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Watershed-scale agricultural land-use impact on instream physicochemical parameters

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ABSTRACT

Nonpoint source (NPS) pollution is often the result of runoff losses from agricultural or urban areas. Even though the watershed approach to controlling NPS pollution is identified as the most efficient approach, data linking watershed scale land use and specific water quality implications are very limited. The objective of this study was to quantify the impact of agricultural land use on stream physico-chemical properties. The upper reach of Flint Creek was monitored at two sampling points draining an agricultural land. At each of these points, continuous measurement of stream characteristics such as temperature, dissolved oxygen (DO) concentration, depth, pH, and conductivity were taken at three different dates. Also, water samples were collected and analyzed for nitrogen (N) and phosphorus (P) concentrations to discern the impact of agricultural land use on water quality. The results indicated that nitrate N (NO_3-N) and phosphate P (PO_4-P) concentrations increased as the agricultural land use increased in the watershed. Fluctuation in the DO concentration also increased with higher agricultural land use. In order to help decrease the amount of nutrients introduced to the stream, a variety of best management practices (BMPs) could be implemented in the watershed.

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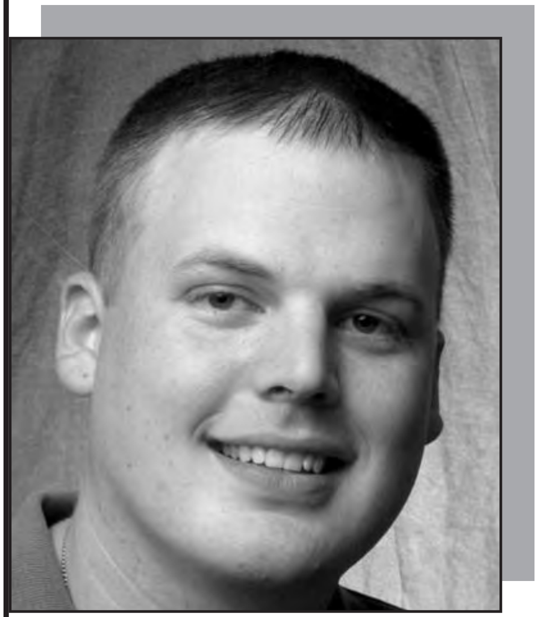
INTRODUCTION

Nonpoint source (NPS) pollution occurs when rainfall, snowmelt, or irrigation runs across land, picking up pollutants before entering a lake, stream, or river, carrying the pollutants to these water bodies (EPA, 1996). NPS pollution has emerged as the single largest source of pollution in the U.S., impairing 40% of assessed water bodies, 500,000 km of rivers and streams, and more than two million ha of lakes (Ritter and Shirmohammadi, 2001). A wide range of activities can result in NPS pollution, including: agriculture, forestry, septic systems, boating, construction, and urban runoff. Of these, however, agriculture is the primary source of impairment for rivers and lakes and third largest source of imapirment to estuaries. Agriculture is also identified as a major contributor to groundwater contamination and wetland degradation (EPA, 1996).

Some agricultural practices that can result in NPS pollution include: confined animal facilities, grazing, plowing, fertilization, planting, and harvesting (EPA, 1996). Sediment, nutrients, pathogens, and pesticides are principal pollutants resulting from these agricultural practices. Agricultural runoff can result in elevated nitrogen (N) and phosphorous (P) concentrations and can promote algal growth in lakes and streams, resulting in an increase in the microbial populations, and an increased oxygen demand by the photosynthetic organisms during the nighttime (Daniel et al., 1996). With this increased oxygen demand, there are lowered dissolved oxygen (DO) concentrations available to fish and other aquatic organisms. If these DO levels drop too low, fish kills can result, or at extremely low levels, anaerobic bacteria will begin the breakdown process, replacing the aerobic bacteria.

The EPA has identified the watershed approach as one of the most efficient ways to control NPS pollution. The watershed approach focuses within hydrologically defined geographic areas, taking into consideration both ground and surface water flow (EPA 1996). However, there is a need to understand the effect of land use on streamwater quality at a watershed scale before an effective NPS pollution control program can be designed. The objective of this research was to quantify linkages between agricultural land use, oxygen demand, and stream nutrient concentrations. This was accomplished by taking water quality measurements at two points along the same stream dominated by agricultural land use. By showing the linkages between agricultural land use and water quality, an effective watershed manage-

MEET THE STUDENT-AUTHOR



William H. Dillahunty

I graduated from Gentry High School in 1998. I then came to the University of Arkansas where I graduated in May 2003 with a B.S. degree in biological engineering as well as a minor in mathematics. I was raised on a dairy farm and still help out with all of the daily chores that keep it running. The stream that I chose for this research project passes through part of our farm.

I am a member of the American Society of Agricultural Engineers (ASAE). My team entered our senior design project in the AGCO National Student Design Competition in summer 2003 and was awarded first place for our Growth Chamber for Bio-Regenerative Life Support. This was a plant-growth chamber that researchers at NASA can use to simulate the atmospheric conditions on Mars. They can use it to find out how well plants will grow in a greenhouse there on future missions.

I am now pursuing a master's degree in biological engineering, during which I will be testing a furnace that can possibly be used to heat chicken houses. It will actually burn the chicken litter that has been removed from the houses for its fuel source. This may help with some of the problems that poultry farmers are facing.

ment plan to protect stream water quality can be developed.

MATERIALS AND METHODS

This study was conducted on the north fork of Flint Creek, located in Benton County, Ark. Arkansas Department of Environment Quality (ADEQ, 2002) has established water quality standards for streams within various ecoregions in Arkansas. This site lies within the Ozark Highlands Ecoregion (Table 1). All measured water-quality parameters at the two sites were within the acceptable levels set by the ADEQ.

Table 1. Acceptable levels for Ozark Highlands Ecoregion (ADEQ, 2002).

Parameter	Ecoregion Standard
Temperature	29°C
Dissolved O_2, <10 sq. mi.	Primary: 6 mg/L Critical: 2 mg/L
pH	6-9
NH_4-N	12.1 mg/L
NO_3-N	10 mg/L (drinking water)

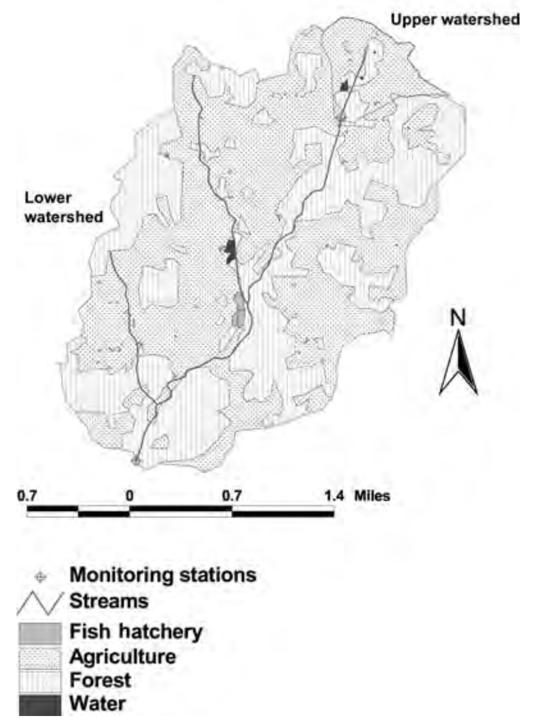


Fig. 1. Locations of sampling sites and land-use distribution within the watersheds.

The upstream sampling location was just below a pond at the source where the stream originates, while the second sampling site was located approximately 5.6 km downstream. The land use within each of the watersheds is predominantly agriculture.

The watersheds draining to the first and second sampling sites are named as the upper watershed and lower watershed, respectively. Location of the two watersheds, stream network, and locations of poultry and fish production facilities are shown in Fig. 1. Table 2 lists the watershed characteristics. The upper watershed contains 6.2% of the total watershed area.

ArcView GIS was used to delineate the watershed boundaries and to quantify watershed characteristics. GIS maps needed for the watershed included: the digital elevation map (DEM), land use map, stream network, road network, and the locations of fish and poultry production facilities. These maps were obtained from the Center for Advanced Spatial Technologies (CAST) at the University of Arkansas.

Water quality data were collected three different times during March and April 2003. Water quality sampling on 24 Mar. 2003 and 30 Mar. 2003 was under base flow condition and under storm flow condition on 19 Apr. 2003. YSI 600XLM data sondes were used to take measurements at 1 min. intervals for 24 h for dissolved oxygen, specific conductivity, pH, temperature, and water depth.

On each sampling date, two 20-mL water samples were collected at each site: one unfiltered, and one filtered using a 0.45 µm nylon-membrane filter. The filtering syringes were field-washed prior to sample collection. Immediately after collection, the samples were cooled, stored in the dark, and transported immediately to the laboratory for analysis of dissolved phosphorus (PO_4-P), nitrate nitrogen (NO_3-N), and ammonia nitrogen (NH_4-N).

Dissolved P was measured with an autoanalyzer using ascorbic-acid reduction, and total nitrate by cadmium-copper reduction method (APHA, 1999).

RESULTS AND DISCUSSION

Average physicochemical data collected at the two sites are shown in Table 3. Depth and flow rate increased significantly, while specific conductivity decreased at the lower watershed sampling site. The decrease in specific conductivity could be attributed to dilution and the increased flow. Average temperature and pH were similar at the two sampling sites.

Table 2. Land use within watersheds

Land Use:	Upper		Lower	
	Area (ha)	Fraction	Area (ha)	Fraction
Water	0.8	0.9%	2.8	0.2%
Forest	19.8	22.6%	586.1	41.6%
Field/Pasture	67.0	76.5%	821.1	58.2%
Total	87.6	100.0%	1410.0	100.0%

The temperature difference between the two sites was most likely caused by an increase in shading at the lower sample site due to a hillside near the stream, as well as increased tree canopy cover. Another factor that could be responsible for some of the difference in temperature is the stream depth. The stream flow depth was shallower at the upper site and had a lower flow rate, allowing a greater fluctuation in the diurnal stream temperature (Table 3). The temperature at the upper sampling site changed more rapidly than the lower site, throughout the day on 30 Mar. 2003 (Fig. 2). The specific conductivity of the water could be greatly affected by the differences in stream flow rates. With two other branches entering between the two sampling sites (Fig. 1), the water was diluted much more at the lower sampling site.

The increases in both nitrate and phosphate levels (Table 3) could be due to a variety of reasons but were most likely due to over-fertilization from the poultry houses within the watershed, or from stock cattle that were on many of the fields. Although an increase is noted in each of these levels, they are still well below the levels set by ADEQ to meet drinking water standards (Table 1).

Fig. 3 shows the dissolved oxygen (DO) concentrations over a 24-h period on 30 Mar. 2003. While the average DO concentrations were very similar for the two watersheds, Figure 3 shows the difference in diurnal cycle of DO, likely resulting from the presence of photosynthetic organisms. During the daytime, these organisms produce oxygen as a byproduct of photosynthesis, resulting in higher peak DO concentrations. During the nighttime hours, however, they consume oxygen, and cause greater instream DO depletion. The increase in nutrient concentrations present at the downstream site allows for greater algal growth and has a noticeable influence on the DO concentration cycle within the stream.

To help alleviate some of these problems, the use of commercial fertilizers may be more practical, where only the needed nutrients would be applied to the fields. With the majority of the pasture in this area being used for stock cattle, overgrazing may be another reason behind increased NPS pollution at the lower watershed. The careful use of commercial fertilizers and rotational grazing could help alleviate these problems. Other BMPs such as vegetative filter strips, removal of selected nutrients from the watershed, and chemical amendment of soils fertilized with animal manure could also be implemented to improve stream water quality.

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Table 3. Physicochemical water-quality data for the study sites.

			Averages (std. dev.)							
Sample	Date	Watershed	Depth (m)	pH	Temp (°C)	DO (mg/L)	Sp. cond. (µs/cm)	Ammonia (mg/L)	Nitrate (mg/L)	Phosphate (mg/L)
1	3/24/03	Upper	0.14 (0.01)	7.5 (0.02)	15.8 (3.20)	9.3 (0.82)	1081 (3.8)	0.020	0.610	0.057
		Lower	0.31 (0.01)	7.6 (0.17)	15.2 (1.88)	9.0 (1.89)	224 (1.64)	0.036	3.390	0.090
2	3/30/03	Upper	0.28 (0.02)	7.6 (0.02)	9.8 (3.22)	10.6 (0.46)	1238 (14.6)	0.016	0.511	0.003
		Lower	0.47 (0.02)	7.7 (0.14)	9.5 (1.95)	10.9 (1.63)	223 (3.87)	0.012	2.865	0.013
3	4/19/03	Upper	0.10 (0.03)	6.9 (0.03)	15.5 (1.23)	6.1 (0.37)	306 (3.53)	0.050	0.420	0.001
		Lower	0.33 (0.03)	7.3 (0.11)	15.4 (0.78)	7.3 (1.41)	230 (3.71)	0.050	1.310	0.003

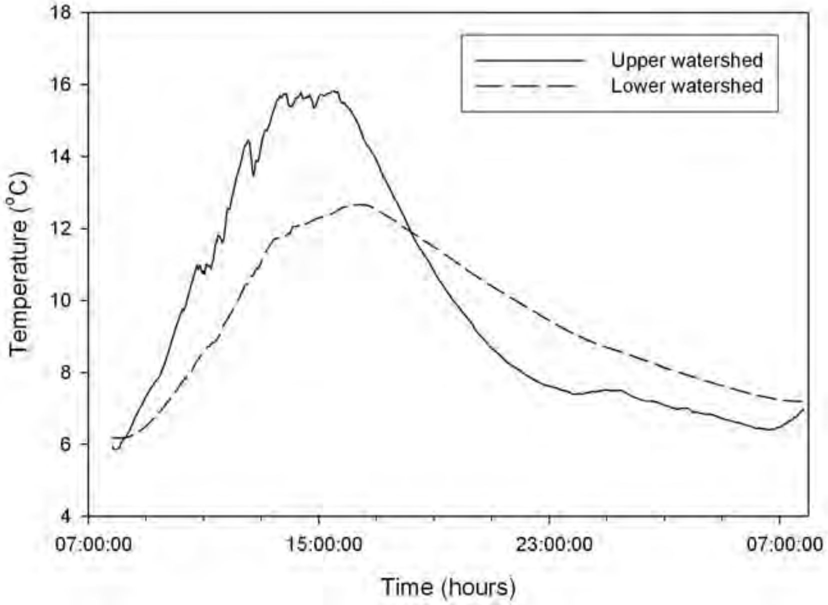

Fig. 2. Temperatures occurring during the 24-h period of sample 2.

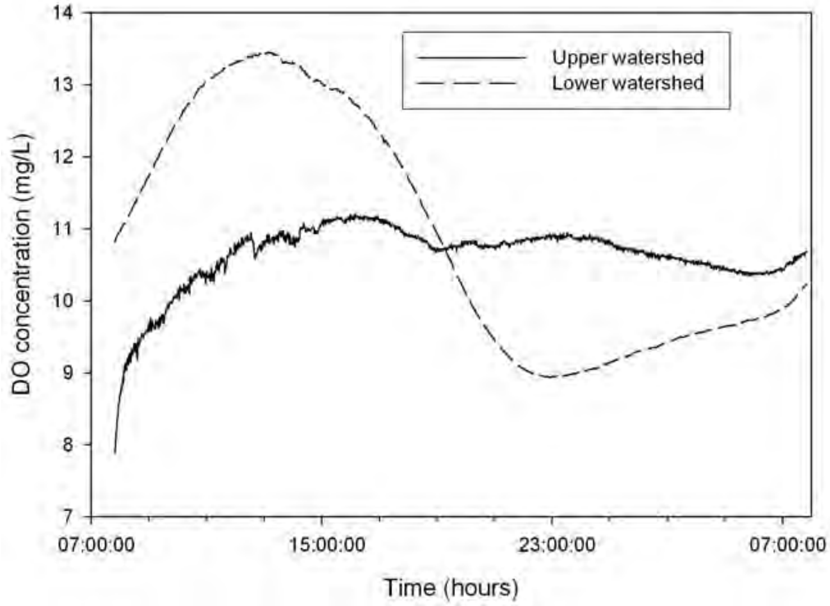

Fig. 3. Dissolved oxygen concentrations measured during the 24-h period of sample 2.