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PASTURELAND IMPACTS ON WATER QUALITY OF TWO SMALL STREAMS, OZARK REGION, USA

Kenneth Steele, Paul Vendrell, Marc Nelson, Robin Roggio and Ronald McNew[1]

ABSTRACT: Two second-order streams were monitored in the Ozark Mountain Region of northwestern Arkansas, U.S.A. for 2.5 years to determine the effect of nutrient management on water quality. Shumate Creek had 22 percent pasture, whereas, Cannon Creek had 11 percent pasture. The remaining land cover in both watersheds is hardwood forest. Shumate Creek received over 5 times more animal waste as fertilizer than Cannon Creek, resulting in greater nutrient concentrations and mass transport for Shumate Creek. Decreasing discharge complicated ascertaining the relative importance of land management impacts on water quality. Concentrations of total suspended solids and all other parameters, except nitrate, increase with increasing discharge, indicating transport by runoff. The lack of this relationship for nitrate is consistent with it being transported to the streams by ground water.
KEY TERMS: Water quality, land use, stream loads, non-point source pollution, management

INTRODUCTION

A study to determine the impact of non-point source pollution from the application of animal wastes to pastureland on surface water was begun in the Beaver Lake Watershed of the White River of Northwest Arkansas, U.S.A. This location was selected because Beaver Lake provides about 80 percent of the over 250,000 people in the region with drinking water, and it is located in the most intense poultry production area in the United States. The objective of this study was to evaluate the impact of pastureland on stream water quality and the ability of best management practices (BMPs) to reduce nutrients, sediments, carbon and microbes in the Upper White River. In order to demonstrate the impact of BMPs on water quality it was necessary to select small (second order) stream basins so that the land use and BMPs could be controlled and measured effectively.

METHODOLOGY

Two adjacent second-order streams, Shumate Creek and Cannon Creek, which are tributaries of the White River in the Ozark Mountain Region (about 13 miles southeast of Fayetteville, Arkansas), were selected for this project. The monitoring sites were located near the confluence of the tributaries with the White River. The monitored portion of Shumate Creek watershed was 1,455 acres of which 326 acres was pastureland in 1992. The Cannon Creek watershed was of comparable size with 1,553 total acres and 171 acres of pasture (Scott and McKimmey, 2000). The remainder of the watersheds was hardwood forest. Relief, topography, and rock and soil types were similar for the two watersheds (Roggio et al., 1997). Automated samplers and data-loggers were used to measure and record the stream stage and collect flow-weighted, composite samples or discrete samples during storm flow events.

[1] Respectively, Professor, Department of Geosciences, University of Arkansas, Fayetteville, AR, 72701, U.S.A. email - ksteele@mail.uark.edu; Director, Feed and Environmental Water Lab, University of Georgia, Athens, GA; Director, Arkansas Water Resources Center Water Quality Lab, University of Arkansas, Fayetteville, AR 72701; Graduate Assistant, Department of Geosciences, University of Arkansas, Fayetteville, AR; Director, Agricultural Statistics Lab, University of Arkansas, Fayetteville, AR 72701

STATISTICAL METHODS

Statistical trend analysis adapted from Edwards et al. (1996 and 1997) and Vendrell et al. (1998) was used to determine if there was an improvement in water quality with time and, therefore, with BMP implementation. Each of the response variables was transformed by the natural logarithm for use as the dependent variable for statistical analysis. The trend analysis was achieved by linear regression on time (months of sample collection). The regression model included the sine and cosine functions of time in order to remove potential seasonal effects. The regression model used was:

$$\ln (y)=B0+B1(\text{time})+B2 \sin(2\pi \text{ time}/12)+B3\cos (2\pi \text{ time}/12) \qquad \text{Equation 1}$$

A significant ($p \leq 0.10$) regression coefficient (B1), determined by a t-test, indicates either an increasing trend (positive coefficient) or decreasing trend (negative coefficient). Because the Shumate Creek watershed had twice as much pastureland as Cannon Creek and more manure (5X) was surface applied as fertilizer (Table 1), it was of interest to compare the water quality of the two watersheds. This comparison was made using the Wilcoxon signed rank test and a significance level of 0.10.

TREND ANALYSIS

Discharge

Despite the similarity of the two basins, Shumate Creek had more (1.5 to 6.4 times) monthly discharge than Cannon Creek (Vendrell, 2000). Because of the close proximity of the two watersheds and similar geology, soils, relief and topography, the increased runoff from Shumate Creek is attributed to more pastureland and less forested riparian zones compared to Cannon Creek. Discharge exhibited statistically significant ($P \leq 0.10$) decreasing trends for both watersheds (Table 2).

Trends for water quality parameters may not be related directly to changes in animal waste management but rather to the result of increasing or decreasing discharge trends. Flow-weighted concentrations can be used to minimize this effect, but cannot completely remove the effects of runoff. During this project, total and base flow significantly decreased in Cannon and Shumate creeks (Table 2). There was not sufficient storm flow data to make a meaningful determination if a trend exists for this flow regime.

Loads

All loads fluctuated in a cyclic nature that was the result of seasonal variations (similar to Figure 1) (Vendrell, 2000). The model used to determine statistical trends accounts for this seasonality. Both creeks exhibited significant decreasing trends for all water quality parameters. There was successively less animal manure applied to pastures in both watersheds (Table 1). Although part of the decrease in loads may be attributed to BMP implementation, it is difficult to ascertain the importance of the BMPs because of the effect of the decreasing discharge trend (Vendrell, 2000).

FLOW-WEIGHTED CONCENTRATIONS

Because of the influence of discharge on loads, flow-weighted concentrations were calculated in order to minimize the differences in discharge between the two watersheds and to minimize the effect of a decreasing trend for discharge on loads. The monthly flow-weighted concentrations were examined for trends under total and base flow conditions (data set of 37 observations) for the period of the project (April 1996 to July 1998). There were not sufficient storm data for statistical analysis. Significant decreasing trends for *Escherichia coli* (E. coli), total organic carbon (TOC), total Kjeldahl nitrogen (TKN), soluble reactive phosphorus (SRP), total phosphorus (TP), and total suspended solids (TSS) were present for both creeks for total flow. Because few storms were measured, similar trends were present for base and total flow conditions with the exception that SRP did not have a statistically significant trend for base flow at Cannon Creek. Low ammonium-nitrogen (NH_4-N) concentrations near the analytical detection limit precluded development of trends for these parameters. Lack of a trend for nitrate-nitrogen (NO_3-N) is probably because the nitrate is derived from multiple sources (grass, leaves, and animal waste) and transported to the streams predominantly by ground water flow (see below) (Table 2).

Flow-weighted concentrations of TSS and all other parameters, except nitrate-nitrogen (NO_3-N), were greater for storms than base flow (i.e., correlated with increased discharge) indicating transport by runoff. The lack of this relationship for NO_3-N is consistent with much of it being transported to the streams by ground water. Although NO_3-N concentrations (i.e., *not* flow-weighted) decrease during storms (Roggio et al., 1997), the increased discharge keeps the loads and the flow-weighted concentrations about the same under storm and base flow conditions (Table 2).

COMPARISON OF WATERSHEDS

With the exception of TOC and TSS under base flow conditions, all parameter flow-weighted concentrations were higher in Shumate Creek under base, storm and total flow conditions. Nitrate-nitrogen, SRP, TKN, and TP flow-weighted concentrations were statistically significantly higher for Shumate Creek. Most of the parameter concentrations are 1.2 to 6 times higher during storm conditions and 1.9 to 2.9 times higher during base flow for Shumate Creek compared to Cannon Creek. These results are consistent with Shumate Creek having twice as much pasture as Cannon Creek. Although not statistically significant ($p=0.11$), E. coli concentrations are also consistent with the land use distribution. Differences in holding times after sample collection could affect organism growth or die off and obscure differences for E. coli. The lack of a statistical difference for TOC is probably a reflection of the ubiquitous sources of organic matter within the two watersheds (grass and forest) and the relatively minor role of animal waste as a source. Shumate to Cannon Creek ratios for TSS are greater for storm than base flow conditions because of the increased erosion of the pastures and the lack of a vegetated riparian zone along much of Shumate Creek, especially the lower portion near the sample collector. The base-flow TSS ratio for the two creeks indicates that there is more TSS at Cannon than Shumate during base flow. This situation may be the result of falsely lower values at Shumate Creek because the collector intake for this stream was occasionally buried under channel sediments (i.e., the overlying channel sediments acted as a filter for suspended sediments).

One might expect the ratio of flow-weighted concentrations for Shumate to Cannon creeks to be higher for storms than base flow because of runoff from pastures; however, other factors need to be considered. Dilution effects for Shumate Creek due to its higher discharge (3.5 times higher during storms and 4.7 times higher during base flow) and greater percent increase in concentrations for Cannon Creek because of its lower initial concentrations explain the generally slightly lower flow-weighted concentration ratios (Shumate to Cannon) during storms compared to base flow (Table 2).

CONCLUSIONS

In order to effectively manage watersheds and to make sensible policy/regulatory decisions regarding stream water quality, it is important to understand the hydrology. Selection of the correct hydrological indicators is critical in making the "right" policy choices. The use of decreasing flow-weighted concentrations as an indicator for water quality improvements due to the implementation of pastureland BMPs can lead to false conclusions, if the stream discharge is also decreasing during the same time period. Although, monthly flow-weighted concentrations decreased in the two streams monitored and the decreases coincided with decreased manure amendments to the pastures in these watersheds, stream discharge also decreased during the term of this study. The data collected during this study does not allow the amount of decrease caused by reductions in manure amendments to be partitioned from declines due to decreasing discharge. In comparative studies of these streams, flow-weighted concentrations are useful because differences in discharge for these streams were attributable to Shumate watershed having twice as much pastureland. In summary, generally flow-weighted concentrations are not useful in determining trends over time because of the effect of discharge but are useful in comparative studies because discharge can differ because of land use.

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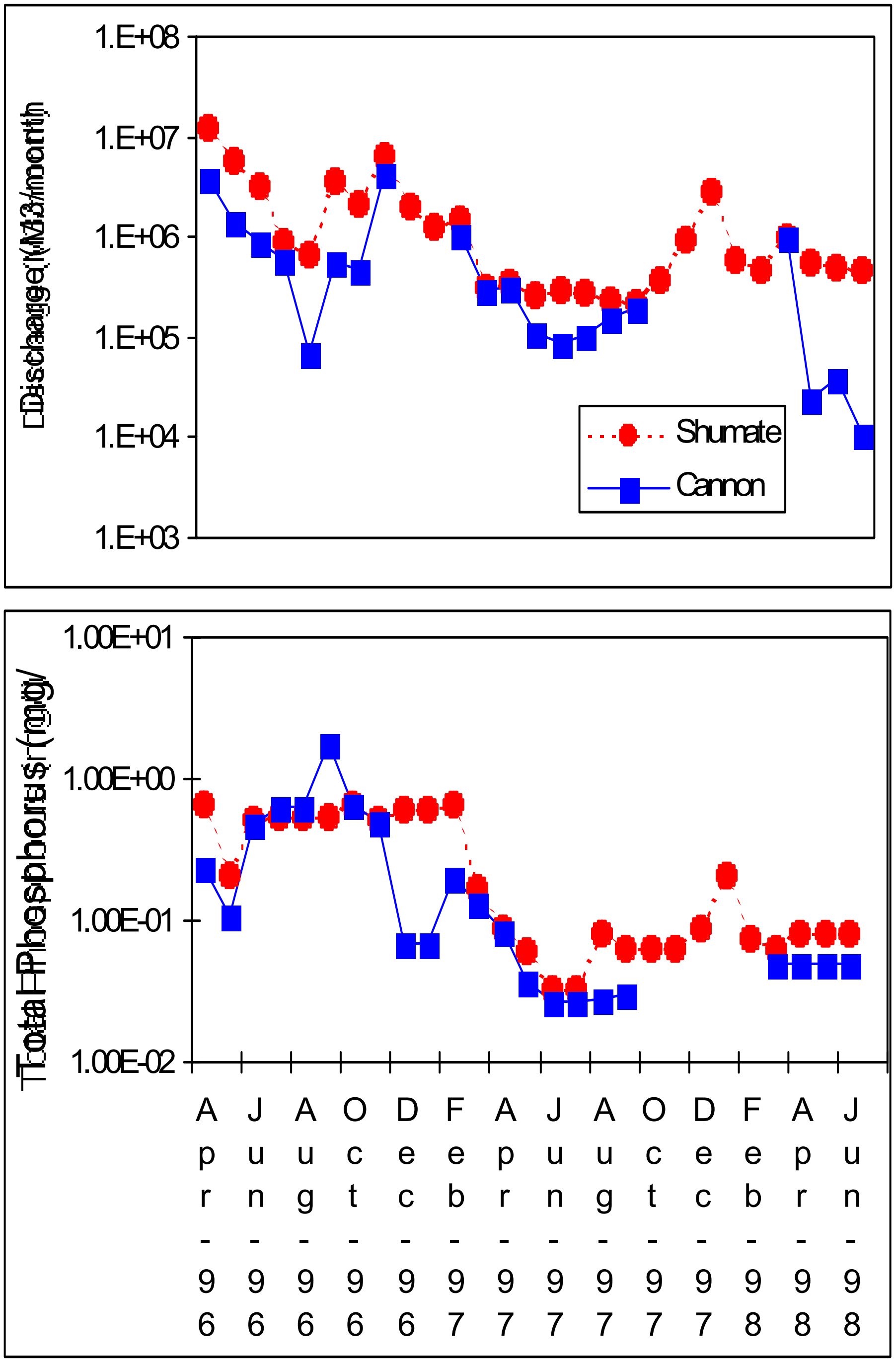

Figure 1. Monthly total flow and total phosphorus monthly flow-weighted concentrations for Cannon and Shumate creeks.

Table 1. Animal manure applications to pasture acreages in the Cannon Creek and Shumate Creek watersheds.

	Pasture Acreage (acres)	Manure (tons)	Nitrogen (tons-N)	Phosphorus (tons-P_2O_5)	
Shumate Creek	326				
1995		3338	28.5	48.8	32.6
1996		1943	16.6	28.4	19.0
1997		1741	14.9	25.5	17.0
1998		305	2.6	4.5	3.0
Four year total		7328	62.6	107.2	71.5
Cannon Creek	171				
1995		521	4.4	7.6	5.1
1996		648	5.5	9.5	6.3
1997		178	1.5	2.6	1.7
1998		0	0	0	0
Four year total		1347	11.5	19.7	13.1

Table 2. Comparison of Shumate Creek to Cannon Creek flow-weighted concentrations and discharge during base, storm and total discharge conditions for the period of the project. Bold values for total flow in the columns headed by "Cannon" and "Shumate" indicate statistically significant ($p \leq 0.10$) decreasing trends. Bold values in the "Ratio" column indicate statistically significant ($p \leq 0.10$) differences between the watersheds. There was insufficient data for storm analysis.

Parameter	Flow Type	Cannon	Shumate	Ratio of Shumate to Cannon
E. coli organisms/ 100 mL	Base	**31.4**	**99.8**	**3.18**
	Storm	28.7	1.76	6.12
	Total	**30.5**	**1.08**	**3.55**
NH_4-N mg/L	Base	0.01	0.02	**3.33**
	Storm	0.04	0.11	2.70
	Total	0.02	0.04	2.29
NO_3-N mg/L	Base	0.39	1.10	**2.85**
	Storm	0.46	1.10	2.39
	Total	0.41	0.99	**2.41**
SRP mg/L	Base	0.04	**0.10**	**2.89**
	Storm	0.07	0.16	2.23
	Total	**0.05**	**0.10**	**2.15**

TKN	Base	**0.70**	**1.36**	**1.93**
mg/L	Storm	1.50	2.24	1.49
	Total	**0.96**	**1.44**	**1.50**
TOC	Base	**5.78**	**5.75**	1.00
mg/L	Storm	7.56	7.78	1.03
	Total	**4.96**	**5.66**	1.14
TP	Base	**0.15**	**0.41**	**2.80**
mg/L	Storm	0.53	0.65	1.24
	Total	**0.27**	**0.46**	**1.70**
TSS	Base	**170**	**158**	**0.93**
mg/L	Storm	186	387	2.08
	Total	**175**	**227**	**1.29**
Discharge	Base	**10,622,335**	**50,041,549**	**4.71**
m^3/month	Storm	4,999,242	17,409,445	3.48
	Total	**15,621,577**	**32,632,105**	**2.09**