each site and for each project year can be found in Appendix 2.

The overall project geomeans from each site were related to HDI using simple linear regressions, generating a linear model for each parameter. This statistical analysis shows how geomean concentration increases across a gradient of human development within the watershed. The predictive equation, associated with the linear regression, may have some merit in setting achievable water quality targets across the LWW. We cannot expect a stream with relatively high HDI to have constituent concentrations reflective of near background conditions. However, it may be feasible to expect streams with constituent concentrations well above the regression line to be reduced to near or below the line.

Changepoint analysis is another way to examine how HDI might influence constituent concentrations in streams. Changepoint analysis looks for a threshold in the geomean concentration and HDI relation, where the mean and variability in the data changes. This statistical analysis is not dependent on data distributions, and it gives a threshold in HDI where the geomean concentrations likely increase. For constituent changepoint analyses the overall geomeans from each site were plotted against the HDI for each site.

RESULTS AND DISCUSSION

Nitrogen

Annual geomean concentrations of NH_4-N across the streams ranged from 0.01 to 0.17 mg L^{-1} over the course of the study. NH_4-N did not vary annually, and annual geomean concentrations were not different from the project geomean (F3,100=0.767; P=0.575). While NH_4-N was not variable between years, it did vary seasonally (F3,300=4.30; P=0.005), with concentrations greatest in the summer and least in the winter (Figure 3E). This difference in NH_4-N concentrations between seasons was driven by Site 23, which consistently exceeded 0.2 mg L^{-1} during the summer months. Overall, we would not expect to see relatively high NH_4-N concentrations, except maybe downstream from effluent discharges, as is the case with Bandy Creek (Merbt et al. 2011) because it is quickly nitrified in streams (Haggard et al. 2005).

Nitrate concentrations were relatively low across the streams sampled, where annual geomean concentrations of NO_3-N varied from 0.01 to 0.55 mg L^{-1}. There were no clear annual or seasonal patterns in NO_3-N across the streams sampled (F3,100=0.831; P=0.480, F3,300=0.420; P=0.739; respectively) possibly because NO_3-N was less than 0.1 mg L^{-1} at most sites throughout each year. While there were no seasonal trends in NO_3-N, sites with elevated NH_4-N in summer tended to have elevated NO_3-N in the summer as well, likely due to increased rates of nitrification from increased NH_4 availability ((Kemp and Dodds 2002)).

The majority of TN in the flowing waters was in the particulate form, where dissolved inorganic N (DIN: NH_4-N plus NO_3-N) was on average less than 30% of the total. Annual geomean concentrations for TN ranged from 0.07 to 1.59 mg L^{-1}. This range in TN is fairly consistent across all three years (F3,100=0.506; P=0.679; Figure 2A), and there was no real seasonal pattern (F3,300=1.341; P=0.270; Figure 3A). Overall, nitrogen concentrations tended to be within the range nutrient supply threshold concentrations needed to promote algal growth and cause shifts in algal community composition (0.27-1.50 mg L^{-1}; (Evans-White et al. 2013),

Table 3: Sample sites and land cover within the Lake Wister Watershed organized by HUC 10s. The number in the HUC 12 column is the final two digits associated with the HUC10 number listed at the top of each group of sites.

Site #	HUC 12	Stream Name	Area (km^2)	%F[1]	%AG[2]	%U[3]	% HDI[4]	Latitude	Longitude
HUC10-1111010503: Upper Poteau River									
*1	3	Poteau River	694	66	25	5	30	34.880	-94.483
*2	4	Poteau River	768	66	25	5	30	34.859	-94.566
*3	5	Poteau River	1335	74	18	5	22	34.858	-94.629
HUC10-1111010505: Middle Poteau River									
4	2	Conser Creek	34	95	3	2	5	34.867	-94.704
5	4	Holson Creek	73	94	3	2	5	34.807	-94.838
6	5	Holson Creek	132	92	4	3	7	34.823	-94.876
7	6	Holson Creek	182	91	5	3	7	34.879	-94.853
8	2	Rock Creek	11	67	30	2	32	34.843	-94.636
9	3	Coal Creek	27	72	19	2	21	34.951	-94.890
HUC10-1111010502: Black Fork Poteau River									
10	2	Black Fork	122	88	6	2	9	34.760	-94.490
11	1	Big Creek	112	90	3	5	8	34.769	-94.499
12	3	Black Fork	323	89	5	3	8	34.793	-94.526
*13	4	Shawnee Creek	48	88	1	6	8	34.768	-94.628
14	5	Cedar Creek	48	95	1	4	4	34.779	-94.640
*15	6	Black Fork	509	88	6	4	9	34.843	-94.625
*26	4	Shawnee Creek	23	93	1	5	6	34.789	-94.628
HUC10-1111010504: Fourche Maline									
16	8	Long Creek	180	80	13	1	15	34.908	-94.980
17	7	Long Creek	77	83	12	1	13	34.851	-95.066
18	7	Long Creek tributary	20	87	8	3	12	34.840	-95.054
*19	9	Fourche Maline	417	63	28	4	32	34.929	-94.981
*20	6	Red Oak Creek	71	54	37	6	43	34.936	-94.981
21	4	Little Fourche Maline	55	70	23	3	26	34.927	-95.163
*22	5	Fourche Maline	313	67	26	4	30	34.912	-95.156
*23	3	Bandy Creek	59	49	37	10	47	34.902	-95.261
24	2	Fourche Maline	72	81	12	4	16	34.933	-95.319
25	1	Cunneo Creek	45	90	7	>1	7	34.942	-95.298

[1] %Forest, includes deciduous, evergreen and mixed forest; [2] %Agriculture, includes crops, grassland, and pasture/hay; [3] % Urban, includes barren, developed-open space, low, medium, and high intensity development; [4] %Human Development Index is the sum of %agriculture and %urban; and * indicates sites downstream of EPA NDPES permitted point sources.

potentially creating nuisance algal conditions.

The geomean concentrations of the N species varied across the LWW, reflecting changes in nutrients sources and land uses within the drainage areas. The geomean N concentrations increase with the proportion of agriculture and urban development (Figures 4A, C, &E), i.e., HDI values, in the watershed, explaining:

- 46% of the variability in NH_4-N,
- 35% of the variability in NO_3-N, and
- 70% of the variability in TN.

The relationships with stream N concentrations and HDI have been observed across the region (e.g. see Haggard et al. 2003; Migliaccio & Srivastava 2007; Giovannetti et al. 2013). The regression lines provide a possible water-quality target to where N concentrations might be reduced at a given HDI. The sites, or streams, with concentrations well above this line might be of specific interest for management, e.g. Site 23.

The geomean concentrations of the N species also showed changepoints or threshold responses to in-

Table 4: Laboratory parameters with specific EPA approved analytical procedures

Parameter	Method	Units	RL	MDL
NO_3-N	EPA 353.2	mg L^{-1}	0.01	0.005
NH_3-N	EPA 351.2	mg L^{-1}	0.01	0.01
Cl	EPA 300.0	mg L^{-1}	0.5	0.06
SO_4	EPA 300.0	mg L^{-1}	0.5	0.11
SRP	EPA 365.1	mg L^{-1}	0.005	0.004
TP	APHA 4500PJ	mg L^{-1}	0.02	0.003
TN	APHA 4500PJ	mg L^{-1}	0.05	0.01
Chl a	APHA 10200 H1&2C	µg L^{-1}	--	--
TSS	EPA 160.2	mg L^{-1}	4	--
Turbidity	EPA 180.1	NTU	--	--

creasing HDI; that is, the average and deviation of the geomeans increased above an HDI value. The changepoints were relatively similar across the N species at 28% HDI (Figures 5A, C, &E). The average of the data above the changepoint was generally 2 to 3 times greater than the data below that HDI value. Subwatersheds with measured values greater than the site average above the changepoint should be considered as higher priority than sites below the site average of sites beneath the changepoint.

Phosphorus

Geomean concentrations of SRP across the streams ranged from less than 0.005 to 0.189 mg L^{-1}, with 45% of the values measured less than the lab's reporting limit (0.005 mg L^{-1}). Geomean concentrations of SRP did not vary between project years (F3,100=0.465; P=0.707 Figure 2D) or between seasons (F3,300=2.059; P=0.106 Figure 3D). Overall, SRP concentrations across the streams of the LWW were low with nearly 75% of sites having geomean concentrations less than 0.015 mg L^{-1}.

Geomean concentrations for TP ranged from 0.013 to 0.265 mg L^{-1}; much of which was in the particulate form, where the dissolved form (SRP) typically made up less than 33% of the measured TP. TP concentrations were not different between project years (F3,100=0.350; P=0.789; Figure 2B), whereas TP concentrations in the summer were greater than concentrations in the fall and winter (F3,300=3.400; P=0.018; Figure 3D). The increase in TP across the streams during the summer corresponded with slight increases in TSS and Chl-a in the water column (discussed later). Like TN, TP concentrations tended to be within the range or nutrient supply threshold concentrations needed to increase algal growth and drive shifts is algal community composition in streams (0.007 – 0.100 mg L^{-1}; (Evans-White et al. 2013) and potentially cause nuisance algal conditions; although, two sites with values much higher than this range were directly downstream of effluent discharges (Bandy Creek and Shawnee Creek at Hwy 59).

Geomean P concentrations varied across the streams draining the LWW, showing that over 70% of the variability in SRP and TP concentrations was explained by HDI (Figures 4B & D). These relationships between stream P concentrations and HDI, like N species, have been observed across the region (e.g. see (Haggard et al. 2003, Cox et al. 2013), reflecting the potential P sources such as poultry litter applied to pastures (DeLaune et al. 2004, Cox et al. 2013). The regression lines provide a realistic water quality target to where P concentrations might be reduced and show sites that deviate greatly from concentrations at a given HDI.

The geomean concentrations of the P species also showed changepoint responses to increasing HDI. The changepoints for P species were slightly lower than for N species at 24% HDI. In both cases mean values to the right (above) of the threshold were 3 times greater than the mean values to the left (below) of the threshold. Site 23 consistently shows elevated P and N concentrations relative to other sites across the LWW, suggesting nutrient sources upstream might need to be investigated (Figure 5B & D).

Chlorophyll a

Annual geomean concentrations of sestonic Chl-a (algal biomass in the water column) ranged from 0.2 to 18.5 µg L^{-1} across the streams in the LWW. Overall, CHL-a was less than 5 µg L^{-1} in nearly 80% of the samples collected from July 2016 through May 2019. Geomean Chl-a concentrations were consistent across project years (F3,100=2.318; P=0.080; Figure 2F), but showed some variability between seasons with concentrations greatest in the summer and least in the spring (F3,300=2.761; P=0.042; Figure 3F).

The geomean concentrations of Chl-a increased with the proportion of human development in the watershed (i.e., HDI values), where HDI explained 54% of the variability in sestonic Chl-a (P<0.001; Figure 4F). This strong relationship was surprising, because many physical, chemical, and biological factors influence algal growth in streams (Evans-White et al. 2013). However, in steams hydrology (e.g. discharge; Honti et al. 2010) is one of the most important factors since most algal growth would be on substrates not generally in the

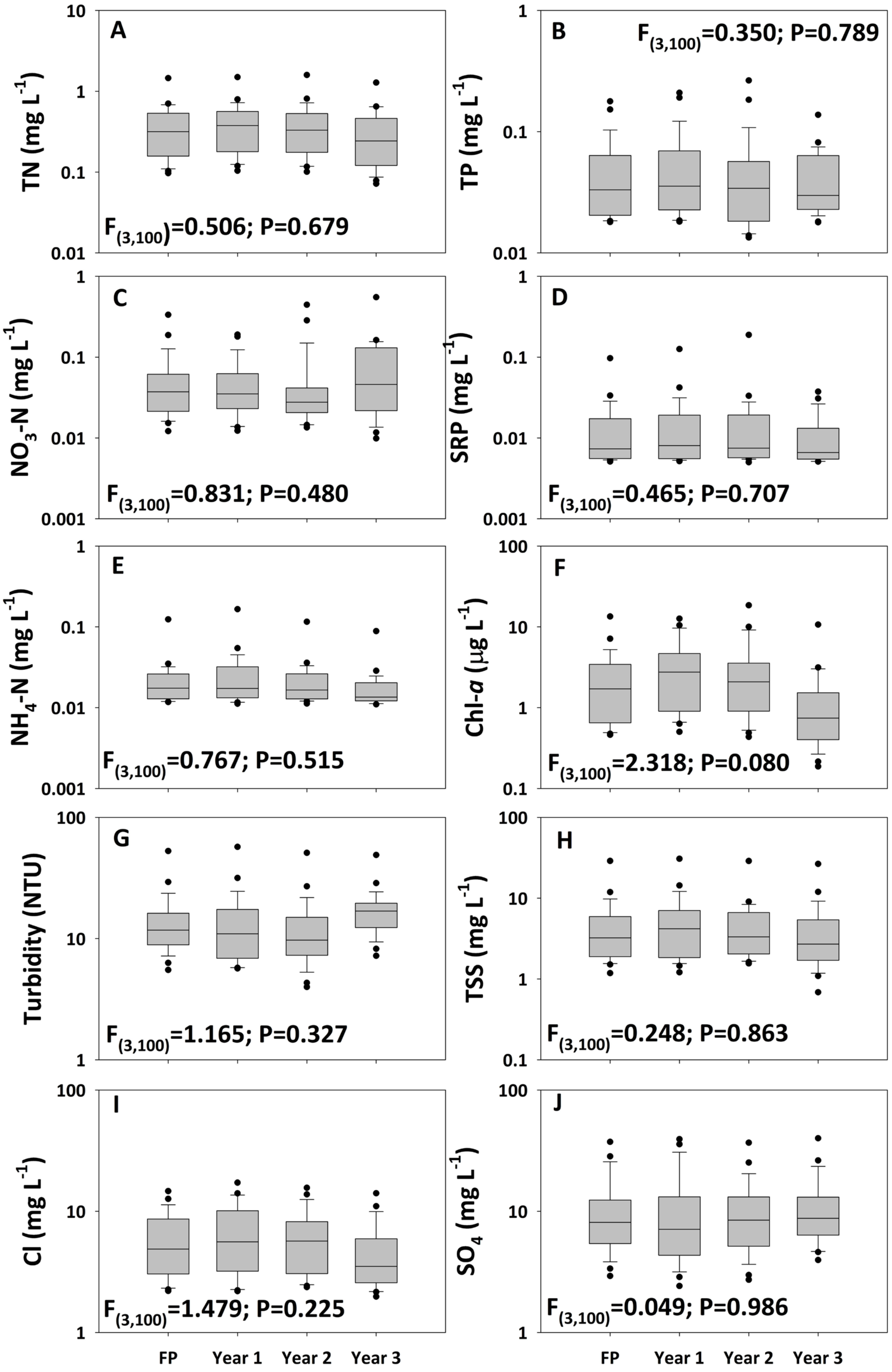

Figure 2: Box and whisker plots of constituents showing medians (horizontal line within each box), range (error bars show the 5th and 95th percentiles), and outliers (points above and below error bars) for each of the constituents analyzed at the Oklahoma sites in the Lake Wister Watershed. The full project (FP) median and range is shown to the right of the individual project years.

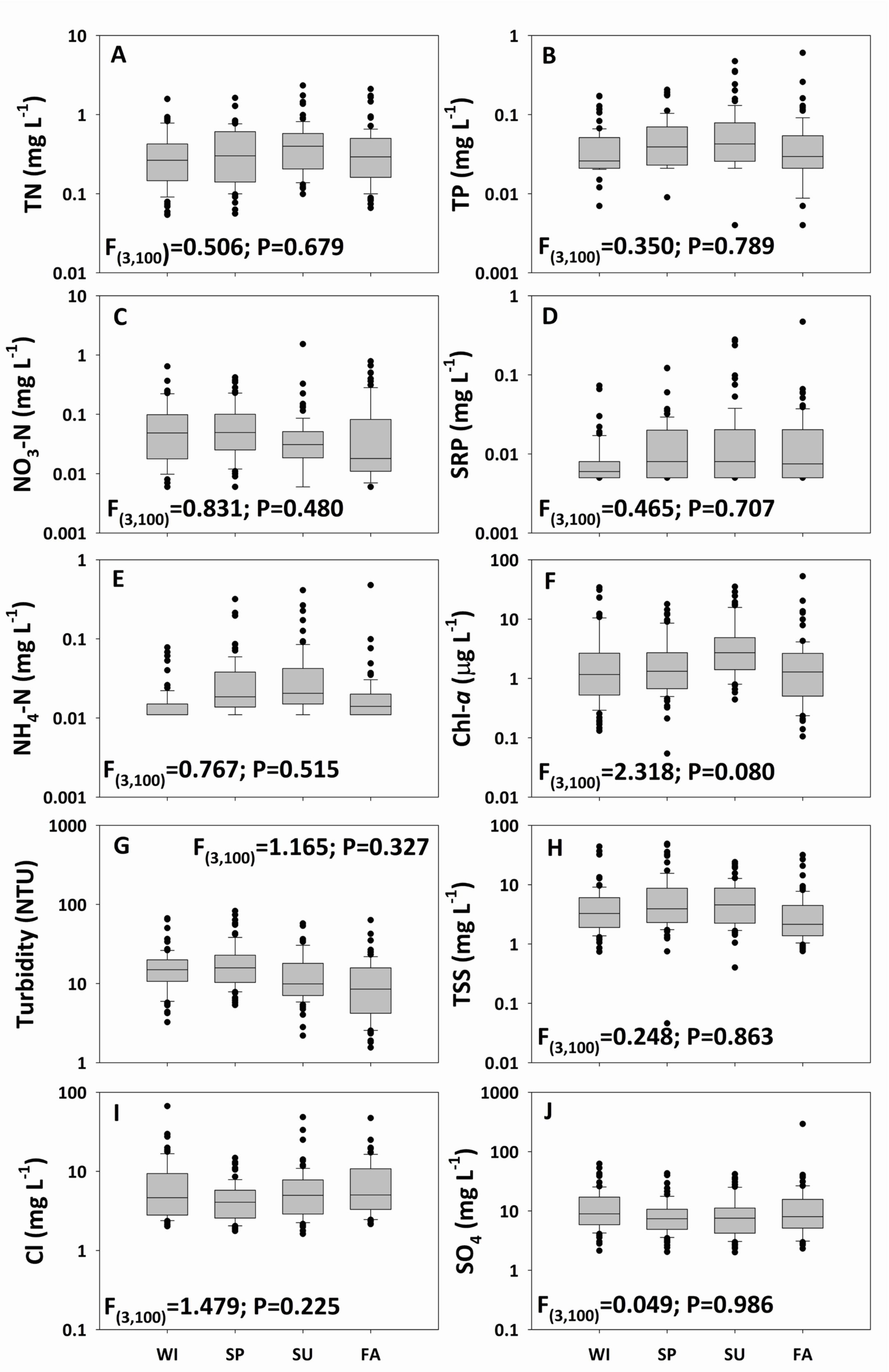

Figure 3: Box and whisker plots of seasonal variability in constituents showing medians (horizontal line within each box), range (error bars show the 5th and 95th percentiles), and outliers (points above and below error bars) for each of the constituents analyzed at the Oklahoma sites in the Lake Wister Watershed.

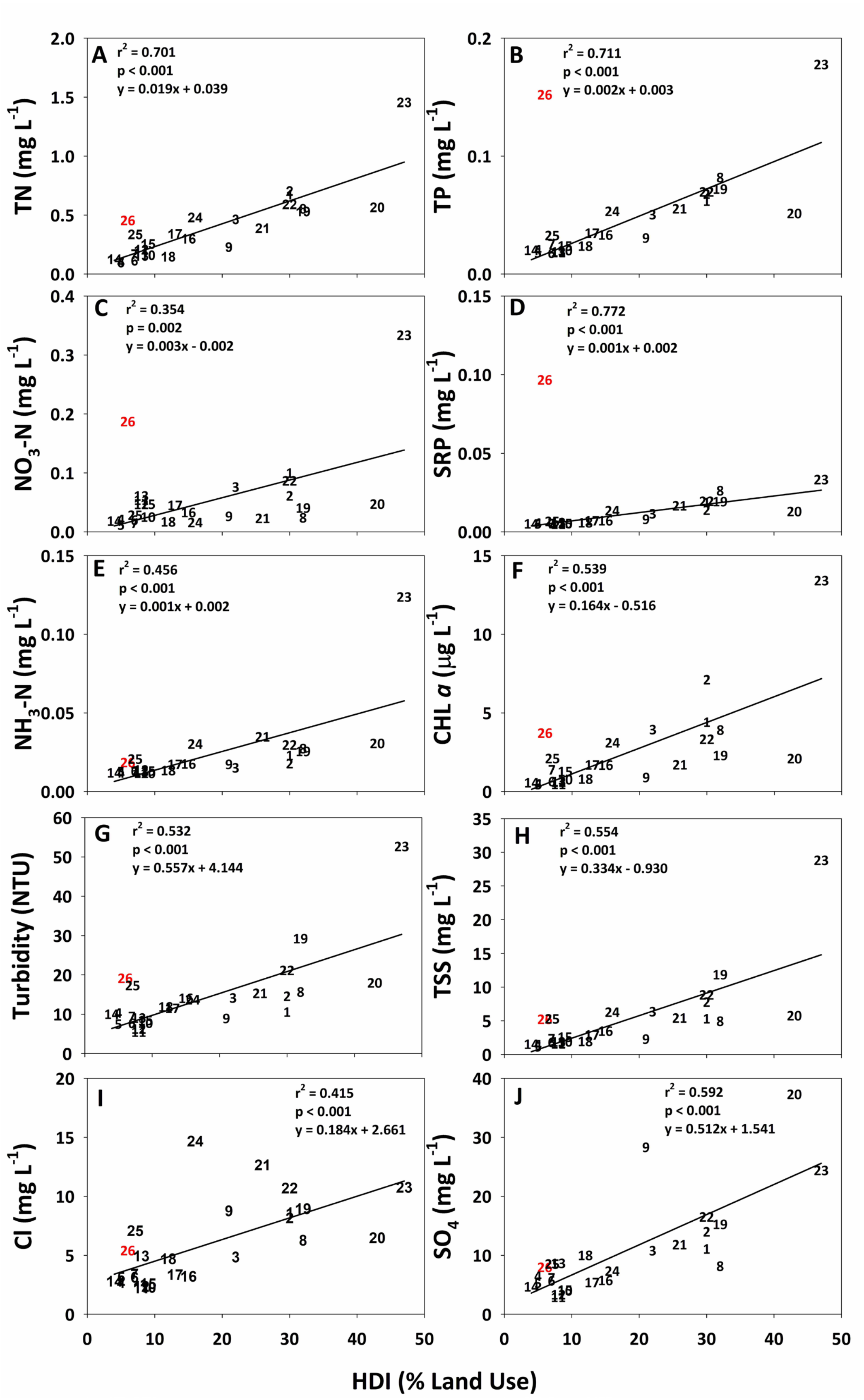

Figure 4: Simple linear regression of geomean constituent concentrations verse human development index (HDI) values for the Oklahoma portion of the Lake Wister Watershed. The site number in red is Shawnee Creek at highway 59 downstream of effluent discharge, thus it was not used in the statistical analysis.

water column (i.e., sestonic). It is likely that this correlation is driven by the increased nutrient concentrations found at sites with higher HDI values. Geomean Chl-a concentrations across these sites were strongly (positively) related to both TP (r2=0.47; P<0.001) and TN (r2=0.79; P<0.001). The sites with elevated Chl-a had increased total nutrient concentrations and supply available, as seen in other systems (Chambers et al. 2012, Haggard et al. 2013). Not suprisngly, based on its relationship with TN and TP, sestonic Chl-a showed a threshold at an HDI value (28%) similar to that observed with nutrient concentrations (Figure 5F).

Suspended Sediments and Turbidity

Annual geomeans for turbidity and TSS were from 4 to 57 NTU and from 1 to 31 mg L^{-1}, respectively. These two constituents were strongly correlated (r=0.90; P<0.001) and show similar seasonal patterns, with greater values in the spring and lesser values in the fall (Figures 3G & H). Low values in the fall, for both constituents, may be explained by the drier conditions during the fall. The less frequent rainfall events producing runoff, reduces erosion from the landscape and within the fluvial channel, and the lower flows throughout this season have less power to erode the channel and keep particulates in the water column (Morisawa 1968). The more frequent storms and elevated base flow during spring and early summer likely keep TSS and turbidity elevated in streams (relative to fall) across the LWW.

Many factors influence turbidity and the amount of particulates in the water column of streams, including rainfall-runoff, discharge, channel erodibility, and even algal growth to some degree. The myriad of factors that influence turbidity (and particulates) in water are also influenced by human activities, which is likely why HDI explained more than 50% of the variability in geomeans of turbidity and TSS across the streams of the LWW (Figure 4F & H). These relations are not well defined regionally but where data is available similar observations have been made (Price and Leigh 2006). Turbidity and TSS often are positively correlated to TP in streams (Stubblefield et al. 2007), which was also the case across the streams in the LWW (r=0.70; P<0.001 and r=0.73; P<0.001; respectively).In addition to the significant linear relationships, there was also a significant threshold response in turbidity and TSS at 30% HDI (Figure 5F & H), with mean values above the threshold 2.5 to 3.5 times greater than the mean value below the threshold. It is interesting that turbidity and TSS, during base flow conditions were so strongly correlated to HDI across these sites.

Anions

Annual geomean concentrations of Cl ranged from 2 to 17 mg L^{-1}, site Cl geomeans for individual project years were not significantly different from the overall project geomean (Figure 2I). However, Cl geomeans varied significantly between seasons, with Cl greatest in the winter (Figure 3I), this was likely due to greater groundwater inputs during the winter. Also, greater Cl concentrations during the winter may be due to the use of road deicers during icy road condition as has been found elsewhere (Sun et al. 2014). Despite having greater concentrations in the winter, Cl was consistently below EPA secondary drinking water standards of 250 mg L^{-1} across all sites sampled. Relatively few studies have focused on toxicity of Cl on freshwater fish. However, the reported values in this study for Cl were 2 to 3 orders of magnitude less than those reported to have chronic toxicity effects on fat head minnows and rainbow trout [704 mg L^{-1} and 1174 mg L^{-1}, respectively (Elphick, Bergh, et al. 2011)].

Annual geomean concentrations of SO_4 ranged from 2 to 40 mg L^{-1}. Like Cl, annual geomeans for SO_4 were not different from the overall project SO_4 geomean (Figure 2J), but showed seasonal variability, with increased concentrations during the winter (Figures 3J). This was likely due to a combination of increased groundwater inputs and the use of road deicers (Sun et al. 2014). Sulfate concentrations were consistently below EPA secondary drinking water standards of 250 mg L^{-1} across all sites sampled. Chronic toxicity of SO_4 on aquatic organisms varies in relation to the water hardness, with greater SO_4 toxicity under soft water conditions (hardness<80 mg L^{-1} measured as $CaCO_3$) which is common in sandstone dominated systems such as the LWW. Sulfate values measured were lower than suggested standards for protecting aquatic life in soft water systems [129 mg L^{-1} SO_4 (Elphick, Davies, et al. 2011)].

The geomean concentrations of both Cl and SO_4 were both positively related to the HDI gradient within the Oklahoma portion of the LWW, explaining 42% of the variability for Cl and 59% of the variability for SO_4 (P<0.001; Figure 4I & J). The geomean concentrations of these two anions also showed changepoint responses to increasing HDI, which were similar between constituents (15−18% HDI) but slightly less than other parameters. The average value for the data above the changepoint tended to be 2 to 3 times greater than the average of the values below the changepoint line (Figure 5I & J).

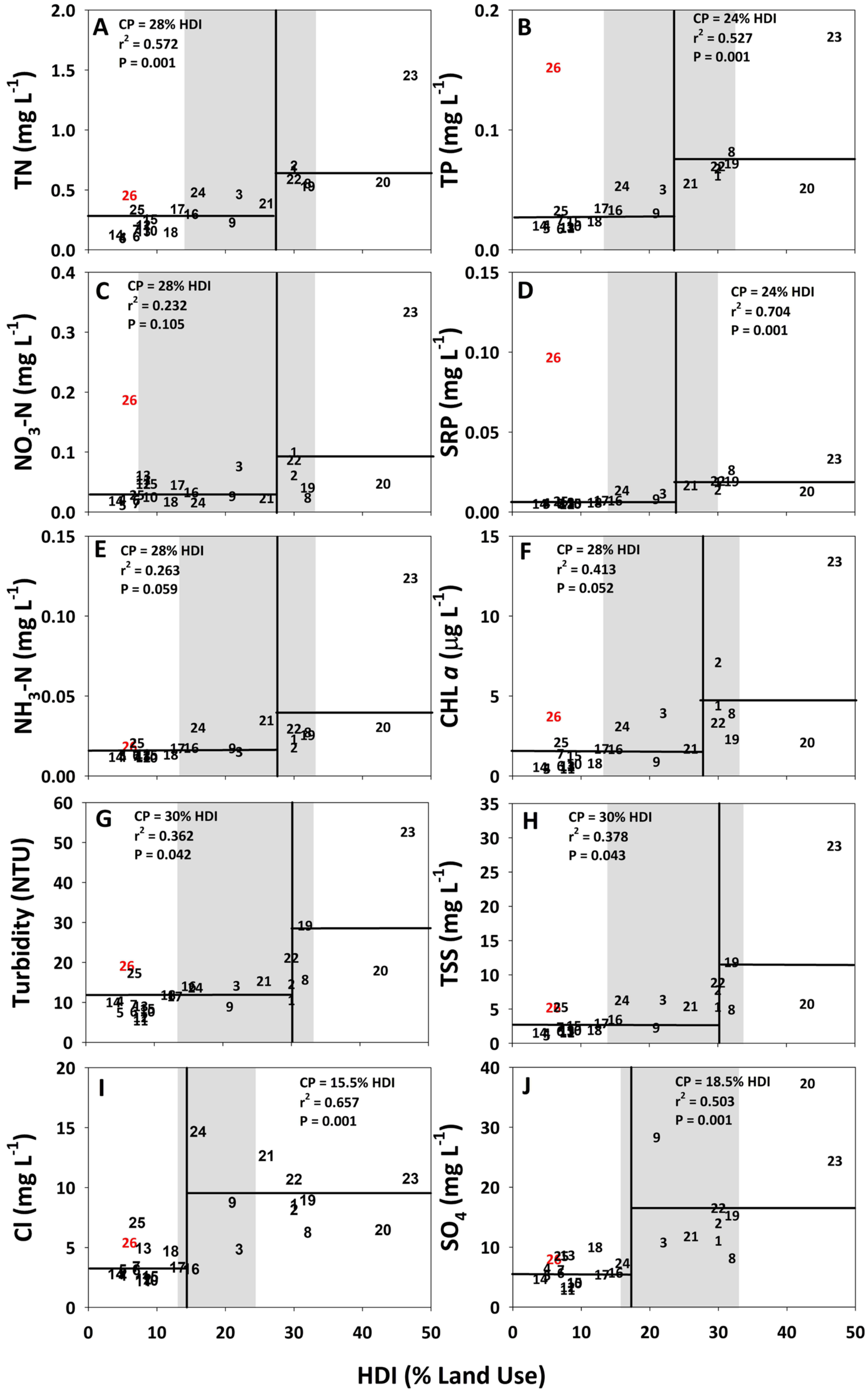

Figure 5: Change point analysis of geomean concentrations verse human development index (HDI) value for sites in the Oklahoma portion of the Lake Wister Watershed. The vertical line represents the change point values specific to each constituent. The gray box shows the 90% confidence interval about the changepoint. Horizontal bars represent the mean of the data points to the left and right of the change point. The site number in red is Shawnee Creek at highway 59 downstream of effluent discharge was not used in the statistical analysis.

Special Studies

Based on work completed during the first year, a few of the subwatersheds or sampling sites were of specific interest: the Little Fourche Maline (site 21) and Oil Branch, one of the four Poteau River tributaries sampled in the first special studies. We sampled additional sites within these subwatersheds to help determine where potential nutrient and sediment sources might be or to confirm the influence of a known specific source. The additional sampling was short-term (n=3) sampled during routine monitoring from January through March 2019 sample periods.

During the first project year, measured water chemistry highlighted the Little Fourche Maline site as a medium level priority HUC 12. For the little Fourche Maline subwatershed we wanted to see where among the tributaries were constituent concentrations greatest. So, we sampled four tributaries and one additional site along the main stem upstream of the main site on the Little Fourche Maline (Figure 1). These additional data showed:

- Total N, P, and suspended solids (SS), along with SO_4 increased with %HDI in the Little Fourche Maline watershed.
- Tributaries LFM-2, 3, and 4 tended to have greater constituent concentrations than sites along the main stem (LFM-5 and Site 21; Figure 6).
- The Little Fourche Maline watershed north of Hwy 270 is predominantly forested (i.e., 87%) and had relatively low constituent concentrations (Figure 6).

These data suggest that the majority of total nutrients and suspended solids enter the Little Fourche Maline watershed between Hwy 270 and the Little Fourche Maline's confluence with the main stem of the Fourche Maline. Implementation of BMP's within this portion of the watershed would likely have the greatest effect at reducing constituent concentrations in the Little Fourche Maline.

The second subwatershed we focused on was Oil Branch, a tributary of the main stem of the Poteau River. Previously we had sampled one location in this watershed; site OB-5 which is just upstream of Oil Branch's confluence with the Poteau River. Previous work at this site found some of the greatest concentrations of dissolved and total N and P across all sites sampled during the first project year. This site and watershed were also of special interest to PVIA and stakeholders due to the Heavner WWTP (Table 2) which discharges effluent into this watershed. Four additional sites were sampled, two

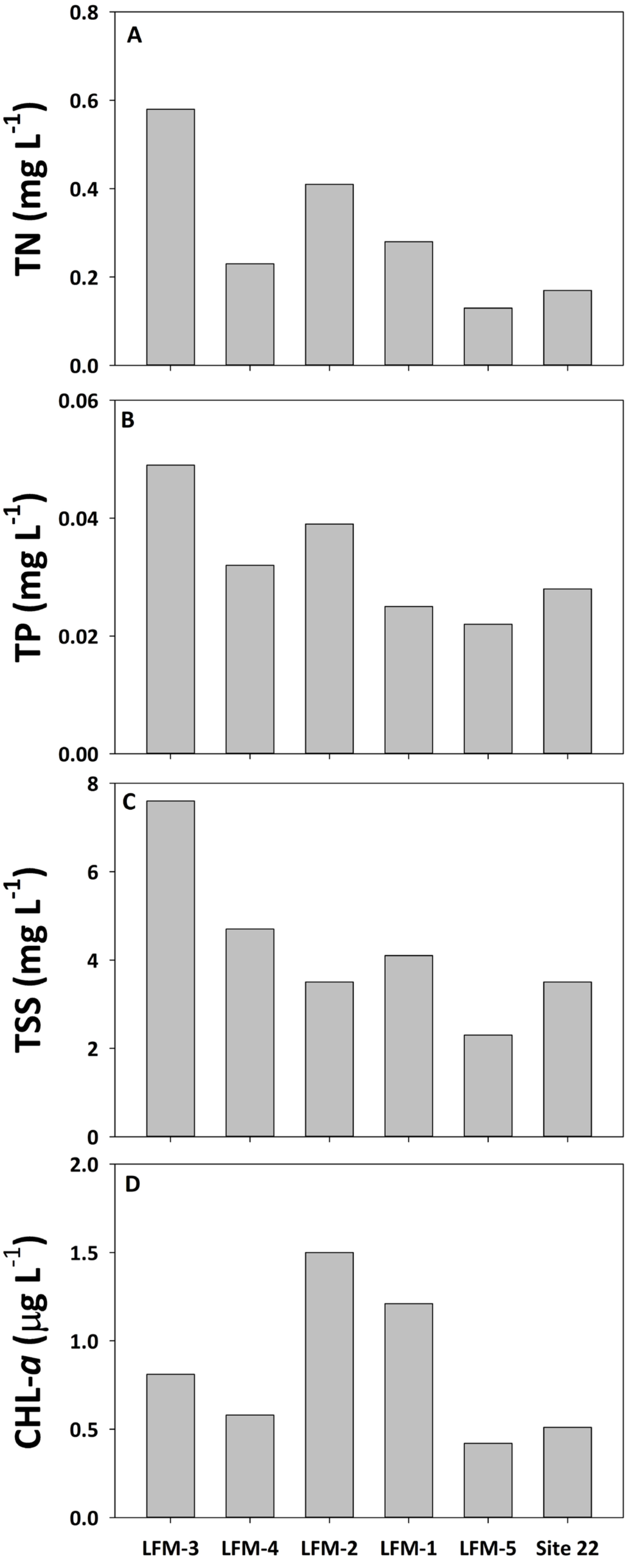

Figure 6: Geomean concentrations across the sites within the Little Fourche Maline Watershed sampled from January through March of 2019 for the special study. With geomean concentrations of TN (A); TP (B); TSS (C); and CHL-a (D).

upstream of the WWTP and two tributaries that flowed into the main stem of Oil Branch after the WWTP (Figure 1). Data from these additional sites show:

- Total N and P, and chl-a were greatest at the site below the Heavner WWTP (Figure 7).
- TSS was greatest at OB-4 and OB-5, suggesting that the OB-4 tributary is likely a source of suspended solids to the watershed (Figure 7).
- There were no significant relationships between the constituent concentrations and %HDI when the point source influenced site (OB-5) is included in the analysis.
- With OB-5 excluded, Cl and SO_4 are positively related to %HDI; while turbidity, TP, NO_3, and NH4 are all negatively related to %HDI.

Finer scale sampling of this watershed suggests that the Heavner WWTP is the dominant source of nutrients to the watershed. Across the tributaries of Oil Branch creek only Cl and SO_4 related positively with %HDI whereas TP and dissolved N were inversely related to %HDI. Further sampling may be needed to determine why these sites relate to %HDI differently than other sites.

Criteria for Selecting Priority HUC 12s

Changepoint analysis is a powerful statistical tool, and one of its most useful aspects is that it gives a threshold, i.e., specific value on the x–axis. In this case, the changepoint gives an HDI value or the proportion of the watershed that is agriculture and urban. This is the point where watershed land use has an influence on water quality, increasing the constituent concentrations. Thus, this information can be used to help design a process from which PVIA and its stakeholders could establish which HUC 12s or smaller subwatersheds are priorities for NPS management. The following sections provide some guidance on how this might be done.

In the absence of water quality data at all subwatersheds, specific HDI thresholds can be used to help identify which HUC 12s or smaller watersheds might be a priority for NPS management. The HUC 12s could be prioritized and separated into categories based on the example (Figure 8A). The hypothetical categories could include:

- Preservation: HDI<15%; these subwatersheds would be background or reference sites as established by the lower end of the 90th percentile confidence interval about the changepoints.
- Low priority: HDI from 15-25%; these subwatersheds would be a low priority for NPS man-

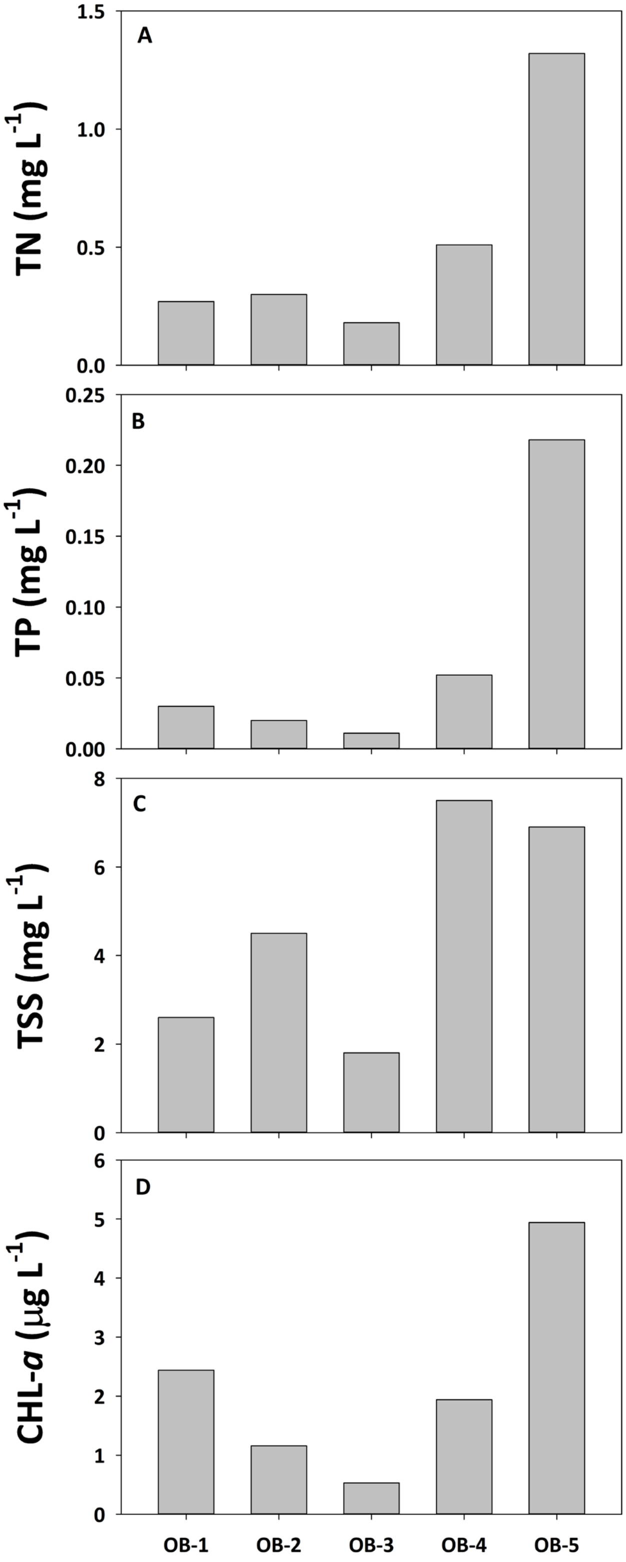

Figure 7: Geomean concentrations across the sites within the Oil Branch Watershed sampled from January through March of 2019 for the special study. With geomean concentrations of TN (A); TP (B); TSS (C); and CHL-a (D). The vertical dashed line represents the Heavener waste water treatment plant.

agement as established by the lower end of the 90th percentile confidence interval about the changepoint and the changepoint.

- Medium priority: HDI from 25-30%; these subwatersheds would be a medium priority for NPS management as established by the changepoint and the upper end of the 90th percentile confidence interval about the changepoint.
- High priority: HDI>30%; these subwatersheds would be a high priority for NPS management as established by the upper end of the 90th percentile confidence interval about the changepoint.

Based on the LWW stream data, sites with HDI values less than 90th percentile confidence interval about the changepoint had low constituent concentrations (Figure 8A). The goal here would be to keep or preserve these HUC 12s to maintain existing water quality conditions. On the opposite end of the spectrum, streams with HDI values greater than the 90th percentile confidence interval around the change point generally had greater constituent concentrations. So, PVIA and stakeholders might want to focus efforts on HUC 12s with HDI values above 30% when establishing NPS management priorities. If we just use the LULC for each individual HUC 12 (Table 1), then following this classification scheme, HUC 12s along the Fourche Maline and Poteau River would be ranked as medium to high priority and HUC 12s along the southern border of the Wister Watershed would be classified as preservation (Figure 9). In the absence of water quality data, this option can be a good method for selecting HUC 12s when developing the watershed management plan.

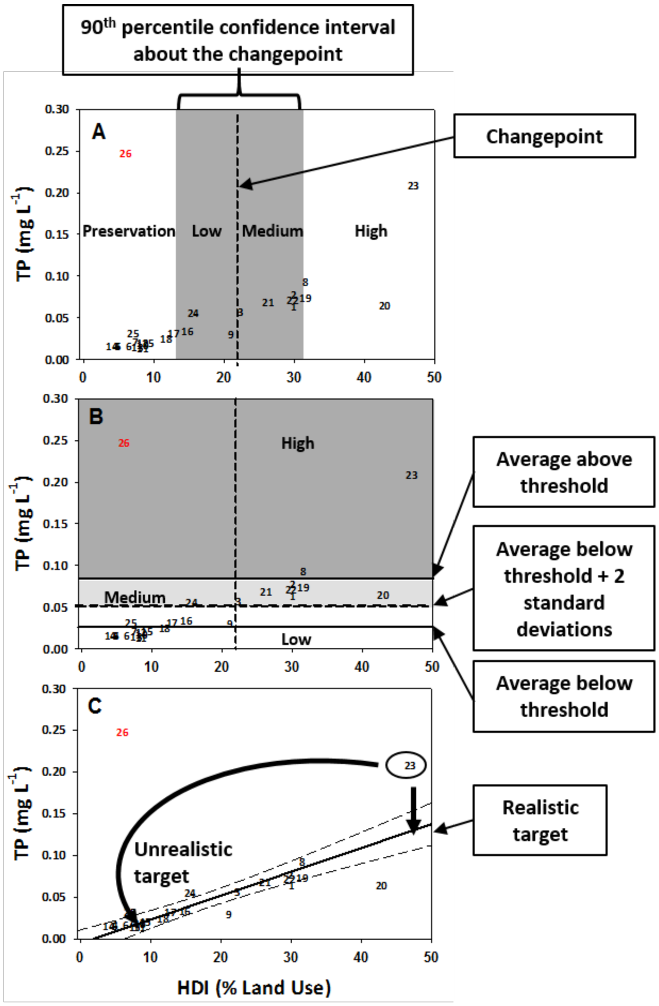

Figure 8: Potential methods using changepoints to identify watersheds for nonpoint source management. Categorization of HUC 12s based on their human development index (HDI) value only (A); separation of HUC 12s based on measured water quality data (B). Linear models (regression line) represent realistic targets for improving water quality within a HUC 12 of a given HDI value (C).

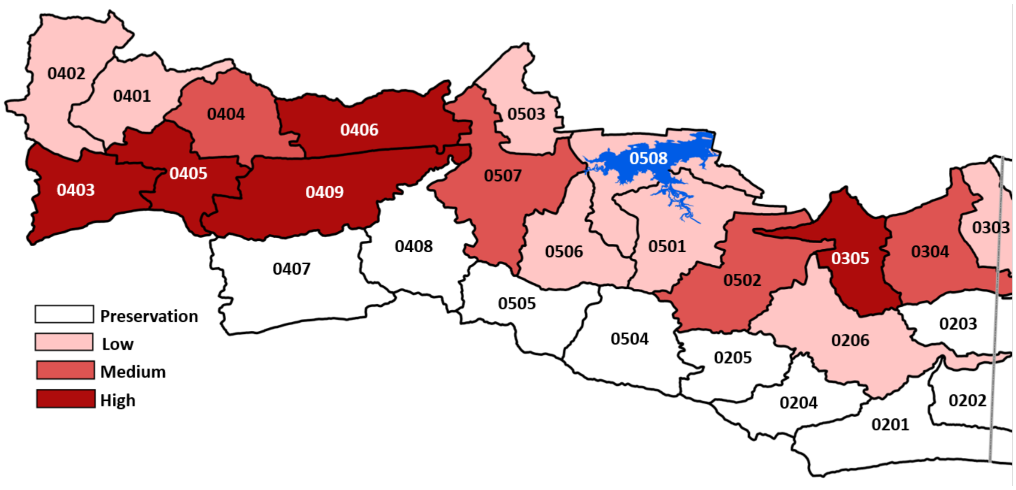

Figure 9: Potential prioritization of hydrologic unit code (HUC) 12 subwatersheds based on the threshold response of constituent concentration to the human development index (HDI) as shown in Figure 8A; the priority for nonpoint source management varies from lightest (preservation) to darkest (highest priority). HUC 12 subwatersheds are labeled with the last four digits of their HUC 12 code.

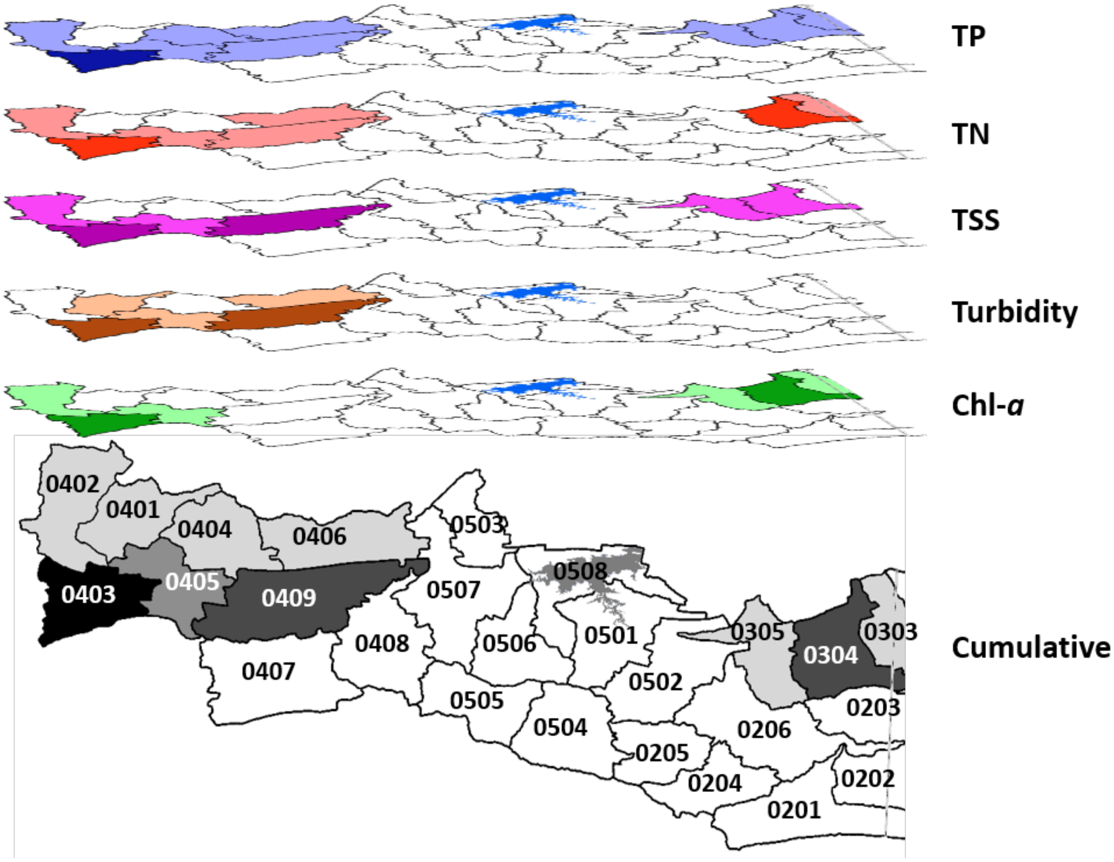

Figure 10: Potential prioritization of HUC 12 subwatersheds when chemical concentrations are available in streams. Using specific constituents to meet specific management needs, or using a cumulative approach, where priorities are added across multiple constituents. For each constituent shown and for the cumulative map the priority for nonpoint source management varies from lightest (low priority) to darkest (highest priority). Each subwatershed is labeled with the last four digits of their HUC 12 code.

When water quality data is available, thresholds can be used differently to select HUC 12s based on measured constituent concentrations as opposed to predicted values that are based on human development (Figure 8B). This method focuses on the average constituent concentrations on either side of the threshold. The HUC 12s could be prioritized and separated into categories based on the example in Figure 8B. The hypothetical categories could include:

- Low priority: HUC 12s with constituent concentrations less than average constituent concentration below the threshold plus 2 standard deviations (horizontal dashed line; Figure 8B).
- Medium priority: HUC 12s with constituent concentrations greater than the horizontal dashed line but less than the average constituent concentration above the threshold (upper solid line; Figure 8B)
- High Priority: HUC 12s with constituent concentrations greater than upper solid line.

As stated earlier, constituent concentrations below the thresholds were generally low. The horizontal dashed line provides a realistic bench mark for separating low and medium priority watersheds, as it represents the upper limits of baseline conditions for the constituents analyzed in this study. This method could be carried out for each constituent of interest, resulting in the selection of constituent specific HUC 12s (Figure 10).

A weight of evidence approach may be used to combine HUC 12 priorities developed for individual constituents. Low, medium, and high priorities can be ranked 1, 2, and 3, respectively, for each constituent. Rankings for each constituent can then be added together to form a cumulative rank for each HUC 12. The cumulative ranks across all HUC 12s within the Oklahoma portion of the LWW were divided into 5 categories where the subwatersheds labeled as the highest priority had the highest rank (Figure 10).

With this approach you must be mindful of the nested nature of the LWW in that several subwatersheds are down river of one or more other subwatersheds. It is possible that water quality in an upstream subwatershed may result in higher than expected constituent concentrations based on the level of human development. In this case, it may be beneficial to compare subwatershed priorities identified by both methods.

Constituent concentrations change with land use, where the relation can often be described with a simple linear model (Figure 4). Once subwatersheds have been prioritized, the goal should be to move the higher priority HUC 12s below the linear regression which represents the average conditions for a given HDI (Figure 8C). The methods should follow previous routine monitoring methods used to develop these relationships, where 12 monthly base flow samples should be used to determine an annual geomean concentration data point. The data point should be plotted against the most current land use information available, to reflect the changing LULC and HDI gradient. Once the data point shifts from above the line to below the line, then this site has reached its target concentration as defined by the original regression. However, it would be wise to make sure the HUC 12s have consistently changed priority categories (e.g., moved from high to low) over multiple years before assuming the end point has been met.

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