Beaver Lake Numeric Chlorophyll-a and Secchi Transparency Standards, Phases II and III: Uncertainty Analysis and Trend Analysis

J. Thad Scott[1*], Brian E. Haggard[2], Zachary Simpson[2], and Matthew Rich[1]

[1]Crop, Soil and Environmental Sciences Department, University of Arkansas, Fayetteville, Arkansas

[2]Arkansas Water Resources Center, University of Arkansas, Fayetteville, Arkansas

*Corresponding Author: jts004@uark.edu

Prepared for:

Beaver Watershed Alliance

June 30, 2016

Introduction

The State of Arkansas recently adopted its first effects-based water-quality criteria related to nutrients. A site specific chlorophyll-a (chl-a) and Secchi Transparency (ST) standard were adopted for Beaver Lake in Northwest Arkansas (APCEC 2012). According to State of Arkansas Regulation Number 2, which is the state regulation defining water quality standards (APCEC 2012), the growing season (May – October) geometric mean chl-a concentration in Beaver Lake near Hickory Creek shall not exceed 8 µg/L and the annual average ST shall not be less than 1.1 m. The standards were adopted from the recommendations of a working group that conducted a multi-tiered analysis (FTN 2008). The basis for choosing the 8 µg/L chl-a standard and the 1.1 m ST standard came from a weight of evidence approach and included the following six specific considerations (from FTN 2008, Section 9.3):

1. Chl-a and ST criteria adopted into regulation or recommended for adoption in surrounding states
2. Ecoregional values published by the EPA
3. Percentile values for reference lakes and extant values for Beaver Lake
4. Statistical analysis of Beaver Lake and reference lake data
5. Empirical nutrient loading relationships
6. Dynamic modeling results

The recommended standards for both chl-a and ST were derived to protect the designated uses of Beaver Lake, which include its role as a drinking water source to Northwest Arkansas (FTN 2008). However, it is also clear that the standards recommended in the report and ultimately adopted by the State of Arkansas represent an expected average condition at the

Hickory Creek location in Beaver Lake. This is supported by the following quotation borrowed from Section 9.3 of the standard development report (FTN 2008):

"The chlorophyll regression equation was used to estimate concentrations at Lowell, and subsequently at the Hickory Creek site by averaging the values from the Highway 412 and Lowell sites. The Hickory Creek site is located about half the way between Highway 412 and Lowell. A growing season geometric mean chlorophyll concentration of 10 and 12 µg/L at Highway 412 results in a predicted geometric chlorophyll mean of 4.5 and 4.8 µg/L at Lowell, with the upper 95% geometric means at Lowell estimated as 6.5 and 6.9 µg/L, respectively. The associated Hickory Creek growing season geometric chlorophyll means estimated for the Hickory Creek site were 7.5 and 8.5 µg/L, respectively. The DeGray reference lake chlorophyll concentration was 9 µg/L, which is consistent with this estimated value."

Although it is not obvious why the exact "*10 to 12*" µg/L chl-a was used for the Highway 412 location in the above quotation, those values are in the same range as promulgated chl-a criteria in other states. However, the criteria in those states typically applies to the deepest location in the lake near the outfall or dam. The Highway 412 location in Beaver Lake is immediately below the input of the White River, which is almost 50 km from the dam. The range of chl-a reported for the Highway 412 location throughout the standard development document was 5.2 to 32.6 µg/L (FTN 2008). This reported range included geometric means for different observation periods and from empirical and dynamic modeling activities. The application of this average condition as shown above quotation demonstrates that the average expected chl-a concentration in Beaver Lake at Hickory Creek is approximately 7.5 to 8.5 µg/L. Thus, the adopted 8 µg/L is practically equivalent to the long-term expected average condition at Hickory Creek. A similar methodology was used to derive the 1.1 m ST standard, and numerous references throughout the standard development document indicate that the long-term expected condition at Hickory Creek was approximated by this value (FTN 2008).

The intent of the standard development activities reported by FTN (2008) was clearly to identify values of chl-a and ST that when exceeded would result in a failure of Beaver Lake to meet its designated uses. This range of values is similar to other standards in neighboring states and are supported by the scientific literature discussed previously. However, the standards recommended and ultimately adopted were not expected to result in Beaver Lake being immediately listed on the Arkansas 303d list of impaired water bodies. This is clear from the following quotation borrowed from Section 9.4.2. – Rationale for Criteria in standard development document (FTN 2008):

"*The chlorophyll and Secchi transparency mean values are considered conservative and protective of the designated uses, but should not result in frequent non-attainment assessments*."

Thus, the approximate average expected conditions of 8 μg/L chl-a and 1.1 m ST at the Hickory Creek location in Beaver Lake were not expected to result in frequent violations. However, data collected since 2009 indicate that Beaver Lake may be impaired due to violations of the chl-a water quality standard at Hickory Creek (Scott and Haggard 2015). What remains unknown is whether or not this potential violation in water quality standards for Beaver Lake were the result of environmental conditions actually changing in the lake or simply the natural variability associated with choosing a water quality standard that is effectively a long-term average.

Study Objectives

The objective of Phases II and III of this study were to 1) assess the variation in chl-a and ST across multiple spatial and temporal scales in Beaver Lake in order to validate the assessment method, and 2) quantify trends in chl-a, ST, and nutrient (total phosphorus and total nitrogen) concentrations in Beaver Lake and the major inflowing rivers to verify any potential water quality impairment.

Scope of Work

Phase II – In order to meet the objective of Phase II, we utilized historical data sources that were not included in the original standard development study and new data that have since been collected on Beaver Lake to assess the effect of spatial and temporal variation on chl-a and ST measurements. We undertook the following activities to meet the objectives of Phase II:

1. Obtain chl-a, ST, and nutrient concentration data for Beaver Lake from a variety of sources including USGS, Beaver Water District, peer-reviewed publications, and theses and dissertations from the University of Arkansas
2. Use data to estimate error rates (standard deviation and relative error) in chl-a and ST using spatially explicit and repeated sampling, where available. We were particularly interested in:
    - Horizontal variation across sites along the riverine-transition-lacustrine gradient
    - Vertical variation across the photic zone (chlorophyll-a)
    - Intra-annual variation during the growing season
    - Interannual variation

Based on the outcomes of these analyses, we anticipated providing revised recommendations (if necessary) to the recommended assessment methodology provided in Phase I.

Phase III – In order to meet the objective of this work, we utilized historical data sources that were not included in the original standard development study and new data that have since been collected on Beaver Lake and some of the major tributaries to Beaver Lake in order to assess the long-term trends in water quality measurements. We undertook the following activities to meet the objectives of Phase III:

1. Trend analysis on Beaver Lake data including all USGS data since 2001 and any other data identified in Objective 2 as suitable for the analysis
2. Trend analysis on inflow data from White River, Richland Creek, and War Eagle Creek

We also searched for obvious shifts in data patterns that could have been driven by changes in analytical methodologies in the long-term datasets. Based on the outcomes of these analyses, we hoped to provide a reasonable judgement as to whether the anticipated water quality impairments on Beaver Lake were likely a function of changing environmental conditions or simply long-term variation in water quality.

Data Gathering and Methods

Data Sources

Four major data sources were identified as having substantial information on chl-a concentrations and ST for Beaver Lake. These included data collected by the USGS at Highway 412, near Lowell, Highway 12, and near the dam since 2001, and at Hickory Creek since 2009. Additionally, the University of Arkansas collected ST data and chl-a measurements from multiple depths at twelve locations from Highway 412 to the dam in the 2015 growing season. Data were also obtained on ST and chl-a concentrations measured multiple times monthly by Beaver Water District near Lowell since 1998 (ST) and 2002 (chl-a). Data were extracted from other literature sources on Beaver Lake that were not used in the standard development process. Also, data were gathered from the Arkansas Water Resource Center on nutrient concentrations in the major inflowing tributaries to Beaver Lake.

The USGS measured ST and collected water samples from approximately 2 m below the surface. The water samples were collected from Beaver Lake and then transported to the USGS National Water Quality Lab, where each water sample was analyzed for chl-a. Secchi transparency was measured and water samples collected approximately 6-8 times per year on average, and the frequency of collection was greater during the growing season (defined as May through October). All USGS data used in this study are publicly available through the USGS National Water Information System (NWIS, http://waterdata.usgs.gov/nwis).

The University of Arkansas measured ST and collected samples for chl-a from twelve locations along the riverine-transition-lacustrine gradient in Beaver Lake (Figure 1) in the 2015 growing season. Seven sites were spaced approximately equidistant apart from Highway 412 to Highway 12, and specifically included sampling sites at Hickory Creek and Lowell (BWD intake). Another five sites were located approximately equidistant apart from Highway 12 to the dam. Samples were collected from these sites twice monthly beginning in May 2015 and ending in October 2015. Secchi transparency was measured in the field using common methods. Photic depth was also measured at each location using a Li-COR quantum sensor on a vertical lowering frame. Photic depth was defined as the depth at which measured irradiance was 1% of the surface irradiance. The water column was divided into multiple sampling depths, depending on the photic depth. A minimum of three depths were sampled when the photic depth was small, and up to six depths were sampled when the photic zone was great. Samples were placed on ice and returned to the laboratory at the University of Arkansas. Chl-a was measured on a Turner Trilogy Fluorometer following overnight extraction with acetone.

Secchi transparency and chl-a data were also gathered from Beaver Water District. Briefly, BWD collected ST at their intake approximately weekly to biweekly since 1998. Similarly, BWD collected chl-a at their intake approximately weekly to biweekly since 2002. Chl-a was measured by spectrophotometer following acetone extraction. Additionally, BWD utilized a fluorescence probe on the profiling sonde to estimate algal biomass with depth. These data were also obtained from BWD and a regression model of extracted chl-a versus in-vivo fluorescence was derived in order to standardize the depth-specific data from the sonde.

Literature sources were searched for other data on ST and chl-a for Beaver Lake. Unfortunately, very few studies had data that were of acceptable spatial or temporal resolution, or acceptable quality. One notable exception was Haggard et al. (1999), in which ST and chl-a data on Beaver Lake were collected at multiple locations along the riverine-transition-and upper lacustrine zone 36 times over a two year period. These data were not as spatially explicit as those collected in 2015 by the University of Arkansas, nor were they as broad as the data collected by USGS, however, they did provide a solid frame of reference for water quality in Beaver Lake from approximately 20 years into the past.

In addition to ST, chl-a, and nutrient data on Beaver Lake, data from the major inflowing tributaries to Beaver Lake were compiled from ongoing monitoring by the Arkansas Water Resources Center. All monitoring sites, with one exception, were located at U.S. Geological Survey (USGS) stream gages where mean daily stream discharge is provided. These sites included: White River near Fayetteville (USGS Station No. 07048600), Richland Creek at Hwy 45 (USGS Station No. 07048800; this gage has been discontinued and moved in summer 2015), and War Eagle Creek near Hindsville (USGS Station No. 07049000). Stream discharge at the one exception, White River at Hwy 45, was estimated by Arkansas Water Resources Center (AWRC; see Scott et al., 2016). Water samples were collected by the AWRC from July 2009 to June 2015, which includes baseflow and storm event samples, following a quality assurance project plan (QAPP). The monitoring program, sampling techniques, and analysis were consistent over this time period, where water samples were collected from bridges using a horizontal alpha sampler just under the surface and then analyzed at the AWRC certified water quality lab. The lab methods and detection limits are available at http://arkansas-water-center.uark.edu/waterqualitylab.php. Details of the data collected for the study period are provided by Massey et al. (2010) and Scott et al. (2016).

Uncertainty Analyses

Data from all four major sources were used to compute uncertainty estimates for ST and chl-a for multiple locations in Beaver Lake. Briefly, we computed central tendencies and error rates (standard deviation) for the various data sets based on the spatial and temporal conditions over which the data were collected. Annual average ST and the standard deviation of annual ST, along with growing season geometric mean chl-a and the standard deviation of growing season chl-a, were computed from long-term data sets collected at the five locations monitored by USGS. Arithmetic mean ST and standard deviation, as well as geometric mean chl-a and standard deviation, were computed for each of the twelve locations sampled by the University of Arkansas on Beaver Lake in 2015. Additionally, these same central tendencies and error rates were computed by date across all sites for Beaver Lake in 2015. In the case of chl-a, average and standard deviation values across the photic zone were also computed. ST data obtained from

Beaver Water District was used to compute a monthly average and standard deviation ST and chl-a for Beaver Lake near Lowell (BWD intake) since 1998 and 2002, respectively. Average and standard deviation ST and chl-a were computed for the four locations for which data were reported by Haggard et al. (1999). In addition to central tendencies and standard deviations, we also computed the percent error of the measurements presented herein. Percent error was simply the standard deviation for any set of observations divide by the central tendency measurement and multiplied by 100. Thus, percent error standardized the error rate to the magnitude of the central tendency measured.

Trend Analyses

Trend analyses were conducted on both spatially-explicit and temporally-explicit data. Spatially-explicit trend analyses were intended to demonstrate the spatial dependence of chl-a and ST to the location of sampling stations along the riverine-transition-lacustrine zones in Beaver Lake. Temporally-explicit trend analyses were intended to demonstrate any changes in chl-a and ST, as well as total P and total N, that have occurred over relatively long-term periods (>10 years) at various monitoring locations in Beaver Lake. Because these data sources were different, we conducted these analyses separately by data source, and not all analyses were conducted on all data sources, but only those with appropriate data for analysis.

Temporal trend analysis of the ST, chl-a, and nutrient data from Beaver Lake were conducted with a two-step process. First, visual trends were explored by plotting raw data and fitting a locally weighted regression (LOESS) line to the data. A consistent smoothing parameter of 0.5 was used in all LOESS trend analyses for water quality at all sites in Beaver Lake. Second, linear regression analyses were conducted on appropriate central tendency data that were relevant to the water quality standards. For example, linear regression was conducted on the growing season geometric mean chl-a concentration at Lowell measured since 2001.

Trend analysis of the water quality data from tributaries to Beaver Lake followed the three step procedure outlined by White et al. (2004). First, both water chemistry concentrations (C) and streamflow (Q) data were log-transformed. This step improves the skewness of the data as well as reduces the influence of outliers. Next, a semi-parametric smoother (locally weighted regression; LOESS) was fitted to the plot of lnC on lnQ. LOESS is a locally-fitted weighted linear regression that is able to characterize unknown relationships in water quality data (see Ch. 12, Helsel and Hirsch, 2002). The smoothing parameter in LOESS (f, where $0<f\leq1$), which controls how ‘stiff’ or ‘wiggly’ the LOESS fit is, was selected for each dataset in order to provide the smoothest fit possible while still capturing the important curvilinear behavior of the data. For the last step, the residuals from the LOESS plot, termed as flow-adjusted concentrations (FACs), were modelled with time using simple linear regression. This linear regression was used to determine whether a significant monotonic trend was present (using the overall f-test) and to provide the magnitude of the trend if significant (slope of the line, interpreted as percent change in concentrations per year).

Results

USGS Data

USGS data were evaluated in Phase I of this study, the evaluation of the assessment methodology, in explicit detail (Scott and Haggard 2015). Thus, for the purposes of uncertainty we report the average annual ST and growing season geometric mean chl-a for the five USGS sites on Beaver Lake (Table 1). Briefly, the average annual ST ranged from 0.9 ± 0.4 m at the

Highway 412 monitoring location to 5.5 ± 1.7 at the dam. Average annual ST consistently increased along the riverine-transition-lacustrine zone of Beaver Lake. More importantly, the percent error across all five sites was remarkably consistent. Percent error was approximately 50% at Highway 412, Hickory Creek, Lowell, and Highway 12. Percent error in ST at the dam location was 30%. The geometric mean chl-a ranged from 8.7 ± 7.0 µg/L at the Highway 412 monitoring location to 1.3 ± 1.5 at the dam. Geometric mean chl-a consistenly decreased along the riverine-transition-lacustrine zone of Beaver Lake. Percent error in chl-a was much greater than that observed for ST. For example, percent error was approximately 100% at the Highway 412 and dam sampling locations. Percent error in chl-a was greater than 50% at the Lowell and Highway 12 sampling locations, and slightly less than 50% at the Hickory Creek monitoring location.

Total N, total P, chl-a, and ST collected by USGS at all five sites exhibited tremendous seasonal variability which obscured any obvious long-term trends in the raw data of these variables (Figure 2). However, some patterns in these raw data were noteworthy. Total P concentrations at Highway 412 seemed to exhibit a weak positive trend between 2001 to 2010, but this may have been driven by the lack of relatively low TP values in 2008-2009, two relatively wet years for the watershed. Total N and chl-a concentrations at Lowell exhibited a slight increase from 2003 to 2014, which coincided with a slight decrease in ST at the same location. Similar patterns, although weaker, were observed at the Highway 12 location. Total P concentrations appeared to be decreasing at the Highway 12 and dam locations over the period of record, but this pattern was caused by a decreasing laboratory detection level for total P that occurred in 2004.

Only two parameters exhibited a statistically significant linear trend in the USGS Beaver Lake data. Average annual total N concentrations at Lowell increased by 0.018 mg L^{-1} $year^{-1}$ from 2001 to 2014 and average annual ST decreased by 0.05 meters per year at Lowell during this same period (Figure 3). When the computed central tendency was geometric mean, two other parameters exhibited statistically significant long-term trends in the USGS Beaver Lake data. Growing season geometric mean ST at the Hickory Creek location actually increased by 0.15 meters from 2009 to 2014 (Figure 4). However, growing season chl-a concentrations at Lowell actually increased by 0.29 µg L^{-1} $year^{-1}$.

University of Arkansas Data

Secchi transparency collected by University of Arkansas in 2015 ranged from 0.1 to 8.5 m across all dates and all twelve monitoring locations (Table 2). When ST was averaged for each site by date, percent error ranged from approximately 50% at sites 1-5, and then systematically decreased from 30% to 20% as sampling sites progressed into deeper water near the dam. When all sites were average for each date, whole-lake ST was 3.0 ± 1.2 m, which is slightly less than 50% error. Average annual ST was always greater than 1.1 m across all monitoring locations, however, the error rates for sites 1-5 overlapped with 1.1 m, suggesting that these values could not be distinguished as different from 1.1 m ST standard for Hickory Creek (Figure 5). Site six, 16 km downstream from the Highway 412 bridge and the next sampling location downstream from Lowell was the most upstream sampling location to have an annual average ST that was statistically greater than 1.1 m. Secchi transparency also increased systematically with increasing distance downstream from Highway 412 and a linear distance was a strong predictor of ST (Figure 5).

Chlorophyll-a collected by University of Arkansas in 2015 ranged from a low of 1.7 ± 0.9 µg/L averaged across six depths at the dam on July 1st, to 22.4 ± 2.3 µg/L averaged across 2 depths at site 3 on June 2nd (Table 3). When chl-a was averaged for each site by date, percent error ranged from approximately 30 - 60% and exhibited no systematic spatial pattern within the lake. When all sites were average for each date, whole-lake ST was 6.0 ± 2.9 µg/L, representing approximately 50% error. Growing season geometric mean chl-a was greater than 8.0 µg/L at Hickory Creek and at 2 of the 3 monitoring locations upstream from Hickory Creek (Figure 6). However, the error rates for sites 1-7 all overlapped with the 8.0 µg/L, suggesting that these values could not be distinguished as different from the chl-a standard for Hickory Creek (Figure 6). Site eight, 23.4 km downstream from the Highway 412 bridge was the most upstream sampling location to have a growing season geometric mean chl-a that was statistically less than 8.0 µg/L. Chlorophyll-a also decreased systematically with increasing distance downstream from Highway 412 and linear distance was a strong predictor of chl-a, particularly if the two most upstream sites were excluded from the regression (Figure 6).

Beaver Water District Data

Beaver Water District collected ST at their intake approximately weekly to biweekly from 1998 through 2015. Chl-a data were also collected during the same sampling but didn't start consistently until 2002. Monthly average ST shown for all months of the year from 1998 through 2015 are provided in Table 4. Briefly, ST ranged from as low as 0.1 m to as great as almost 3 m at the BWD intake structure. Secchi transparency varied drastically by both month and year. For example, water tended to be most transparent during July and August of all years when ST was approximately 2 m with approximately 25% error. Alternatively, ST was typically less than 1 m with approximately 20 – 100% error during the cool months of January, February, March, November and December. Secchi transparency at the BWD intake did not exhibit a strong long-term trend. Although average annual ST was 2.1 meters in 1998, this likely reflected the limited data collected in that year. Average annual ST ranged from 1.0 to 1.7 across all other years from 1999 to 2015.

Chl-a average across depths at the BWD intake ranged from near zero to 35 µg/L (Figure 7). There was a strong pattern of seasonal variation in chl-a measured by BWD at the intake structure near Lowell. Interestingly, chl-a values appeared to be relatively low in through most of 2006 and into 2007, and then increased systematically through 2015 (Figure 7). However, this trend computed on data averaged by date across depths was not statistically significant.

Other Beaver Lake Data

Although several theses and dissertations at the University of Arkansas included various water quality data for Beaver Lake, very few of them had enough data from which to conduct a meaningful analysis. One interesting exception was an MS thesis that resulted in a paper published by Haggard et al. (1999). These authors sampled 10 locations in Beaver Lake, but most of these locations were far upstream. For example, six of the sampling locations included in that study were further upstream than the Highway 412 location sampled by USGS from 2001 to 2014 and by the University of Arkansas in 2015. However, four other stations, Highway 412, Hickory Creek, Lowell, and Highway 12 were sampled and corresponded to USGS and University of Arkansas sites. These data represent some of the oldest data collected on Beaver Lake in a temporally (monthly) and spatially (four locations upstream to downstream) systematic way.

Average ST from 1993 to 1995 increased from 1.2 ± 0.3 m at Highway 412 to 2.8 ± 0.7 m at Highway 12 (Table 5). This pattern was very similar to the distinct spatial pattern in ST observed in University of Arkansas data collected in 2015. Similarly, average chl-a from 1993 to 1995 decreased from 5.4 ± 3.7 µg/L at Highway 412 to 3.0 ± 1.3 µg/L at Highway 12. Again, this pattern was very similar to the spatial pattern observed in chl-a across the wider spatial gradient in 2015. Interestingly there was very little difference in ST measured by Haggard et al. (1999) from 1993 to 1995 (Table 5) when compared with ST measured by University of Arkansas in 2015 (Table 2). For example, ST at Highway 412, Hickory Creek, Lowell, and Highway 12 was 1.2, 1.4, 1.7, and 2.8 m, respectively in 1993-1995. Average ST was 1.2, 1.6, 1.9, and 2.9 at these same sites, respectively, in 2015. However, chl-a in the transition zone of Beaver Lake did appear to increase between the mid-1990's and 2015. For example, average chl-a at Highway 412, Hickory Creek, Lowell, and Highway 12 was 5.4, 5.2, 4.1, and 3.0 µg/L, respectively in 1993-1995. Average chl-a was 9.6, 8.7, 7.2, and 5.6 µg/L at these same sites, respectively, in 2015.

AWRC Tributary Water Quality Data

Data from the major tributaries to Beaver Lake exhibited variable results in flow-corrected nutrient concentration trends from 2009 through 2015. There was no trend in flow-corrected nitrate, total N, soluble reactive P, or total P observed during this period for the White River at Highway 45 based on the linear regression analyses (Figure 8). However, the LOESS fit did indicate that flow-corrected nitrate and total N may have exhibited a weak increase in concentrations from 2011 to 2013, only to decrease again in more recent years. Flow-corrected nitrate, total N, soluble reactive P, and total P in Richland Creek all increased from 2009 through

2015 (Figure 9). In fact, each of these parameters increased between 6 to 8% during the six year period over which data were collected. LOESS regressions indicated that both flow-corrected nitrate and total N may have decreased again in recent years, but the linear increase from 2009 through 2015 was statistically significant. LOESS regressions for soluble reactive P and total P were almost identical to the linear regression results for Richland Creek. There was no trend in flow-corrected nitrate, total N, soluble reactive P, or total P observed from 2009 through 2015 for the War Eagle Creek based on the linear regression analyses (Figure 10). LOESS regressions indicated that flow-corrected nitrate concentrations may have decreased in recent years in War Eagle Creek, but this trend was not statistically significant.

Implications

The first objective of these analyses was to quantify the uncertainty associated with ST and chl-a measurements in Beaver Lake relative to the recently adopted water quality standards for these variables. We found that, based on years of data collected from multiple sources, both ST and chl-a vary significantly both intra- and inter-annually. Secchi transparency often varies by as much as 50% regardless of the location in Beaver Lake in which data are collected. Thus, if average annual conditions at Hickory Creek are near the 1.1 m standard, then this value cannot likely be distinguished statistically from 0.6 or 1.6 m. Alternatively, the percent error in chl-a concentrations were dynamic depending on the spatial location of sampling in Beaver Lake. The most upstream and most downstream chl-a data were highly dynamic with almost 100% error. However, percent error tended to decrease in mid-lake locations and was 50% or less at the Hickory Creek sampling location in multiple data sources. This indicates that if the growing season geometric mean approaches 8.0 µg/L in Beaver Lake at Hickory Creek, we cannot statistically distinguish this value from 4 or 12 µg/L. Thus, the degree of variation in ST and chl-a do not lend themselves to the bright-line single value water quality standards which were recently adopted by the State of Arkansas.

A second objective was to explore long-term trends in ST, chl-a, and nutrient concentrations in Beaver Lake, as well as, nutrient concentrations from the major tributaries flowing into the lake. These analyses indicated that water quality in Beaver Lake is likely changing. However, the magnitude of these changes in very small compared to the magnitude of intra- and inter-annual variability. Nevertheless, depending on the measure of central tendency used, the specific monitoring location in the lake, and the source of the data used in the analysis, ST in Beaver Lake appears to have decreased in the last 10 to 20 years. With the same qualifications, chl-a and nutrient concentrations appear to be increasing very slightly over the same period. Although data were not available for a long-term analysis, there did to be an increase in both dissolved and total nutrient concentrations entering Beaver Lake from the Richland Creek watershed from 2009 through 2015.

The results of these analyses should be interpreted with great care and caution. These results suggest that water quality in Beaver Lake exhibits tremendous variability both within and among years, but that some evidence suggests that water quality may be worsening in the lake. It is unclear if these trends are associated with a real change in watershed nutrient inputs, but some evidence suggests that they may. We encourage the State of Arkansas and the relevant stakeholders to remain vigilant in assessing water quality in Beaver Lake.

Recommendations:

The overall conclusions of this study were that:

1. The relative error rates on both ST and chl-a central tendencies were quite high (50% for ST and 50 – 100% for chl-a) indicating that great care should be taken in interpreting data within these error rates.
2. Very few long-term trends existed in lake water quality except, the decrease in annual average ST and increase in growing season geometric mean chla at Lowell, which coincided with an increase in total N at Lowell. This indicates that the water quality in Beaver Lake, at least as measured at the Lowell location, is deteriorating.
3. Some increases in nutrient concentrations from inflowing rivers were observed. In particular, nutrient concentrations in Richland Creek increased somewhat dramatically, but have waned in recent years.

These findings seem to suggest that the water quality in Beaver Lake may be deteriorating slowly, but not at a rate so that it is obvious at all monitoring locations. These trends could indeed be caused by climatic variation, particularly since increased nutrient concentrations in inflowing rivers have waned in recent years. Based on these conclusions, our primary recommendation remains similar to that proposed in Phase I, that the number of years in violation should be greater than one-half of the number of years in any assessment period (i.e. 3/5, 4/7, 5/9, etc.). Further, due to the large relative error observed in both ST and chl-a over the 15-year data set, we recommend that the assessment period be increased to a longer revolving window. Increasing the assessment period should permit observations to represent a greater range of the natural environmental conditions that control ST and chl-a in Beaver Lake.

Literature Cited

APCEC (Arkansas Pollution Control and Ecology Commission). 2012. REGULATION NO. 2: Regulation establishing water quality standards for surface waters of the State of Arkansas. APCEC #014.00-002.

FTN and Associates. 2008. Beaver Lake site-specific water quality criteria development: Recommended criteria. FTN No. 3055-021.

Haggard, B.E., P.A. Moore, T.C. Daniel, and D.R. Edwards. 1999. Trophic conditions and gradients of the headwater reaches of Beaver Lake, Arkansas. Proceedings of the Oklahoma Academy of Science 79: 73-84.

Helsel, D.R., and R.M. Hirsch. 2002. Statistical methods in water resources. In Hydrologic Analysis and Interpretation, (pp. 1-510). United States Geological Survey.

Massey, L.B., B.E. Haggard, R.S. Avery, and R.A. Morgan. 2010. Water quality monitoring and constituent load estimation in the Upper White River Basin, 2009. Arkansas Water Resources Center, Fayetteville, Arkansas, MSC Publication 362: 40 pp.

Scott, J.T., and B.E. Haggard. 2015. Implementing effects-based water quality criteria for eutrophication in Beaver Lake, Arkansas: Linking standard development and assessment methodology. Journal of Environmental Quality 44: 1503-1512.

Scott, E.E., Z.P. Simpson, and B.E. Haggard. 2016. Constituent loads and trends in the Upper Illinois River Watershed and Upper White River Basin. Arkansas Water Resources Center, Fayetteville, Arkansas, MSC Publication 377: 89 pp.

White, K.L., B.E. Haggard, and I. Chaubey. 2004. Water quality at the Buffalo National River, Arkansas, 1991-2001. Transactions of the American Society of Agricultural Engineers 47(2): 407-417.

Table 1. United States Geological Survey (USGS) Annual Average Secchi transparency (AAST) and Growing Season Geometric Mean Chlorophyll-a (GSGMCHLA) across all sites and sampling dates expressed as mean [chlorophyll-a] ± standard deviation and (n).

Duration	**Site #**	**AAST (m) ± SD (n)**	**GSGMCHLA (µg/L) ± SD (n)**
2001-2015	Hwy 412	0.9 ± 0.4 (103)	8.7 ±.0 (66)
2009-2015	Hickory Creek	1.1 ± 0.5 (79)	8.2 ± 3.8 (42)
2001-2015	Lowell	1.5 ± 0.8 (110)	5.4 ± 3.1 (66)
2001-2015	Hwy 12	2.1 ± 0.8 (110)	3.7 ± 2.7 (66)
2001-2015	Dam	5.5 ± 1.7 (182)	1.3 ± 1.5 (64)

Table 2. Table 1: Beaver Lake Secchi Transparency (m) across all sites and sampling dates expressed as mean Secchi ± standard deviation and (n).

Date	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12	μ ± SD (n)
5/12/15		0.1	0.5	0.3	0.4	2.1	3.1	3.4	4.1	4.7	5.6	8.3	3.0 ± 2.6 (11)
6/2/15	0.5	0.6	0.7	0.8	1.2	1.5	1.8	2.5	3.5	5.0	5.7	7.6	2.6 ± 2.4 (12)
6/16/15	1.7	1.8	1.6	1.7	1.5	1.6	2.1	2.9	4.6	5.8	6.1	7.3	3.3 ± 2.1 (12)
7/1/15	1.5	1.3	1.4	1.5	1.6	1.9	2.1	2.7	3.7	5.1	5.4	6.4	2.9 ± 1.8 (12)
7/15/15	0.5	0.6	1.6	1.7	2.7	2.2	2.5	2.9	3.1	4.4	4.8	6.2	2.8 ± 1.7 (12)
8/3/15	1.5	1.6	2.1	2.2	2.7	2.9	3.2	3.7	4.4	5.1	6.2	8.5	3.7 ± 2.1 (12)
8/17/15	1.6	2.0	2.2	2.4	2.7	2.9	3.3	2.8	3.8	3.9	4.3	6.4	3.2 ± 1.3 (12)
9/2/15	2.1	2.4	2.6	2.8	3.5	3.9	4.0	4.1	3.7	4.6	4.3	6.2	3.7 ± 1.1 (12)
9/16/15	1.3	1.7	2.3	2.0	2.8	2.6	3.7	3.5	3.7	4.3	4.4	5.9	3.2 ± 1.3 (12)
9/30/15	1.4	1.8	2.4	2.6	2.9	3.6	3.6	3.3	3.5	3.3	3.5	4.4	3.0 ± 0.9 (12)
10/14/15	1.2	1.1	1.5	1.7	1.7	3.0	3.8	3.5	4.3	4.2	4.0	4.1	2.8 ± 1.3 (12)
μ ± SD (n)	1.2 ± 0.5 (10)	1.1 ± 0.7 (11)	1.6 ± 0.7 (11)	1.6 ± 0.8 (11)	1.9 ± 0.9 (11)	2.5 ± 0.8 (11)	2.9 ± 0.8 (11)	3.2 ± 0.5 (11)	3.8 ± 0.5 (11)	4.5 ± 0.7 (11)	4.9 ± 0.9 (11)	6.3 ± 1.4 (11)	3.0 ± 1.2

Table 3. Beaver Lake Chlorophyll-a (µg/L) across all sites and sampling dates expressed as mean chl-a ± standard deviation and (n).

Date	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**	**Site 8**	**Site 9**	**Site 10**	**Site 11**	**Site 12**	**µ ± SD (n)**
5/12/15		5.1 ± 0.0 (1)	13.9 ± 0.3 (2)	11.6 ± 0.5 (3)	5.1 ± 1.3 (3)	5.1 ± 2.1 (4)	3.4 ± 1.5 (6)	3.4 ± 0.7 (3)	3.2 ± 1.4 (6)	6.0 ± 2.0 (6)	4.5 ± 1.0 (6)	2.5 ± 0.9 (6)	5.1 ± 3.6 (11)
6/2/15	6.0 ± 4.3 (2)	5.6 ± 6.1 (2)	22.4 ± 2.3 (2)	16.9 ± 3.9 (2)	15.5 ± 11.0 (3)	16.7 ± 9.4 (3)	14.6 ± 9.6 (4)	6.2 ± 1.9 (4)	5.1 ± 2.2 (5)	2.9 ± 1.3 (6)	3.2 ± 1.1 (6)	3.1 ± 1.1 (6)	7.7 ± 6.8 (12)
6/16/15	6.1 ± 0.2 (3)	7.8 ± 1.4 (3)	11.7 ± 5.7 (3)	11.4 ± 9.6 (3)	16.1 ± 4.9 (3)	16.0 ± 5.4 (4)	12.1 ± 7.8 (4)	3.2 ± 3.8 (5)	5.3 ± 1.8 (5)	3.3 ± 1.5 (6)	2.7 ± 1.1 (6)	2.7 ± 1.5 (6)	6.7 ± 5.1 (12)
7/1/15	9.2 ± 5.6 (3)	6.2 ± 3.1 (3)	14.5 ± 4.9 (4)	20.4 ± 9.5 (4)	15.6 ± 6.6 (4)	12.4 ± 5.0 (4)	11.5 ± 3.1 (5)	8.2 ± 1.6 (4)	6.2 ± 4.2 (6)	5.4 ± 3.5 (6)	2.6 ± 0.5 (6)	1.7 ± 0.9 (6)	7.7 ± 5.6 (12)
7/15/15	17.5 ± 11.9 (2)	15.2 ± 5.7 (2)	10.0 ± 5.9 (2)	9.5 ± 4.6 (4)	7.0 ± 1.9 (4)	9.1 ± 2.2 (4)	7.7 ± 2.0 (5)	6.0 ± 2.6 (5)	4.6 ± 0.8 (6)	3.9 ± 2.2 (6)	2.9 ± 1.5 (6)	2.2 ± 0.8 (6)	6.7 ± 4.7 (12)
8/3/15	10.8 ± 0.1 (2)	8.5 ± 5.5 (4)	10.2 ± 2.9 (4)	7.7 ± 1.9 (4)	9.9 ± 2.1 (5)	6.5 ± 3.3 (5)	6.6 ± 5.2 (5)	7.2 ± 4.8 (5)	4.6 ± 4.0 (6)	3.3 ± 2.5 (6)	3.9 ± 2.8 (6)	2.1 ± 1.7 (6)	6.0 ± 2.7 (12)
8/17/15	11.2 ± 2.7 (4)	9.8 ± 2.0 (4)	8.8 ± 1.2 (4)	7.3 ± 2.2 (4)	6.0 ± 2.0 (5)	5.9 ± 1.7 (5)	4.9 ± 1.2 (6)	5.4 ± 1.5 (5)	6.8 ± 6.1 (6)	10.0 ± 10.5 (6)	7.7 ± 6.2 (6)	3.4 ± 1.2 (6)	6.9 ± 2.3 (12)
9/2/15	10.7 ± 1.9 (4)	8.5 ± 2.6 (4)	7.6 ± 2.0 (4)	6.4 ± 1.7 (5)	5.7 ± 1.9 (5)	4.4 ± 2.3 (6)	3.9 ± 1.5 (6)	4.6 ± 0.5 (4)	3.9 ± 1.2 (6)	6.0 ± 4.3 (6)	5.9 ± 3.6 (6)	3.3 ± 1.1 (6)	5.6 ± 2.2 (12)
9/16/15	8.8 ± 0.9 (3)	9.2 ± 0.4 (3)	7.5 ± 0.6 (4)	6.0 ± 0.4 (4)	4.6 ± 0.5 (5)	5.4 ± 0.5 (5)	3.5 ± 0.5 (5)	2.5 ± 1.2 (6)	2.4 ± 1.1 (6)	3.1 ± 0.3 (6)	3.6 ± 0.7 (6)	2.7 ± 1.0 (6)	4.4 ± 2.5 (12)
9/30/15	9.1 ± 0.5 (4)	5.5 ± 3.1 (4)	6.0 ± 0.4 (5)	4.0 ± 0.1 (5)	3.7 ± 0.3 (5)	2.8 ± 1.0 (6)	1.9 ± 0.6 (6)	2.4 ± 0.1 (5)	2.1 ± 0.8 (6)	2.8 ± 1.0 (6)	3.5 ± 0.7 (6)	3.6 ± 0.6 (6)	3.6 ± 2.1 (12)
10/14/15	11.3 ± 0.7 (3)	6.8 ± 0.5 (3)	6.4 ± 0.6 (3)	5.7 ± 1.1 (4)	4.3 ± 0.8 (4)	3.3 ± 0.3 (5)	3.4 ± 0.4 (5)	3.0 ± 0.5 (5)	3.0 ± 0.4 (6)	3.1 ± 0.6 (6)	3.7 ± 0.2 (6)	4.4 ± 0.3 (6)	4.5 ± 2.4 (12)
µ ± SD (n)	9.6 ± 3.2 (10)	7.6 ± 2.9 (11)	10.0 ± 4.8 (11)	8.7 ± 5.1 (11)	7.2 ± 4.9 (11)	6.7 ± 4.9 (11)	5.6 ± 4.3 (11)	4.4 ± 2.0 (11)	4.0 ± 1.5 (11)	4.2 ± 2.2 (11)	3.8 ± 1.5 (11)	2.8 ± 0.8 (11)	

Table 4. Table 3: Beaver Water District Secchi depth (m) at Lowell Intake expressed as mean ST ± standard deviation and (n).

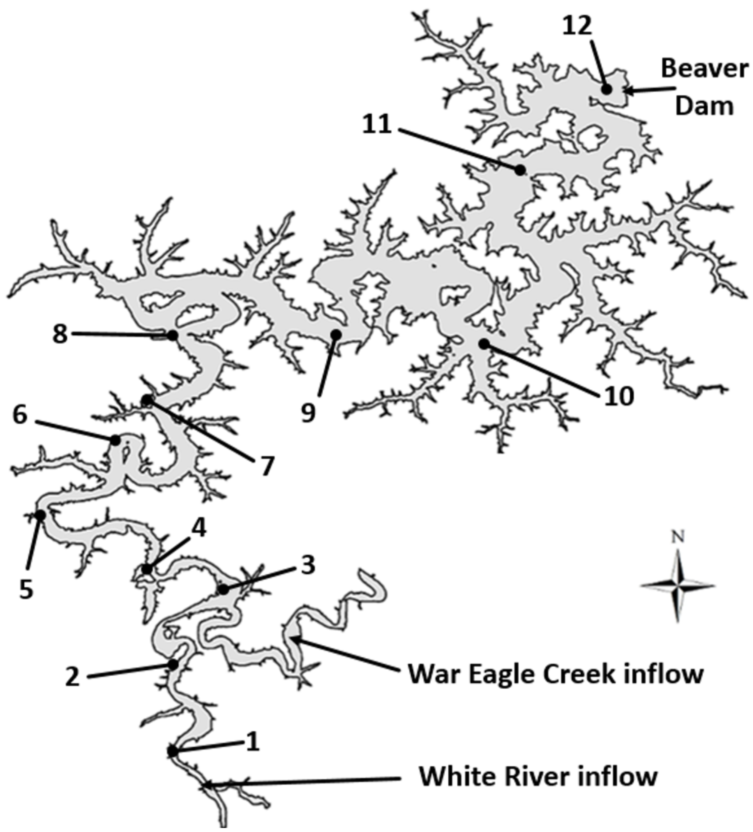
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	m ± SD (n)
1998					2.6 ± 1.1 (2)	2.2 ± 0.5 (5)	2.4 ± 0.3 (4)	2.4 ± 0.5 (4)	3.1 ± 0.3 (5)	1.9 ± 0.7 (4)	1.2 ± 0.2 (2)	1.8 (1)	2.1 ± 0.5 (8)
1999	1.5 (1)	1.4 (1)	0.6 (1)	0.3 (1)	1.4 ± 0.2 (2)	2.1 ± 0.4 (4)	1.8 ± 0.6 (5)	1.8 ± 0.3 (5)	1.6 ± 0.5 (4)	1.3 ± 0.7 (3)	1.4 (1)	0.8 (1)	1.3 ± 0.4 (12)
2000	1.1 (1)	1.2 (1)	1.8 (1)	1.8 (1)	1.1 ± 0.9 (2)	1.0 ± 0.7 (6)	1.6 ± 0.2 (4)	2.0 ± 0.2 (5)	1.8 ± 0.2 (5)	1.9 ± 0.5 (5)	1.0 (1)	1.1 (1)	1.5 ± 0.5 (12)
2001	2.0 (1)	0.9 ± 0.8 (2)	0.6 (1)	1.4 (1)	2.3 ± 0.6 (3)	2.3 ± 0.4 (4)	3.0 ± 0.4 (4)	2.1 ± 0.3 (5)	1.7 ± 0.3 (4)	1.5 ± 0.3 (5)	1.6 ± 0.4 (3)	0.5 ± 0.5 (3)	1.7 ± 0.5 (12)
2002	0.4 (1)	0.3 (1)	0.3 (1)	0.2 ± 0.1 (3)	1.5 ± 0.3 (2)	1.8 ± 0.2 (3)	2.6 ± 0.3 (5)	2.4 ± 0.2 (5)	2.6 ± 0.5 (5)	2.1 ± 0.5 (4)	1.0 ± 0.1 (2)	1.1 (1)	1.4 ± 0.3 (12)
2003	1.4 (1)		1.5 (1)	2.6 (1)	0.9 (1)	1.0 ± 0.9 (2)	2.0 ± 0.5 (5)	2.4 ± 0.4 (5)	1.8 ± 0.1 (5)	1.8 ± 0.3 (4)	1.3 ± 0.4 (3)	0.4 (1)	1.5 ± 0.4 (11)
2004	1.2 (1)	1.4 (1)	1.8 (1)	0.9 ± 1.1 (2)	0.4 ± 0.3 (4)	1.5 ± 0.4 (4)	1.9 ± 0.3 (2)	1.6 (1)	2.6 (1)	1.0 (1)	0.9 (1)	0.9 (1)	1.3 ± 0.6 (12)
2005	0.5 (1)	0.7 (1)	1.4 (1)	1.3 (1)	2.3 (1)	2.4 (1)	2.1 (1)	2.1 (1)	2.1 (1)		0.9 (1)	1.2 (1)	1.6 (11)
2006	1.0 (1)	1.0 (1)	1.1 (1)	1.4 (1)	0.9 ± 0.4 (4)	1.5 ± 0.7 (4)	1.5 ± 0.7 (4)	1.6 ± 0.2 (4)	1.4 ± 0.3 (4)	1.6 ± 0.5 (5)	1.1 ± 0.4 (2)	0.2 (1)	1.2 ± 0.4 (12)
2007	0.2 (1)	0.8 (1)	1.6 (1)	1.7 ± 0.2 (2)	1.7 ± 0.5 (3)	1.6 ± 0.3 (5)	2.0 ± 0.2 (4)	2.3 ± 0.4 (5)	2.1 ± 0.5 (4)	2.4 ± 0.4 2)	1.1 ± 0.2 (2)	1.4 (1)	1.6 ± 0.4 (12)
2008	0.4 (1)	0.2 (1)	0.2 (1)	0.6 (1)	1.1 (1)	1.5 ± 0.4 (2)	1.8 ± 0.1 (5)	1.8 ± 0.3 (4)	1.5 ± 0.4 (4)	1.5 ± 0.3 (5)	1.3 ± 0.8 (2)	1.0 ± 0.1 (3)	1.1 ± 0.3 (12)
2009	0.9 (1)	0.5 (1)	0.8 (1)	0.8 (1)	0.7 ± 0.5 (4)	1.4 ± 0.1 (4)	1.9 ± 0.2 (6)	1.7 ± 0.1 (4)	1.5 ± 0.4 (5)	0.6 ± 0.3 (3)	0.8 (1)	0.6 (1)	1.0 ± 0.3 (12)
2010	1.7 (1)	0.8 (1)	0.9 (1)	2.1 (1)	1.8 ± 0.5 (4)	1.5 ± 0.4 (2)	2.0 ± 0.8 (4)	1.9 ± 0.3 (4)	1.6 ± 0.3 (5)	1.4 ± 0.4 (3)	1.1 ± 0.2 (3)	0.7 (1)	1.4 ± 0.4 (12)
2011	1.2 (1)	1.4 (1)	0.8 (1)	0.1 (1)	0.2 ± 0.1 (4)	0.8 ± 0.4 (5)	1.5 ± 0.5 (4)	1.8 ± 0.1 (4)	1.8 ± 0.3 (5)	1.5 ± 0.5 (4)	1.0 ± 0.3 (2)	0.9 (1)	1.1 ± 0.3 (12)
2012	0.8 (1)	0.5 (1)	0.5 (1)	1.3 ± 0.1 (3)	1.6 ± 0.3 (6)	1.6 ± 0.1 (4)	1.7 ± 0.2 (4)	1.6 ± 0.2 (5)	1.8 ± 0.4 (4)	1.2 ± 0.0 (2)	1.1 (1)	0.6 (1)	1.2 ± 0.2 (12)
2013	1.2 (1)	0.6 (1)	1.5 (1)	1.7 (1)	1.7 ± 0.7 (4)	1.6 ± 0.2 (4)	2.1 ± 0.2 (4)	2.1 ± 0.4 (5)	2.2 ± 0.2 (3)	1.6 ± 0.2 (5)	1.3 ± 0.1 (2)	1.5 (1)	1.6 ± 0.3 (12)
2014	0.8 (1)	1.1 (1)	0.3 (1)	0.8 (1)	1.9 ± 0.4 (4)	2.3 ± 0.7 (4)	1.9 ± 0.5 (5)	1.9 ± 0.3 (4)	1.4 ± 0.1 (4)	1.7 ± 0.4 (5)	1.2 (1)	1.2 (1)	1.4 ± 0.4 (12)
2015	1.2 (1)	0.3 (1)	1.7 ± 0.2 (2)	0.9 ± 0.8 (4)	1.2 ± 0.2 (4)	1.7 ± 0.4 (5)	2.0 ± 0.2 (5)	2.2 ± 0.2 (3)	1.9 ± 0.4 (5)	0.9 1)	0.3 (1)	0.2 (1)	1.2 ± 0.4 (12)
m ± SD	1.0	0.8 ± 0.8	1.0 ± 0.2	1.2 ± 0.5	1.4 ± 0.5	1.6 ± 0.4	2.0 ± 0.4	2.0 ± 0.3	1.9 ± 0.3	1.5 ± 0.4	1.1 ± 0.3	0.9 ± 0.3	1.4 ± 0.4

(n)	(17)	(16)	(17)	(17)	(18)	(18)	(18)	(18)	(18)	(17)	(18)	(18)	(210)

Table 5. Annual Average Chlorophyll-a (AV CHL) and Annual Average Secchi transparency (AV ST) across all sites and sampling dates expressed as mean [chlorophyll-a] ± standard deviation and (n) from Haggard et al. (1999).

Sampling Location	**AV Chl-a (µg/L)**	**AV ST (m)**
White River	5.4 ± 3.7 (36)	1.2 ± 0.3 (36)
Hickory Creek	5.2 ± 3.4 (36)	1.4 ± 0.3 (36)
Lowell	4.1 ± 1.9 (36)	1.7 ± 0.4 (36)
Prairie Creek	3.0 ± 1.3 (36)	2.8 ± 0.7 (36)

Figure 1. Map of sampling locations for monitoring conducted by the University of Arkansas in 2015.



Site #	River miles	Latitude	Longitude
12	48.6	36° 25' 28"	93° 51' 15"
11	42.8	36° 23' 17"	93° 53' 23"
10	37.2	36° 19' 51"	93° 54' 05"
9	28.9	36° 20' 02"	93° 57' 27"
8	23.4	36° 20' 06"	94° 01' 09"
7	20.3	36° 18' 28"	94° 01' 29"
6	16.4	36° 17' 36"	94° 02' 15"
5	13.1	36° 15' 37"	94° 04' 07"
4	9.31	36° 14' 29"	94° 01' 43"
3	7.19	36° 14' 23"	94° 00' 01"
2	3.13	36° 12' 31"	94° 00' 59"
1	0	36° 10' 34"	94° 01' 11"

Figure 2. LOESS trends on USGS raw data collected at the five routine monitoring stations on Beaver Lake.

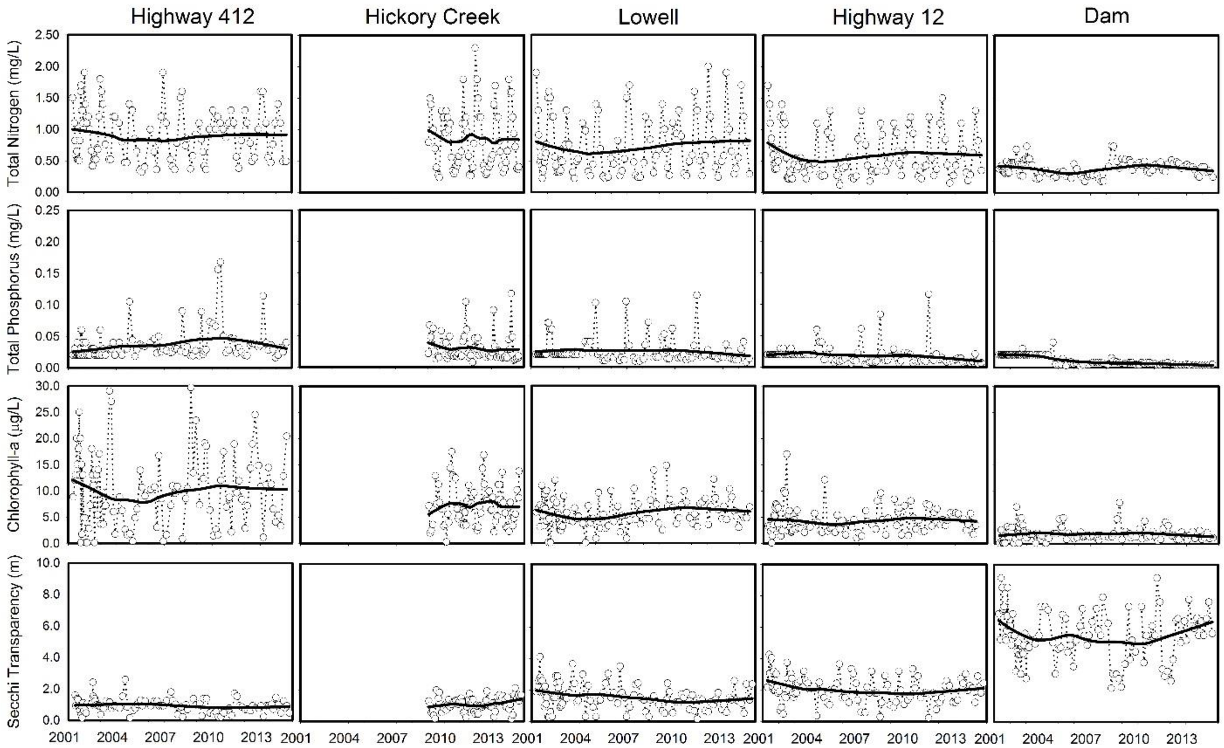


Figure 3. Linear trends on USGS average annual data (where applicable) collected at the five routine monitoring stations on Beaver Lake.

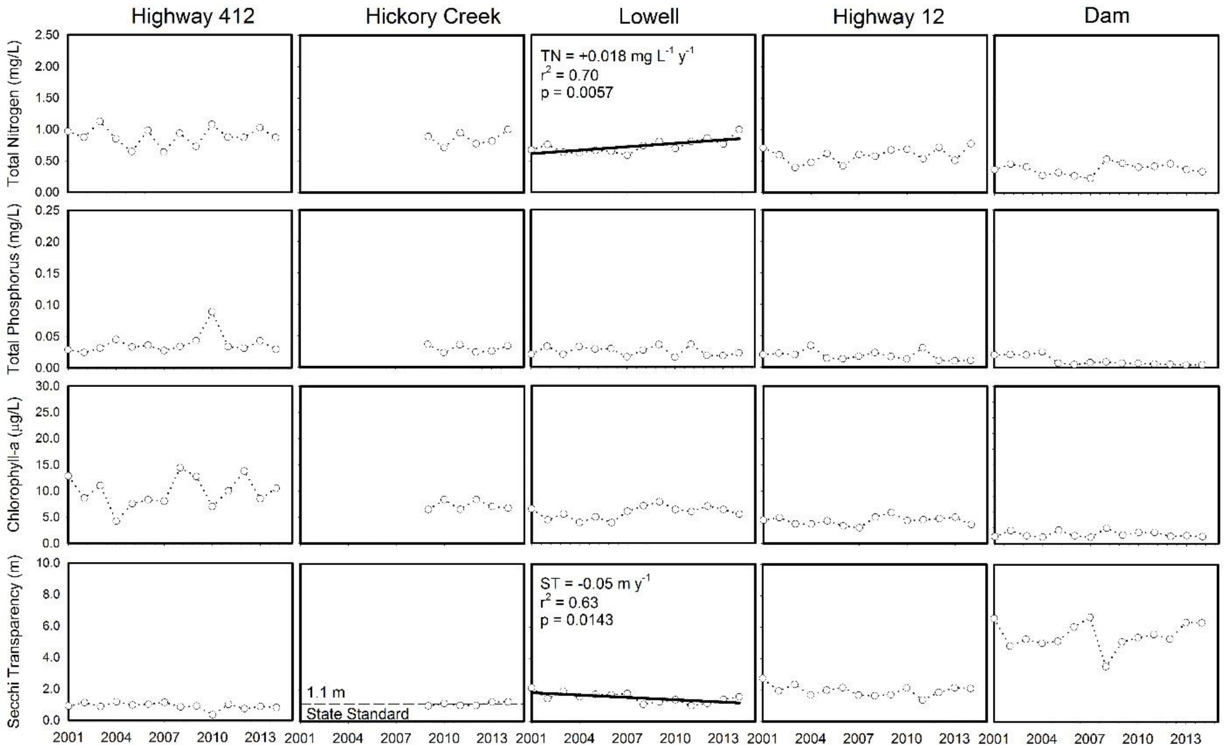


Figure 4. Linear trends on USGS growing season geometric mean data (where applicable) collected at the five routine monitoring stations on Beaver Lake.

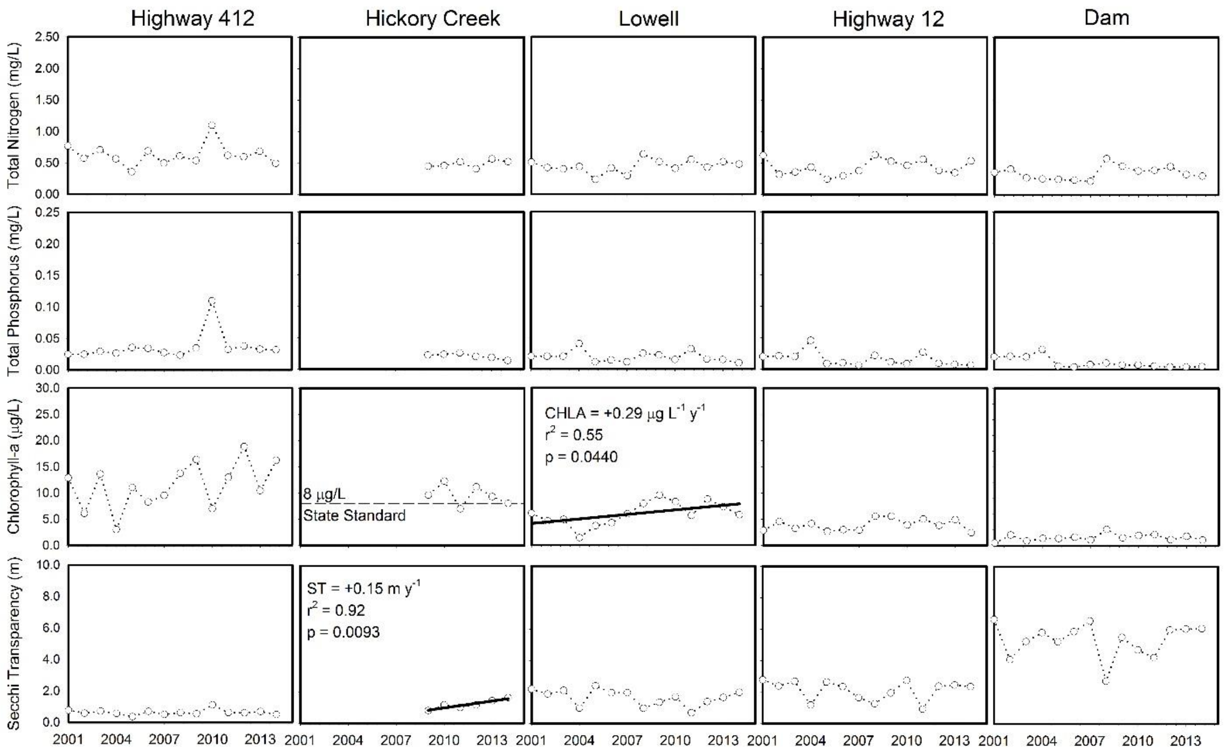


Figure 5. Secchi transparency along the riverine-transition-lacustrine gradient in 2015 growing season sampled by the University of Arkansas.

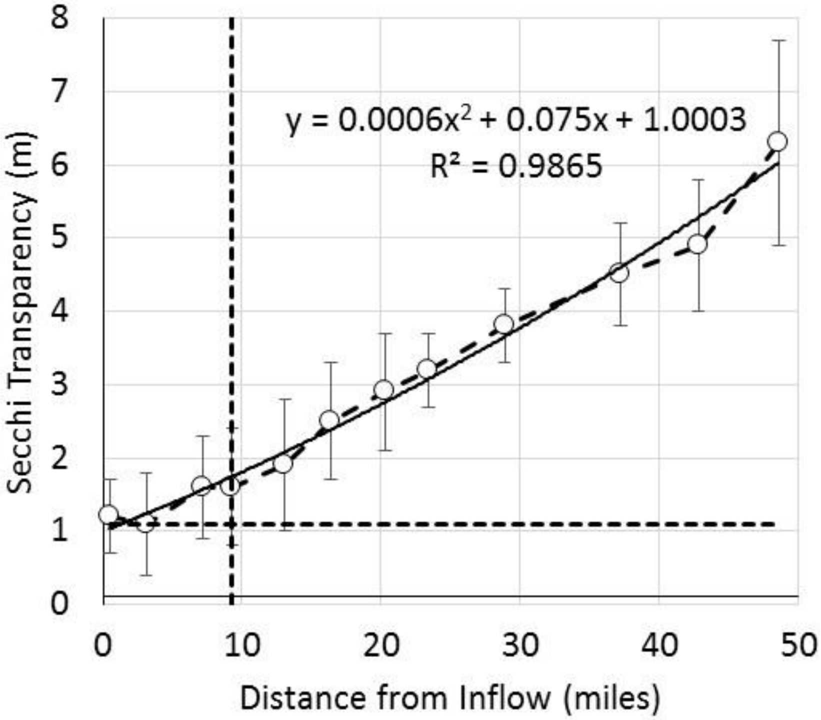


Figure 6. Chlorophyll-a along the riverine-transition-lacustrine gradient in 2015 growing season sampled by the University of Arkansas.

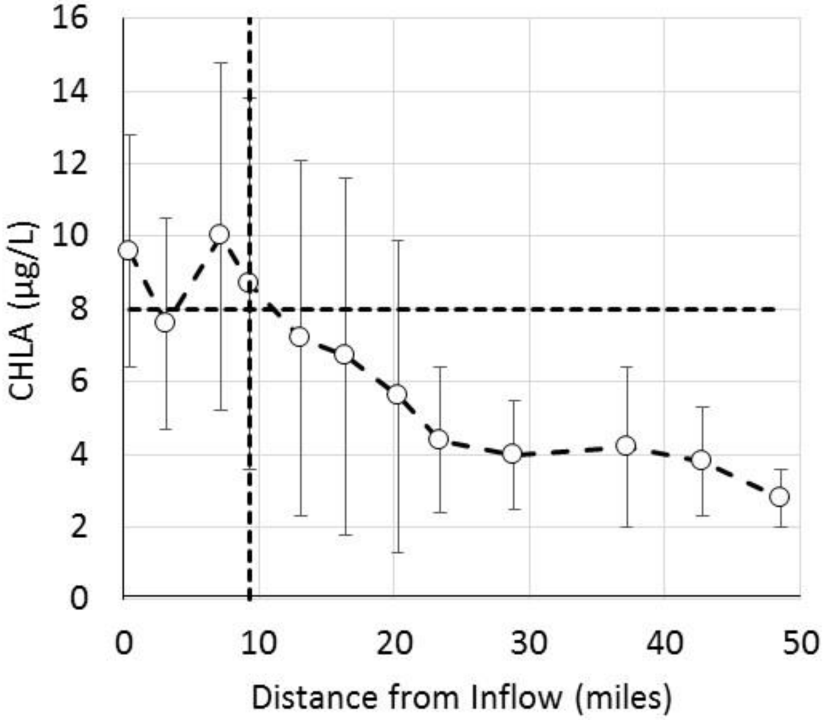


Figure 7. Time-series and LOESS trend in chl-a measured by Beaver Water District at the drinking water intake since 2002.

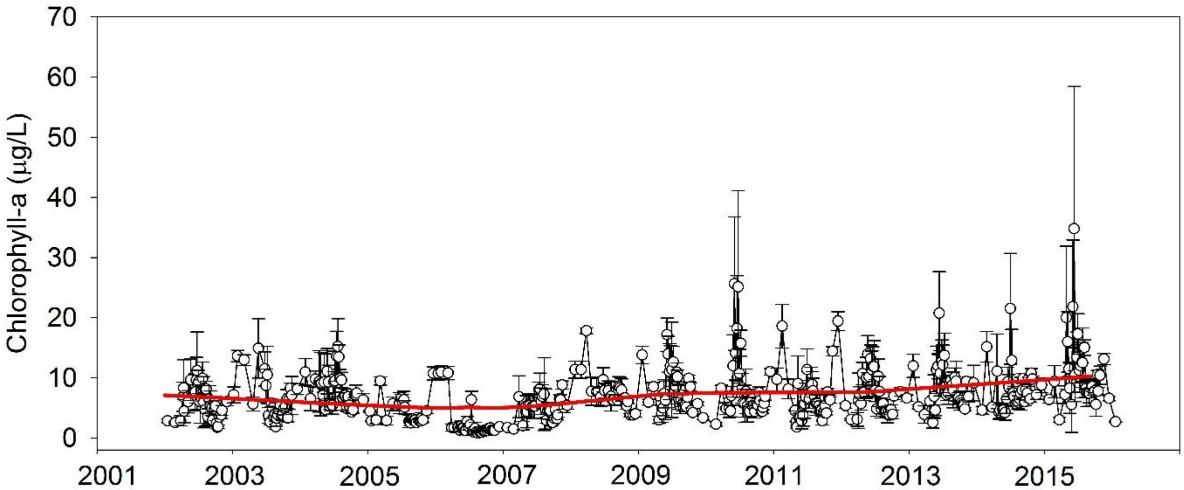


Figure 8. Changes in flow-adjusted concentrations (FACs) of nitrate-nitrogen (NO3), total nitrogen (TN), soluble reactive phosphorus (SRP), and total phosphorus (TP) at the White River at Arkansas Highway 45, showing monotonic increases or decreases based on simple linear regression (blue lines) and subtle changes over time using locally weighted regression (LOESS, red line).

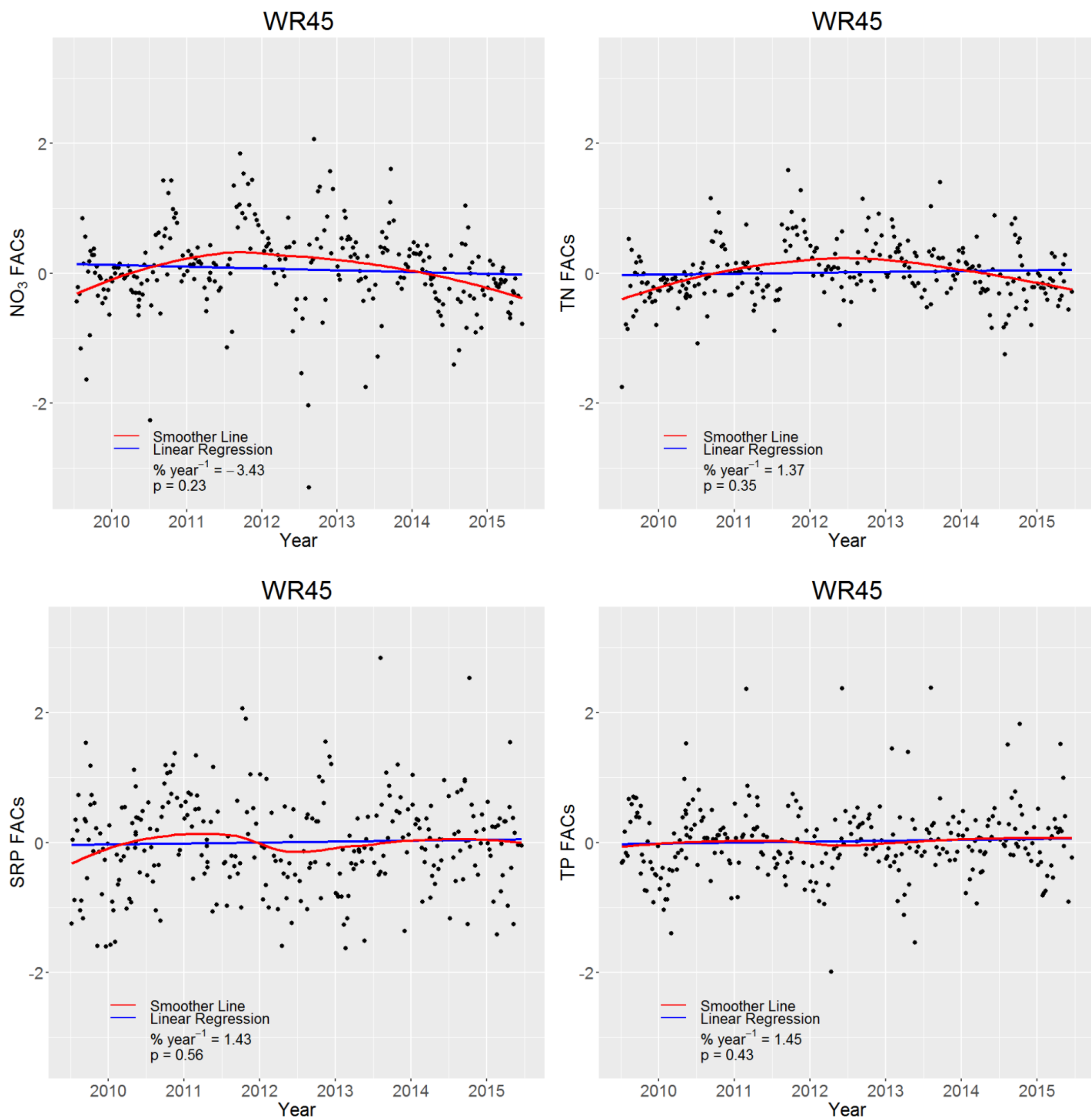


Figure 9. Changes in flow-adjusted concentrations (FACs) of nitrate-nitrogen (NO3), total nitrogen (TN), soluble reactive phosphorus (SRP), and total phosphorus (TP) at Richland Creek – Arkansas Highway 45, showing monotonic increases or decreases based on simple linear regression (blue lines) and subtle changes over time using locally weighted regression (LOESS, red line).

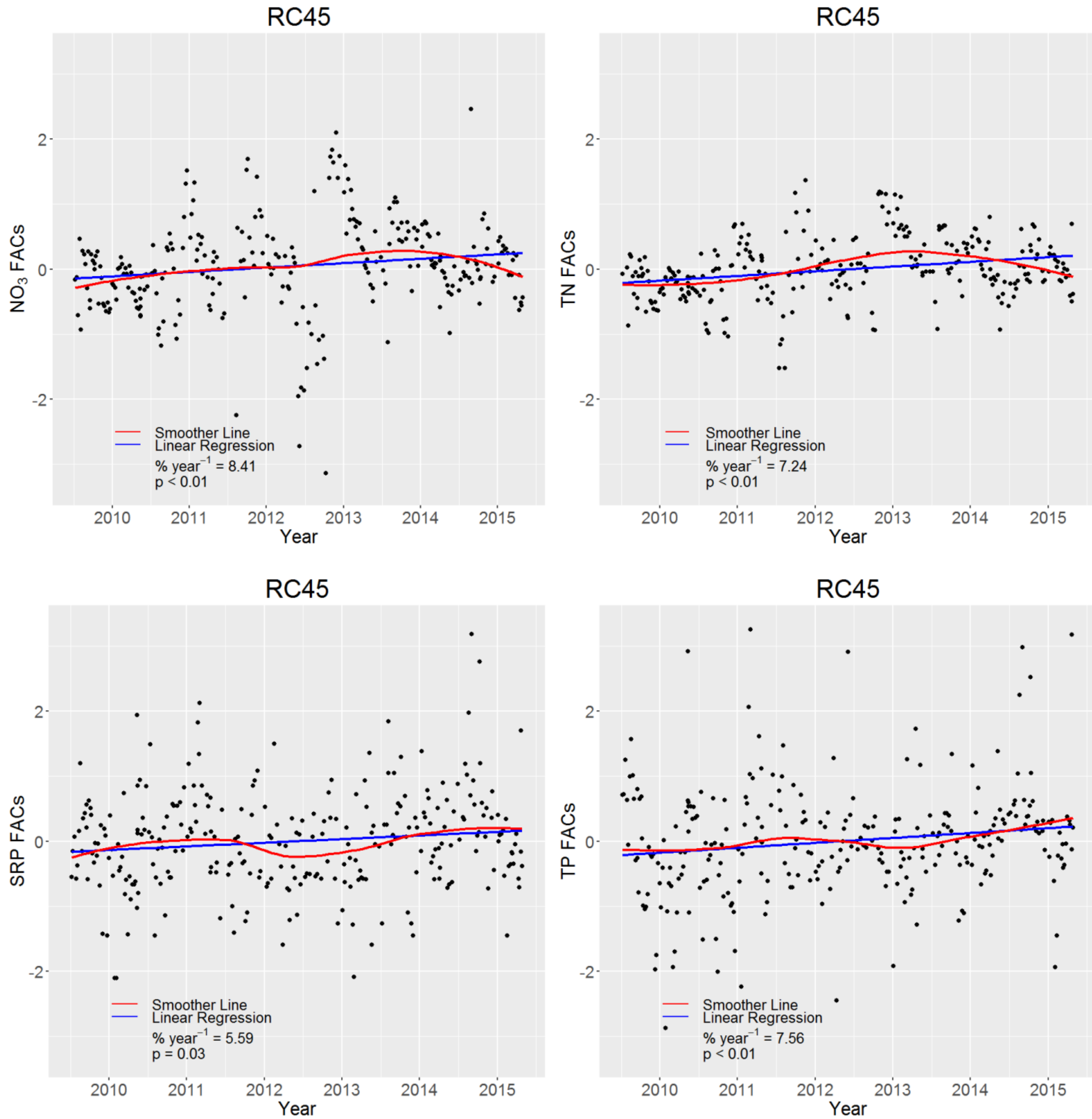


Figure 10. Changes in flow-adjusted concentrations (FACs) of nitrate-nitrogen (NO3), total nitrogen (TN), soluble reactive phosphorus (SRP), and total phosphorus (TP) at War Eagle Creek, showing monotonic increases or decreases based on simple linear regression (blue lines) and subtle changes over time using locally weighted regression (LOESS, red line)..