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ABSTRACT

Accelerated eutrophication of Beaver Lake in northwest Arkansas is a major environmental concern. When developing watershed-management plans to protect lake water quality, it is important that linkages among land-use activities and water quality of tributary streams be quantified. This study assessed longitudinal base-flow and storm-flow water quality at War Eagle Creek and quantified linkages between stream water quality and land-use conditions within the War Eagle Creek sub-watershed of the Beaver Lake watershed. We collected six water samples: three from base-flow conditions and three from storm-flow conditions during Spring 2002. In general, concentrations of nitrate nitrogen (NO_3-N), total N (TN), total organic carbon (TOC), conductivity, and total dissolved solids (TDS) increased as the sampling moved downstream. All stream water-quality parameters, except phosphate phosphorus (PO4-P), were significantly correlated to the ratio of agricultural-to-forest land-use (r^2 = 0.90 to 0.97). These results indicate that the ratio of agricultural-to-forest land-use within the watershed can be used to evaluate stream water quality, and that increases in this ratio may result in increased TDS, NO_3-N, TN, and TOC concentrations.

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MEET THE STUDENT-AUTHOR

Scott Dennis

I graduated in May 2002 with a major in biological engineering. I also attended high school in northwest Arkansas where baseball was a major part of my life. I planned to play baseball in college. I visited many colleges that wanted me to play for their team, however, none had a major in which I was interested. An acquaintance of mine told me about biological and agricultural engineering and immediately I knew that discipline is what I would rather focus on.

In my career as a student at the University of Arkansas, I have worked with teams in many design projects. I participated in an experiment where we built a growth chamber to test the affects of global warming. I was on a team that designed a sensor that would detect water clarity and participated in the design of an infrared switch for a feed bin in a chicken house that shuts an auger off when a bin is full in order to eradicate feed spills. I also helped develop and build a chicken controlled retractable chicken cage that allowed a chicken to determine the optimal area needed in order to reduce psychological stress.

I specialized my degree in environmental aspects, thus allowing me to research a river that not only is important to the welfare of northwest Arkansas but also is important to me. My family owns a farm through which the river flows. I enjoy nature, and I feel it is important to protect natural areas throughout the nation.

I am a member of the American Society of Agricultural Engineers (ASAE). ASAE allows me to continue my education in the newest developments and latest technologies in the agricultural industry.

INTRODUCTION

Nonpoint source (NPS) transport of nutrients, sediment, and pathogens from agriculturally dominated watersheds is a major concern in Arkansas (Edwards and Daniel, 1992; Edwards et al., 1997). There is ample evidence to suggest that row crop agriculture and excess land application of animal manure have led to surface and ground-water pollution (Edwards et al., 1996). Increasingly, watersheds are unable to utilize and degrade the high levels of inorganic fertilizers and animal manures applied to the landscape. The result is increases in noxious oxygen-consuming and sometime toxic algal blooms, deteriorations of fisheries, and general degradation of water quality (Park et al., 1994; Sharpley et al., 1994). The Arkansas 303(d) list (list of waterbodies not supporting their designated use) for 2002 includes 59 stream segments totaling 1,269 miles and five lakes totaling 17,062 acres of impairment. Nine of the stream segments, totaling 70 miles, are located on small streams dominated and impacted by point-source discharges (ADEQ, 2002).

In northwest Arkansas, concern over non-point-source (NPS) pollutants entering War Eagle Creek from the application of animal waste and inorganic fertilizers has been increasing. War Eagle Creek is a major tributary to Beaver Lake, which provides drinking water to Northwest Arkansas. The water quality of War Eagle Creek directly affects Beaver Lake, and accelerated eutrophication from nitrogen (N) and phosphorus (P) in Beaver Lake is a major concern. Thus, it is imperative that the water quality of tributary streams be assessed so that watershed management plans can be developed. The agricultural land-use in the War Eagle Creek watershed is dominated by poultry growers and beef operations; therefore, animal manure is the main source of fertilizer for these farmers. Even though animal manure is a good source of nutrients, excess land application may result in runoff losses of nutrients and lead to accelerated eutrophication of downstream waterbodies.

To develop a watershed management plan for the Beaver Lake watershed and to protect the lake water quality, the linkages among land-use activities and stream water quality must be understood. Similarly, there is a need to survey current land-use practices in the watershed so that areas contributing the majority of nutrients can be identified. Currently, data are not available to quantify the changes in base-flow and storm-flow water quality in the War Eagle Creek sub-watershed in relation to land-use conditions; however Haggard et al. (2002) observed increasing nutrient concentrations and export with increasing pasture land-use throughout the Beaver Lake watershed.

Quantification of linkages between land-use and water quality is needed to determine the sources of pollution in streams. Accurate identification of the NPS pollutants involved is also required for designing best management practices (BMPs) for stream and lake water-quality protection.

The objectives of this study were to:

a. Assess longitudinal base-flow and storm-flow water quality of War Eagle Creek at five water-quality sampling stations.
b. Quantify linkages between stream water quality and land-use in the War Eagle Creek sub-watershed.

MATERIALS AND METHODS

This study was conducted in the War Eagle Creek sub-watershed, located within the Beaver Lake watershed (Fig. 1). The total area of the War Eagle Creek sub-watershed is approximately 264 mi^2. The principal land-uses in the War Eagle Creek sub-watershed are forestry and agriculture, which cover 61% and 38% of the total watershed area, respectively. Urban land-use within the War Eagle Creek sub-watershed covers less than 1% of the area.

To quantify the effect of land-use on water quality, five water-quality sampling stations were established at War Eagle Creek. The locations of the sampling stations were based on site accessibility while keeping them as equidistant as possible. Station 1 was the most upstream station at War Eagle Creek, and Station 5 was the most downstream (Fig. 1).

Three water samples were collected during base-flow conditions at two-week intervals between February 2002 and April 2002 at each of the five sampling sites. In addition, water samples were also collected during three storm events. At each site, three filtered samples were collected by filtering 20 mL of stream water using 0.45 µm nylon membrane filter in the field. Three unfiltered water samples, each 500 mL in volume, were also collect-

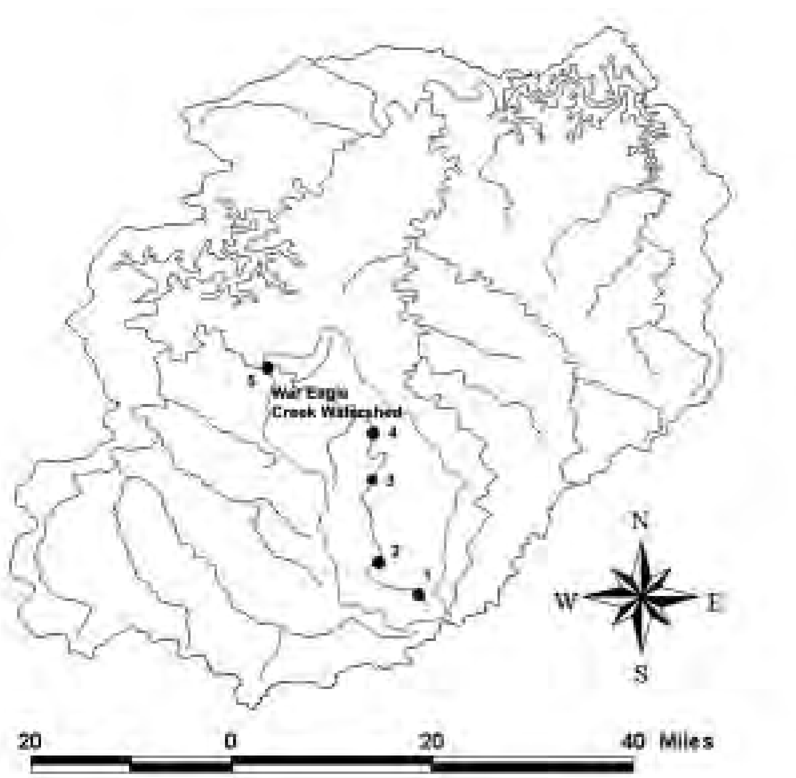

Fig. 1. Location of the War Eagle Creek sub-watershed and water-quality sampling stations within the Beaver Lake basin.

ed at each sampling station. Bottles and filtering syringes were field-washed prior to sample collection. Immediately after collection, water samples were stored on ice in the dark until returned to the laboratory. Samples were transported to the laboratory for analyses of dissolved P (PO_4-P), nitrate N (NO_3-N), total N (TN), and total organic carbon (TOC). We also measured pH at each site using a pH meter (Oktron Corporation, model pH Testr 2), and conductivity, salinity, and temperature using an YSI conductivity, salinity, and temperature meter (YSI Corporation, model YSI85).

We measured dissolved P with an autoanalyzer using ascorbic-acid reduction and NO_3-N using cadmium-copper reduction methods. Total N and TOC were measured by converting all N and organic C into nitrogen oxide (NO) and carbon dioxide (CO2) at 950°C, respectively. These gases were analyzed by infrared detection of CO2 and conversion of NO to nitrogen dioxide (NO2) and followed by NO2 decay measurement by a photo multiplier probe.

The topographic or digital elevation model (DEM) and land-use data for the War Eagle Creek sub-watershed were obtained from the Center for Advanced Spatial Technology (CAST), University of Arkansas, and analyzed using ArcView GIS. The sub-watersheds draining toward the each sampling station were delineated using DEM data and the ArcView GIS. Sub-watershed boundary for each sampling station was then intersected with the War Eagle Creek sub-watershed land-use data to calculate fraction of each land-use type within each sampling station sub-watershed (Table 1).

Table 1. Land-use and area of each sampling station sub-watershed within the War Eagle Creek sub-watershed.

Land-use	Watershed areas under different land use (mi^2)				
	Station 5	Station 4	Station 3	Station 2	Station 1
Residential	1.60	0.28	0.02	0.00	0.00
Agriculture	100.64	39.65	20.40	4.97	0.91
Forest	161.16	115.89	86.68	31.06	4.44
Other	0.22	0.16	0.14	0.05	0.00
Total area	263.62	155.98	107.24	36.09	5.35

The land-use data were used to estimate the agricultural to forest ratio within each sub-watershed. The linkages among stream water quality and land-use were determined by regressing the measured water-quality data for each sub-watershed against the ratio of agriculture to forest area within the sub-watershed.

RESULTS AND DISCUSSION

Table 2 shows the average water quality data, for three dates at each sampling station for the base and storm-flow conditions. In general, concentrations of NO_3-N, TN, TOC, conductivity, and TDS increased as sampling moved downstream in the sub-watershed, during both base-flow and storm-flow conditions. The only exception to this trend was PO_4-P concentration, which decreased at sampling Stations 3 and 4 during base-flow and was highly variable during storm-flow conditions. The variability in PO_4-P during storm-flow conditions may be attributed to transport of particulate matter, which may adsorb PO_4-P during the transport process.

Stream pH did not change significantly among sampling stations. Temperature data are difficult to compare for this study because they are a function of the time of the day and degree of shading by riparian vegetation. Since temperature at all the sampling stations was not collected during the same time of the day, it is difficult to infer trends from upstream to downstream locations.

When we compared the water-quality data during base-flow and storm-flow conditions at each sampling station, the data indicated that concentrations of NO_3-N, TN, and TOC were higher during storm-flow conditions (Table 2). The PO_4-P concentrations were higher during storm-flow conditions at sampling Stations 1, 2, and 3, and lower at Stations 4 and 5. Concentration of TDS was higher during base-flow conditions at Stations 1 and 2. Conductivity values were lower during storm-flow conditions at all the sampling stations except Station 4. This may have been due to dilution of stream conductivity/TDS concentrations during storm-flow conditions.

Total flow of nutrients is a function of concentration and flow volume. Flow volume is always larger during storm-flow events. A higher concentration during storm-flow conditions indicates that a significantly larger amount of nutrients may be transported downstream in War Eagle Creek, eventually entering Beaver Lake during rainfall events.

Table 2. Average data collected from War Eagle Creek. There were 3 storm-flow and 3 base-flow sampling events.

Parameter	Station 1	Station 2	Station 3	Station 4	Station 5
Storm-flow condition					
pH 8.2	8.2	8.2	8.4	8.2	
Temp (°C)	12.1	11.4	9.1	8.1	8.6
Conductivity(mS/cm)	30.3	43.0	70.6	100.2	130.5
TDS (mg/L)	13.7	19.7	32.0	47.3	64.3
NO_3-N (mg/L)	0.23	0.35	0.64	1.02	1.52
TN (mg/L)	0.31	0.41	0.66	1.08	1.33
PO_4-P (mg/L)	0.020	0.036	0.009	0.009	0.033
TOC (mg/L)	1.04	1.13	0.95	1.35	1.76
Base-flow condition					
pH 8.5	8.2	8.2	8.3	8.2	
Temp (°C)	12.8	12.4	11.4	11.0	11.8
Conductivity(mS/cm)	45.9	53.1	63.9	94.7	159
TDS (mg/L)	19.0	23.3	28.3	35.0	59.0
NO_3-N (mg/L)	0.21	0.25	0.34	0.44	1.06
TN (mg/L)	0.26	0.25	0.36	0.39	0.89
PO_4-P (mg/L)	0.007	0.029	0.007	0.024	0.048
TOC (mg/L)	0.58	0.58	0.88	1.10	1.39

To quantify the linkages between land-use and stream water quality, a linear regression was performed between agriculture-to-forest-area ratio and stream water-quality concentration for each sampling station. Agriculture-to-forest-area ratio gives an indication of the dominance of agricultural land-use in the watershed with regard to the degree of watershed development. The ratio ranged from 0.16 (Station 2) to 0.62 (Station 5). In general, as the sub-watershed area increased, the dominance of agricultural land-use also increased. Concentration of stream water-quality parameters as a function of agriculture-to-forest-area ratio for each sampling station is shown in Fig. 2. An increase in the agriculture-to-forest-area ratio resulted in increased concentrations of NO_3-N, TN, TDS, and TOC.

The linear regression showed that all stream water quality parameters, except PO_4-P, were significantly related to agriculture-to-forest-area ratio within the sub-watershed (Table 3). The coefficient of determination (r^2) values ranged from 0.90 – 0.97 and were highly significant ($p < 0.01$). Only 33% of the variability in the stream PO_4-P concentration could be accounted for by the ratio of agriculture-to-forest-area, which was not significant ($p = 0.31$). This was contrary to the expected role of agricultural land-use in controlling stream PO_4-P concentrations; however, annual mean PO_4-P concentrations have shown an increasing relationship with pasture land-use across the entire Beaver Lake watershed (Haggard et al., 2002). More data need to be collected in this watershed to further verify this relationship.

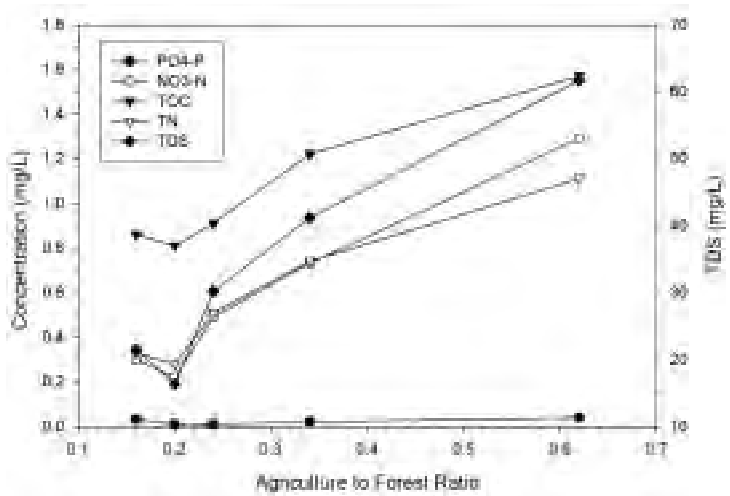

Fig. 2. Concentration of stream water-quality parameters as a function of agriculture-to-forest-area ratio in the sub-watershed.

Table 3. Linear regression results to predict War Eagle Creek water quality as a function of agriculture-to-forest-area ratio.

Water quality parameter	Regression equation[1]	R^2	P
NO_3-N (mg/L)	Y = 2.292 X - 0.109	0.97	< 0.01
TN (mg/L)	Y = 1.801 X + 0.032	0.95	< 0.01
TDS (mg/L)	Y = 94.36 X + 4.72	0.90	< 0.01
TOC (mg/L)	Y = 1.696 X + 0.546	0.95	< 0.01
PO_4-P (mg/L)	Y = 0.044 X + 0.009	0.33	0.31

1 Y = stream water quality (e.g. NO_3-N concentration); X = agriculture-to-forest-area ratio

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