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Research Letter

Can We Manage Nonpoint-Source Pollution Using Nutrient Concentrations during Seasonal Baseflow?

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Core Ideas

- Nutrient concentrations in streams are positively correlated during baseflow and runoff conditions.
- High nutrient concentrations at baseflow suggest high nutrient loads from nonpoint sources.
- Manage nonpoint sources by targeting subwatersheds with elevated nutrient concentrations during baseflow.
- Focusing on baseflow conditions frees up resources to monitor water quality more broadly across watersheds.

Abstract: Nationwide, a substantial amount of resources has been targeted toward improving water quality, particularly focused on nonpoint-source pollution. This study was conducted to evaluate the relationship between nutrient concentrations observed during baseflow and runoff conditions from 56 sites across five watersheds in Arkansas. Baseflow and stormflow concentrations for each site were summarized using geometric mean and then evaluated for directional association. A significant, positive correlation was found for NO_3–N, total N, soluble reactive P, and total P, indicating that sites with high baseflow concentrations also had elevated runoff concentrations. Those landscape factors that influence nutrient concentrations in streams also likely result in increased runoff, suggesting that high baseflow concentrations may reflect elevated loads from the watershed. The results highlight that it may be possible to collect water-quality data during baseflow to help define where to target nonpoint-source pollution best management practices within a watershed.

Eutrophication of surface waters is a significant issue in the United States, resulting from point and nonpoint sources of nutrients. As a result, a substantial amount of resources has been targeted toward improving water quality. For example, effluent management has reduced phosphorus (P) inputs into the Illinois River, Arkansas (Haggard, 2010; Scott et al., 2011). Nonpoint-source (NPS) pollution is addressed by implementing best management practices (BMPs) on landscapes; however, progress has been difficult (Rissman and Carpenter 2015), and reductions in nutrient concentrations may occur after some lag time at the watershed scale (Meals et al., 2010).

The BMPs are often targeted to areas thought to have the greatest chance at producing measureable improvements in water quality or reductions in nutrient loads (Sharpley et al., 2000). The decision on where to invest resources and install BMPs is often guided and evaluated on the basis of watershed hydrology and water-quality models. These models are often used to reduce the spatial scale down to hydrologic unit code (HUC) 12 or smaller targets within priority watersheds (e.g., Pai et al., 2011). These priority subwatersheds are considered critical areas of elevated nutrient loads, based on the modeling effort considering nutrient sources and transport potential.

But what if we could manage NPS pollution by targeting subwatersheds with elevated nutrient concentrations during seasonal baseflow? The specific objective of this paper was to relate the central tendency (i.e., geometric mean) of nutrient concentrations during baseflow and storm events; we hypothesize that there is a positive correlation. The goal of this paper is to explore the argument that elevated nutrients in baseflow are reflective of elevated concentrations and loads during storm events, suggesting that we can manage NPS with a focus on baseflow water chemistry.

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Materials and Methods

Data used in this study came from three separate sources of stream water chemistry across five watersheds in Arkansas (Table 1). In Giovannetti et al. (2013), Massey et al. (2013), and Haggard et al. (2010), water samples were collected from the vertical centroid of flow, where the water was actively flowing and likely well mixed, using a horizontal α water sampler (Wildlife Supply Company, Yulee, FL), telescoping sample pole, or by hand. Quality assurance/quality control protocol, laboratory analysis methods, and method detection limits are all consistent with those described in McCarty et al. (2016), as well as the aforementioned studies.

For Giovannetti et al. (2013), Massey et al. (2013), and Haggard et al. (2010), baseflow conditions were established by two criteria: no runoff-producing rain in the previous 48 h, and no significant change in the hydrograph from the previous day (±10%). Similarly, stormflow conditions were considered when a rainfall event produced a significant rise in the hydrograph (>10%). When a particular site did not have available discharge, the closest USGS gauge (USGS, 2016) and visual observation of flow conditions were used to determine if baseflow or stormflow conditions were present.

Water-quality constituents studied included nitrate-nitrogen (NO_3–N), total N (TN), soluble reactive P (SRP), and total P (TP). For a given site, nutrient concentrations were summarized by geometric mean concentration for each flow condition (i.e., baseflow and stormflow conditions). For ranges in sampled concentrations and discharge, see Giovannetti et al. (2013), Massey et al. (2013), and Haggard et al. (2010). All statistical analysis was performed using JMP Pro (SAS Institute, 2014), with a significance level of 0.05.

Results

A significant ($P < 0.0001$) and positive correlation was found between baseflow and stormflow geometric mean concentrations of NO_3–N, TN, SRP, and TP (all $r^2 > 0.49$; Fig. 1). The geometric mean concentrations of NO_3–N, TN, and SRP at baseflow explained more than 68% of the variability in stormflow concentrations, whereas geometric mean concentrations of TP at baseflow explained only 49% of the variability in stormflow concentrations. For all of these linear regressions, slopes were between 0.71 and 0.95, and intercepts were above zero. For sites that had overall low concentrations (<1.0 mg L^{-1} NO_3–N, TN; <0.05 mg L^{-1} SRP), geometric mean concentrations for NO_3–N, TN, and SRP tended to be greater during stormflows relative to baseflow. However, for sites that had overall high concentrations, NO_3–N, TN, and SRP tended to have greater concentrations during baseflow compared to stormflow.

We also wanted to examine the baseflow–stormflow relationships within individual watersheds. However, only the Beaver Lake and Illinois River Watersheds contained enough sample points for linear regression (see Table 1; Poteau, Strawberry, and Upper Saline River watersheds individually had $n \leq 4$). For NO_3–N and TN, slopes were greatest for the Beaver Lake watershed, midrange for the Illinois River Watershed, and least when Beaver Lake and Illinois River watershed data were combined, ranging from 0.84 to 1.41. Coefficients of determination ranged from 0.76 to 0.90, and both the Beaver Lake and Illinois River watershed subset regression relations were significant. For SRP and TP, slopes were greatest for the Illinois River watershed, midrange when Beaver Lake and Illinois River watersheds were combined, and least for the Beaver Lake watershed, ranging from 0.58 to 0.96. Coefficients of determination ranged from 0.42 to 0.72, and both watershed subset regression relations were significant.

Discussion and Conclusion

Explanation for Observed Variance

Outliers were evaluated for each of the concentration relations with data pooled across all watersheds; however, their removal did not change the significance of the correlations. For example, the Poteau River near Cauthron, AR (specifically, POT-P1; Massey et al., 2013) had consistently greater SRP and TP concentrations during stormflow than in baseflow (Fig. 1). This site is downstream from a wastewater treatment plant, but baseflow concentrations were relatively low. The Poteau River watershed is a relatively turbid system, making it likely that substantial SRP uptake occurs in suspended and bottom sediments within the fluvial channel (e.g., Haggard et al., 2005; Ekka et al., 2006), resulting in low baseflow SRP concentrations. This legacy P source might release SRP back into the water column when resuspended in storm events. According to Jarvie et al. (2012), >50% of the annual P load during storm events can be from internal sources. Total P concentrations for the Poteau River near Cauthron were in the upper 50% of sites for baseflow and contained the greatest TP storm event concentrations. Furthermore, the catchment above this site is used for land application of biosolids and poultry litter; the predominant form of P loss from these sources is in the soluble form (Edwards and Daniel, 1993; DeLaune et al., 2004). Regardless, when

Table 1. Water-quality data sources, sampling periods, and number of samples

Watershed	Data source	Sampling period	Number of sites	Avg. baseflow samples/site	Avg. stormflow samples/site
Beaver Lake	Giovannetti et al., 2013	June 2005–July 2006	20	13	6
Illinois River	Haggard et al., 2010	Feb. 2009–Nov. 2009	29	12	6
Poteau River	Massey et al., 2013	Oct. 2011–Sept. 2012	2	12	21.5
Upper Saline River	Massey et al., 2013	Oct. 2011–Sept. 2012	4	12	24.5
Strawberry River	Massey et al., 2013	Oct. 2011–Sept. 2012	1	12	25

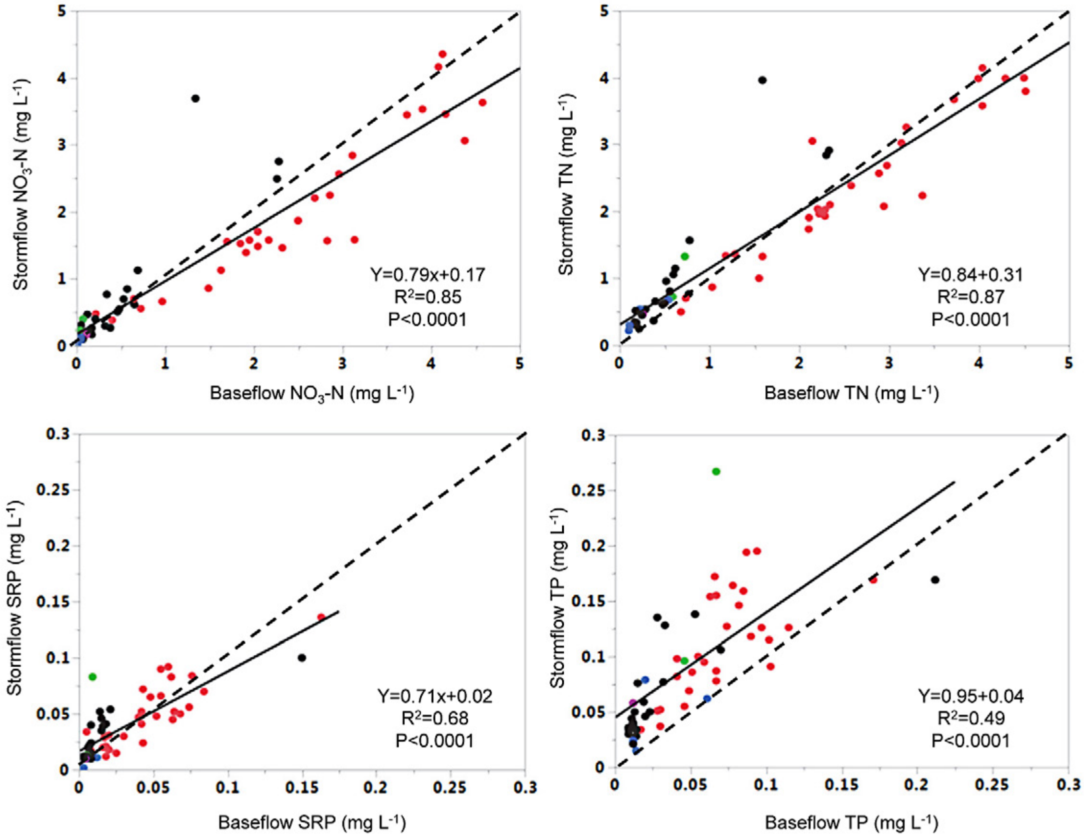

Fig. 1. Constituent geometric mean concentrations during baseflow and stormflow across the Beaver Lake, Illinois River, Poteau River, Strawberry River, and Upper Saline River watersheds. The dashed black line represents the 1:1 relationship, whereas the solid black line represents the baseflow to stormflow linear regression. Watersheds are separated by color: black symbols represent Beaver Lake watershed; red, Illinois River watershed; green, Poteau River watershed; blue, Upper Saline River watershed; and purple, Strawberry River watershed.

the site was removed from the analysis, the linear relationships for SRP and TP concentrations between baseflow and stormflow remained significant, with R^2 improving from 0.49 to 0.56 for TP and 0.68 to 0.75 for SRP.

Many sites had NO_3–N and TN concentrations that were lower during stormflow than in baseflow conditions, when baseflow concentrations were >1 mg L^{-1}. This suggests that stormflow concentrations were likely diluted (see also Poor and McDonnell, 2007) by rainwater (~0.8 mg L^{-1} NO_3–N; NADP, 2011). These sites were primarily within the Illinois River watershed (red dots, Massey et al., 2013). In contrast, for a few sites in the Beaver Lake watershed, NO_3–N and TN concentrations in stormflow were greater than baseflow. The rainwater had the opposite effect on sites with low NO_3–N and TN concentrations (<1 mg L^{-1}).

These watersheds are complex with regard to runoff producing areas (Leh et al., 2008), as well as karst underlying geology (Sauer et al., 1998), which influence N transport. The variations in baseflow NO_3 concentrations are probably the result of variations in groundwater concentrations, which is influenced by the land use overlying the area contributing to groundwater recharge (Cole et al., 2006). The NO_3 concentrations within baseflow would also be influenced by riparian and hyporheic zone processes (Hill and Shackleton 1989, Lowrance, 1992, Harnsberger and O'Driscoll, 2010; Vidon et al., 2010), where denitrification occurs as the water moves laterally through these zones to the stream where sampled.

Geometric mean TP concentrations during stormflow were generally greater than those during baseflow. This observation is likely the result of particulate P transport during runoff events (Sharpley et al., 1994; Sims et al., 1998). Brion et al. (2010) suggested that a similar increase in P during storm events within a smaller headwater catchment of the Illinois River watershed was also likely due to particulate P from sediment in runoff or P being released from instream sediments. This was not seen in the SRP concentrations relation because suspended sediments may potentially adsorb or release SRP from the water column (depending on equilibrium P concentrations).

Watershed Management Using Baseflow Nutrient Concentrations

Landscape BMPs are designed to address NPS pollution, which has traditionally been evaluated in terms of nutrient loads. The majority of nutrient transport occurs during storm events (Owens et al., 1991; Pionke et al., 1999; Green and Haggard, 2001), requiring substantial resources to adequately monitor this flow condition (Harmel et al., 2006). Alternatively, nutrient loadings are often simulated with watershed models to predict potential sources and BMP effectiveness and to prioritize subwatersheds

(Chaubey et al., 2010; Chiang et al., 2010; Pai et al., 2011). What if, instead of estimating total annual nutrient loads, we only needed to monitor baseflow nutrient concentrations? We show here strong, positive correlations between baseflow and stormflow nutrient concentrations, suggesting that baseflow may be a useful surrogate for nutrient concentrations and loads during storm events. Therefore, we make the case that by targeting subwatersheds with increased nutrient concentrations during baseflow, we are effectively targeting NPS pollution.

Admittedly, the data presented here connect concentrations during base and storm flows, but they do not address hydrology—a critical component of nutrient transport. We know that nutrient concentrations in baseflow increase with anthropogenic influence within the catchment (Haggard et al., 2003, 2007; Brion et al., 2010; Cox et al., 2013; Giovannetti et al., 2013). However, the landscape factors that likely are responsible for increased nutrients during baseflow also influence catchment hydrology. Modeling and experimental studies have shown that land uses and management such as pasture, urban, row crop, forest, and grazing, among many others, can influence runoff quantity and quality (Bronstert et al., 2002; Kim et al., 2002). In fact, nutrient yields (loads per unit area) from small watersheds draining predominantly forested to agricultural landscapes were highly correlated with nutrient concentrations observed during baseflow (Romeis et al., 2011). The combined influences of land uses on concentration and hydrology can be used to select for catchments that may experience increased nutrient loadings, which is where BMPs should be targeted to address NPS pollution.

In this study, baseflow nutrient concentrations yielded a significant indication as to the concentrations that might be observed during runoff conditions on average. If we couple this observation with the likelihood that hydrology was also influenced, then it may be feasible to focus water-quality monitoring efforts on baseflow conditions to address NPS. This would free up resources to examine water-quality at finer spatial scales and potentially provide a more robust picture of spatial variability in water quality across the watershed. In our assessment, it seems feasible that the routine monitoring of nutrient concentrations during baseflow, along with an examination of land use, could allow resource managers to target BMPs where they are needed most, at broader spatial scales, and with fewer resources.

This relation may be specific to these watersheds, similar watersheds, or limited to this ecoregion, the Ozark Highlands. However, this approach has the potential to revolutionize how we spend resources to monitor water quality for targeting NPS at the subwatershed level or smaller spatial scales. The sampling sites in these studies were targeted at or near the HUC 12 level, but it is conceivable to collect data at the HUC 14 level or at smaller watersheds (e.g., see Romeis et al., 2011) to even further refine targeting of resources and BMPs to improve water quality. It would be worth evaluating this approach to see how widely applicable it is across US watersheds.

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