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Research Letter

Nutrient Concentrations in Big Creek Correlate to Regional Watershed Land Use

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Core Ideas

- Nutrient concentrations are low at Big Creek relative to expected biological-response thresholds.
- Nutrient concentrations at Big Creek are typical of streams draining watersheds with similar land use.
- Flow-adjusted nutrient concentrations at Big Creek have not increased over the short-term.
- Nutrient concentrations in streams increase as watershed land area in pasture and urban uses increases.

Abstract: Nutrient concentrations in several streams of the Boston and Ozark Mountains region of Arkansas, including the Buffalo National River and its tributaries, have garnered tremendous interest. In particular, Big Creek has been the center of attention within the Buffalo River watershed because of a permitted concentrated animal feeding operation (CAFO). The objectives of this paper were to put nutrient concentrations of Big Creek into the context of the stream nutrient and watershed land-use relationship and develop a framework to evaluate regional land-use impacts on regional water quality. Nutrient concentrations in streams draining the Boston and Ozark Mountains region were related to the intensity of watershed land use. Concentrations in Big Creek were similar to other watersheds in the ecoregion with similar land use, suggesting limited impact of the CAFO on Big Creek at the present time. However, this does not preclude future impacts, and longer-term monitoring continues.

Nutrient impairment of surface waters continues despite widespread conservation efforts to reduce losses from urban, rural, and agricultural land uses (Scavia et al., 2014). Land use within watersheds influences the quality and quantity of water in streams draining the landscape. As land disturbance increases and use intensifies, an increase in stormwater runoff and nutrient inputs that lead to a greater potential for transport to receiving water is generally observed (Dubrovsky et al., 2010; Rebich et al., 2011). This has led to efforts to identify and quantify nutrient sources within watersheds, strategically target, and apportion nutrient loss reduction (Reckhow et al., 2011).

Many factors influence the relationship between land use in a given watershed and nutrient transport downstream from that watershed. With an increase in percentage of the drainage area in pasture, row crop, and/or urban use, a general trend of increasing nutrient concentrations in storm and base flows will manifest (Buck et al., 2004; Giovannetti et al., 2013; Haggard et al., 2003; Migliaccio et al., 2007). Thus, nutrient concentrations in streams draining forested lands tend to be less than in watersheds with considerable anthropogenic land use.

For a range of reasons, great interest has been expressed in nutrient concentrations in several streams of the Boston and Ozark Mountains region of northwest Arkansas, including the Buffalo National River and its tributaries. In particular, Big Creek has been the center of attention within the Buffalo National River watershed (BRW) because of a permitted concentrated animal feeding operation (CAFO). The objectives of this letter are to put nutrient concentrations of Big Creek into the context of the stream nutrient and watershed land use relationship and assess whether stream nutrient concentrations have

Abbreviations: BRW, Buffalo River watershed; CAFO, concentrated animal feeding operation; LOESS, locally weighted regression; SRP, soluble reactive phosphorus; TN, total N; TP, total P; UIRW, Upper Illinois River watershed; UWRW, Upper White River watershed.

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changed over the short term (3 yr of monitoring). The goal is to understand if, how, and why stream nutrient concentrations change downstream at Big Creek and whether the permitted swine CAFO has influenced water quality during the 3 yr since extensive monitoring began in September 2013.

Methods

Water samples have been collected over varying periods at the outlet of subwatersheds of the BRW, Upper Illinois River watershed (UIRW), and Upper White River watershed (UWRW; Fig. 1). Land use and cover (i.e., forest, pasture, and urban) for each subwatershed was obtained from high-resolution (4-m) imagery from the USGS National Elevation Dataset (USGS, 2015; Gesch et al., 2002), National Land Cover Dataset (USGS, 2017b), and National Hydrologic Dataset (USGS, 2017a). In the UWRW, Giovannetti et al. (2013) monitored 20 sites monthly for 1 yr (June 2005–July 2006), collecting water samples during base-flow conditions. In the UIRW, Haggard et al. (2010) monitored 29 sites monthly during calendar year 2009, also collecting water samples during base-flow conditions.

In the BRW, the National Park Service in partnership with the Arkansas Department of Environmental Quality periodically collected water samples and measured nutrient concentrations at 20 stream sites from 1985 through 2015. Nitrate-nitrogen (NO_3–N), total N (TN), soluble reactive phosphorus (SRP), and total P (TP) concentrations were obtained directly from these data. Forest, pasture, and urban land-use areas were determined from 2006 high-resolution (4-m) land use–land cover imagery.

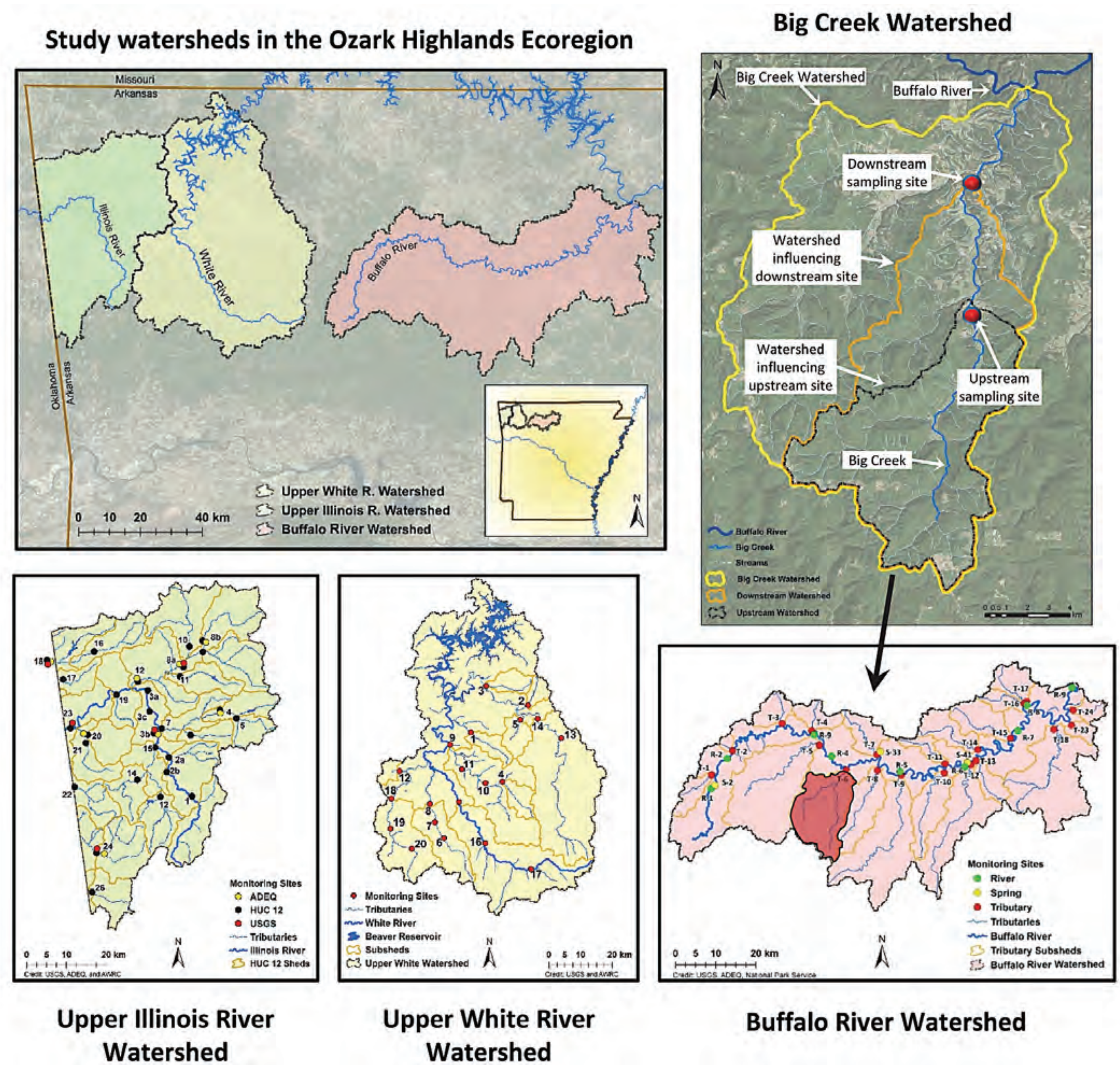

Fig. 1. Location of the Big Creek, Buffalo River, Upper Illinois River and Upper White River watersheds in the Boston Mountains and Ozark Highlands ecoregion. Information from USGS, Environmental Systems Research Institute (ESRI), and NASA.

Big Creek is monitored by the Big Creek Research and Extension Team, a partnership between the University of Arkansas System's Division of Agriculture and USGS. Water samples have been collected upstream and downstream of the swine CAFO on a near-weekly basis since September 2013 (Fig. 1). The water samples were analyzed at an Arkansas Department of Environmental Quality certified water quality laboratory within the Arkansas Water Resources Center (http://arkansas-water-center.uark.edu/water-quality-lab.php), according to methods detailed in Table 1. The data collected is made publicly available at https://bigcreekresearch.org/.

The geometric mean of nutrient concentrations of base-flow samples collected between September 2013 and April 2017 were determined in order to compare with base-flow nutrient concentrations available for BRW, UIRW, and UWRW. Base-flow conditions in Big Creek were classified from hydrograph inspection when flow had not increased or decreased within 3 d of sample collection. McCarty and Haggard (2016) suggested that stream nutrient concentrations under base flow can be used to identify nonpoint sources and target remedial measures in Boston Mountains and Ozark Highland watersheds.

Using all above-listed data sources, the geometric means of nutrient concentrations for streams in the BRW, UIRW, and UWRW were used to develop a relationship with human development within the watershed. Human development is defined as the percentage of pasture plus urban land use within the watershed. Exponential relationships with 95% confidence bands around the observations were developed for NO_3–N, TN, SRP, and TP concentrations to put nutrient concentration at Big Creek into the context of regional stream nutrients and watershed land use.

Data from Big Creek were paired with discharge available from a gaging station just downstream from the swine CAFO, where the USGS developed the rating curve; discharge information was only available from May 2014 through April 2017. The data were then used in a simple three-step process (White et al., 2004) to look at monotonic changes in the nutrients at Big Creek: (i) log-transform concentration (mg L^{-1}) and associated instantaneous discharge (m^3 s^{-1}); (ii) use locally weighted regression (LOESS) to smooth the data with a sampling proportion (n) of 0.5; and (iii) plot the residuals from LOESS (i.e., the flow-adjusted concentrations) over time and use linear regression to evaluate monotonic trends.

Results and Discussion

Putting Stream Nutrient Concentrations into Context at Big Creek

In Big Creek, upstream of the swine CAFO, the geometric mean concentrations of base flow sampled at weekly intervals from September 2013 for NO_3–N, TN, SRP and TP were 0.098, 0.205, 0.009, and 0.030 mg L^{-1}, respectively. Directly downstream of the CAFO, geometric mean concentrations at Big Creek during base flow conditions during the same period were 0.242, 0.356, 0.011, and 0.031 mg L^{-1} for NO_3–N, TN, SRP and TP, respectively. Arkansas has narrative criteria for nutrient concentrations in streams (Arkansas Pollution Control and Ecology Commission, 2016), but its proposed assessment methodology has numeric screening concentrations for TN (0.450–2.430 mg L^{-1}) and TP (0.040–0.100 mg L^{-1}) in the Boston Mountains and Ozark Highlands. The geometric mean concentrations at Big Creek upstream and downstream from the CAFO were below these values for the Boston Mountains and Ozark Highlands ecoregion.

Nutrient concentrations in Big Creek upstream and downstream from the CAFO are low with respect to nutrient–biological response thresholds for algae, macroinvertebrates and fish. Evans-White et al. (2014) reviewed the literature, summarizing nutrient–biological response thresholds across the United States:

- *Algal metric responses.* TN: 0.38–1.79 mg L^{-1}; TP: 0.011–0.28 mg L^{-1}
- *Macroinvertebrate metric responses.* TN: 0.61–1.92 mg L^{-1}; TP: 0.04–0.15 mg L^{-1}
- *Fish metric responses.* TN: 0.54–1.83 mg L^{-1}; TP: 0.06–0.14 mg L^{-1}

Total N concentrations at Big Creek upstream and downstream of the swine CAFO were well below thresholds that result in some expected biological response, whereas TP concentrations were below thresholds for expected macroinvertebrate and fish response and on the low end of the range for expected algal response. However, these lower TP thresholds (0.006–0.026 mg L^{-1}; Stevenson et al., 2008) were focused on shifts in diatom species and metrics rather than nuisance algal biomass. A recent study on the Illinois River Watershed showed that stream TP thresholds with *Cladophora* biovolume and nuisance taxa proportion of biovolume were observed between 0.032 and 0.058 mg L^{-1} (Joint Study

Table 1. Minimum detection limits for each chemical and biological constituent.

Constituent	Analytical method†	Minimum detection limit‡	Reporting limit§
Soluble reactive P, mg L^{-1}	EPA 365.2	0.002	0.010
Total P, mg L^{-1}	APHA 4500-P J; EPA 365.2	0.012	0.020
Nitrate–N, mg L^{-1}	EPA 300.0	0.004	0.050
Total N, mg L^{-1}	APHA 4500-P J; EPA 353.2	0.006	0.050
Total suspended solids, mg L^{-1}	EPA 160.2	No detection limit	4.0

† EPA = Approved CWA Chemical Test Methods (USEPA, 2017); APHA = American Public Health Association from the *Wadeable Streams Assessment, Water Chemistry Laboratory Manual* (USEPA, 2004).

‡ The minimum detection limit of an analyte is the value, which can be measured and reported with 99% confidence that the analyte concentration is greater than zero. Further information is available at USGS (1999).

§ The reporting limit is the least (non-zero) calibrated standard used in analysis, or as defined by method for total suspended solids.

Committee, 2017). Thus, TP concentrations at Big Creek upstream and downstream of the CAFO were in the range in which the natural assemblage of algae is shifting, but these concentrations would likely not be indicative of problematic nuisance algae in this ecoregion.

Geometric mean nutrient concentrations varied upstream and downstream of the swine CAFO at Big Creek, and Kosič et al. (2015) used the publicly available data to allude to the N increase being from human activities on the landscape, such as the CAFO. However, the historic land use and how stream nutrient concentrations during base-flow conditions increase with human development within the Boston Mountain and Ozark Highland watersheds need to be considered (e.g., see Giovannetti et al., 2013; Haggard et al., 2003; Migliaccio et al., 2007). In the Big Creek watershed, the percentage of land influenced by human activities (i.e., pasture plus urban) doubles from ~10 to ~20% in the drainage area upstream and downstream of the CAFO. Nutrient concentrations in Big Creek upstream and downstream of the CAFO are within the range typical of streams draining similar land uses (Fig. 2).

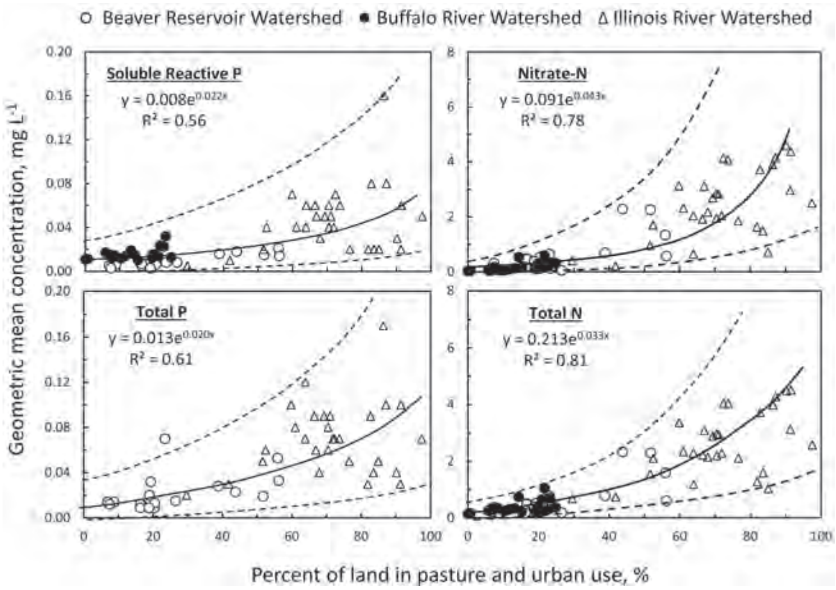

Fig. 2. Relationship between land use and the geometric mean N and P concentrations (mg L^{-1}) in the Buffalo, Upper Illinois, and Upper White River watersheds (no total P data available for the Buffalo River watershed). Dashed lines represent the 95% confidence intervals for the estimated mean (solid line).

At this time, nutrient concentrations in Big Creek upstream and downstream from the swine CAFO are consistent with the range in concentrations for other watersheds with similar pasture and urban land use characteristics (Fig. 2), as well as less than most nutrient thresholds for nuisance water-quality conditions (Omernik and Griffith, 2014). However, this does not preclude the possibility that nutrient concentrations at Big Creek may increase over time, especially if human development and activity in the drainage areas increase. The most important observation is that nutrient concentrations were low in Big Creek, providing the ability to detect changes over time.

Have Nutrient Concentrations Changed in the Short Term at Big Creek?

Understanding that long-term (e.g., decadal-scale) water-quality data are needed to reliably assess how stream nutrient concentrations have changed in response to watershed management and climate variations is of critical importance (Hirsch et al., 2015). The literature shows that stream nutrient concentrations can change relatively quickly in response to effluent management (e.g., Haggard, 2010; Scott et al., 2011), but seeing a response (i.e., decrease in concentrations) from landscape management can take decades or more (Green et al., 2014; Sharpley et al., 2013). A myriad of factors may influence observed nutrient concentrations in streams, including discharge (Petersen et al., 1998), biological processes and climactic conditions (i.e., drought and floods; Jones and Stanley, 2016), and dominant transport pathways (Sharpley et al., 2013). Thus, we need to use caution when interpreting trends in water quality over databases that only cover a limited timeframe.

Three years of flow-adjusted nutrient concentration data at Big Creek downstream from the swine CAFO (May 2014–April 2017) show different relationships with flow for the various constituents:

- Nitrate-nitrogen was greatest (~0.5 mg L^{-1}) during the lowest flows sampled, and concentrations decreased with increasing flow;
- Total N generally decreased with increasing flow until a minimal value occurred; then TN increased with increasing flow;
- Soluble reactive P concentrations did not change much during base-flow conditions, and the greater concentrations (~0.100 mg L^{-1}) sporadically occurred at larger flows, indicating that enrichment from stormflow may have been influenced by availability of source or other nontransport factors; and
- Total P concentrations were also relatively stable during base-flow conditions and then increased in association with rainfall-runoff events, with only a few samples having concentrations >0.100 mg L^{-1}, indicating relatively small enrichment from the landscape.

Flow-adjusted concentrations (White et al., 2004), showed no monotonic (i.e., increasing or decreasing) trends in SRP, TP, or TN ($P > 0.16$) over the current monitoring period (Fig. 3). However, flow-adjusted NO_3–N concentrations decreased over time ($R^2 = 0.05$, $P = 0.01$) by 7% yr^{-1} (Fig. 3c).

Nutrient concentrations at Big Creek upstream and downstream of the swine CAFO, and indeed most tributaries of the Buffalo River, are low relative to other watersheds in this ecoregion (Fig. 2). This provides a starting point to build a framework to evaluate changes in nutrient concentrations of streams as a function of land use and management. The evaluation of flow-adjusted concentrations over time showed that nutrients in Big Creek were not increasing over the short duration of monitoring for which concentration and discharge data were available (May 2014–April 2017). At this point in time (April 2014–April 2017), it is evident that nutrient concentrations in Big Creek have not increased at the monitored site. However, flow and nutrient concentration data over a longer period are needed to reliably quantify water-quality trends and characterize sources, and monitoring needs to continue for at least a decade to evaluate how discharge, season, and time influence nutrient fluxes (Hirsch et al., 2010).

This research details a process by which regional monitoring networks can be developed to establish baseline, in-stream nutrient concentrations and by which time and/or land use and management impacts can be determined.

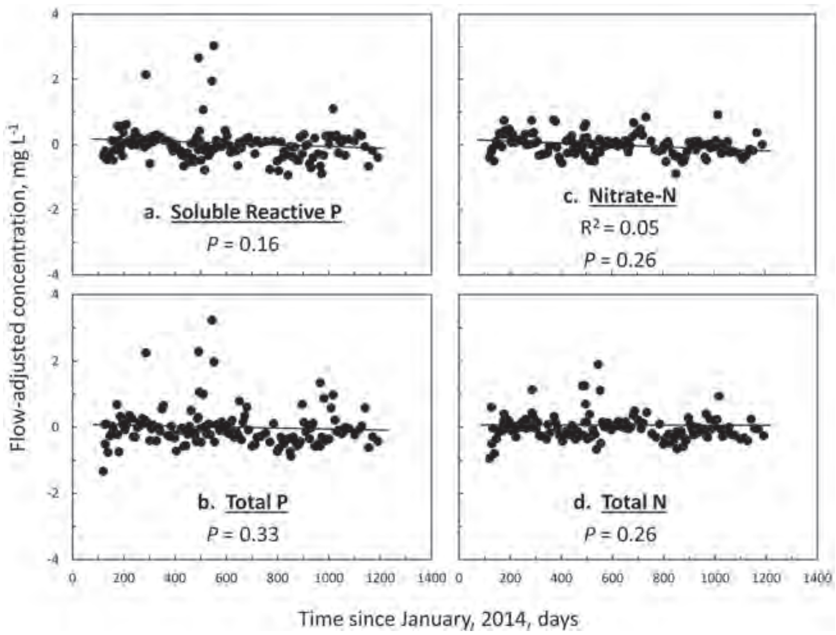

Fig. 3. Flow-adjusted concentration of (a) soluble reactive P, (b) total P, (c) nitrate-N, and (d) total N over time since January 2014, when monitoring in Big Creek started.

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