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ABSTRACT

With the growing concern about elevated phosphorus (P) concentrations in regional lakes, rivers, and streams, it is essential to investigate factors contributing to P transport from the landscape. Phosphorus fluxes from nonpoint sources, particularly land applications of poultry litter and other animal manures, are closely related to the amount and production of surface runoff. Daily stream discharge and the software program, Base Flow Index (BFI), were used to estimate the amount and temporal patterns of surface runoff at different locations within the Illinois River Basin, including selected tributaries in northwest Arkansas and northeast Oklahoma. Daily streamflow data from nine U.S. Geological Survey discharge stations were imported into the BFI program to estimate base flow, where surface runoff was the difference between total streamflow and base flow. Surface runoff was found to be greatest during spring and winter (November-June), and least during the summer and early fall (July-October). Land on which poultry litter and other animal manures are applied during the summer and early fall when runoff is less could pose less risk of P transport, likely helping to minimize nonpoint source P loads introduced into the Illinois River.

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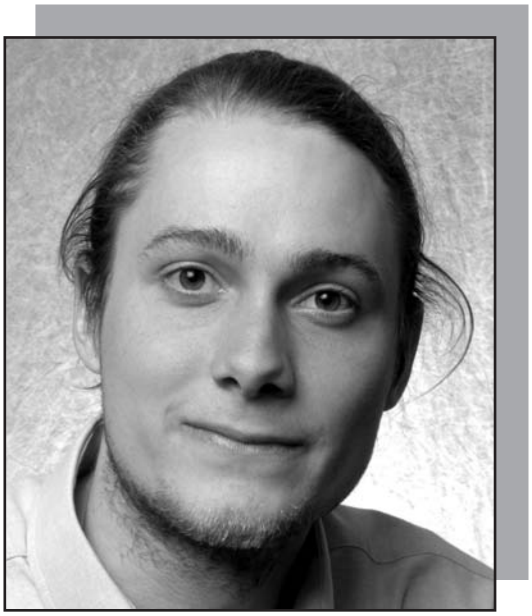

Adam T. McClymont

I am from Ferndale, Ark., and graduated from the Arkansas School for Mathematics, Sciences, and the Arts in 2002. I am majoring in environmental, soil, and water sciences, and will graduate in 2006. During my career at the University of Arkansas I worked for two years in cotton physiology under Dr. Derrick Oosterhuis, and in fall 2004 studied at the Scottish Agricultural College, Edinburgh. After returning in spring 2005 I began working under Dr. Mary Savin in soil microbiology and ecology. My interest in the outdoors led not only to a passion for northwest Arkansas, but also to an internship with the Rocky Mountain Field Institute during summer 2005.

About that time I became interested in the project presented in this paper through conversations with Drs. Tommy Daniel and Brian Haggard. Since then I have also begun work on antibiotic resistance in local streams under Dr. Savin and am excited about continuing this research as a graduate student at the University of Arkansas. I would like to thank those mentioned above for their support and encouragement of my academic career and interests.

INTRODUCTION

Nonpoint source (NPS) pollution has been identified as a major source of phosphorus (P) loading in waterways. NPS pollution contributes more than 80% of P loads to surface waters in the United States (Carpenter et al., 1998). Agriculture and confined animal feeding operations are an important component of NPS pollution because of the practice of land applying fertilizers, poultry litter, and other animal manures. Long-term applications of fertilizers and manures can lead to the build-up of P near the soil surface and can increase the potential for P to be transported from the land surface into waterways (Kingery et al., 1994).

Algal blooms are often a consequence of excessive P loading to waterways and can have several negative effects. The excessive growth and subsequent decomposition of dead algae results in anoxic conditions, which damage the health of freshwater ecosystems (Carpenter et al., 1998). Drinking-water supplies are degraded from the release of secondary compounds (e.g. geosmin, 2-methylisoborneol) from excessive algal production that are difficult and expensive to remove in drinking-water treatment facilities and result in an unpleasant odor and taste in finished drinking water (Smith, 1998; Wnorowski, 1992). The aesthetic problem of taste and odor in drinking water has resulted in lawsuits over elevated P loading from the landscape into drinking water-supply reservoirs.

The amount of NPS-P loading is strongly related to the amount of surface runoff that occurs from a given area. In order to minimize NPS-P loading it is necessary to plan land applications of fertilizers and manures during times when the risk of runoff is lowest. Surface runoff occurs when the amount of precipitation exceeds the amount of water infiltrating the soil, such as during rainfall events of high intensity. Rainfall events that are long or frequent increase the potential for runoff due to soils becoming saturated with water. Land surfaces with higher slope, higher amounts of disturbance, less vegetation, and less permeable surface area have an increased potential for surface runoff (Brady and Weil, 2002).

The objective of this study was to determine the amount of surface runoff that occurs within a month using actual streamflow data from the Illinois River Basin and hydrograph separation techniques. These estimated surface-runoff data were used to determine months of high and low surface-runoff production in the Illinois River Basin. The Illinois River Basin is a trans-boundary watershed situated in northwest Arkansas and northeast Oklahoma that has been the focus of environmental, scientific, and political debates since the early 1990s. This basin contains a large number of poultry and cattle operations where poultry litters are land-applied to fertilize pastures and haylands. This study provides surface-runoff data that will be used to guide poultry litter application in the Illinois River Basin and to define application-timing factors for use in a P index that manages land applications of P. It was hypothesized that monthly runoff estimates will display a unique temporal pattern in the Illinois River Basin, similar to that observed in the Eucha-Spavinaw Basin (DeLaune et al., 2006).

MATERIALS AND METHODS

Sub-basins of the Illinois River (Table 1) were chosen based on the availability of at least 10 years of daily streamflow data available from the National Water Information Systems (NWIS) database of the U.S. Geological Survey (USGS) Arkansas Water Resources (USGS, 2005). Sufficient data were available from nine sites located in the Illinois River basin in northwest Arkansas, including the Illinois River at Savoy, Osage Creek near Cave Springs, Osage Creek near Elm Springs, the Illinois River at Hwy. 16, the Illinois River south of Siloam Springs, Flint Creek at Springtown, Baron Fork at Dutch Mills; and in northeast Oklahoma, including Flint Creek near west Siloam Springs, and Lee Creek near Short. Daily streamflow was downloaded from the on-line NWIS database for these sites and used to determine the daily estimates of base-flow discharge and surface-runoff discharge. Daily streamflow was separated into base-flow and surface-runoff discharge using the Base Flow Index (BFI) program (Wahl and Wahl, 1995), instead of manual hydrograph separation. The BFI is a computer program developed by Wahl and Wahl (1995) for separating base flow from total streamflow using hydrographs, which chart streamflow over time.

The BFI operates on a partition length (N) and turning point test factor (F). The program divides the hydrograph into N-day periods (based on partition lengths), and within each N-day period, minimum flows (Q, $m^3 s^{-1}$) are determined. A partition length (N) of 5 and a turning point test factor (F) of 0.5 were used in this study. These values were based on program defaults and the turning point test factor (F) previously used in streamflow analysis and hydrograph separation in the Eucha/Spavinaw Basin (DeLaune et al., 2006). A minimum flow (Q_1) is defined as a turning point if, when multiplied by the turning point test factor (F), it is less than both the preceding (Q_0) and subsequent (Q_2) minimum flows (Q_1 is a turning point if $Q_1 * F \leq Q_0$ and $Q_1 *$ F $\leq Q_2$). Straight lines are drawn between turning points on the hydrograph and the area below those lines is estimated as base flow; surface runoff is the difference between total flow and base flow.

Daily surface-runoff discharge was calculated for each day using the difference between total streamflow and estimated base flow from BFI. Daily estimates of surface-runoff discharge were averaged within a month, and then these monthly averages were averaged for all available years. Average monthly surface-runoff values were multiplied by the days within a month (i.e., time) to calculate the surface-runoff volume (ft^3) and then divided by catchment area to calculate runoff depth (ft). Runoff depth (ft) was converted to runoff depth (cm) using unit conversion. Average annual rainfall measured for Benton County, Ark. was obtained online (NOAA, 2005) and used to calculate the percentage of rainfall estimated as surface runoff.

RESULTS AND DISCUSSION

Average surface-runoff depth ranged between 9.5 and 28.2 cm annually for the nine sites evaluated in this study (Table 2). The average amount of surface runoff for all nine sub-basins within the Illinois River Basin was approximately 14% of average annual rainfall measured for Benton County, Ark. (NOAA, 2005; Table 3). There was variability in annual average surface runoff among different sub-basins (Table 2). Basin area was taken into consideration since data were presented as runoff depths. However, basin area was investigated as a factor in inter-basin variability, but no relationship was found. Simple linear regression of runoff depth as a function of basin area did not have a slope value significantly different from zero and basin area did not explain a significant amount of the variation in runoff depth, i.e. R-squared was approximately zero (data not shown). The variability among sub-basins may be attributed to factors not considered in this study, such as vegetative characteristics and catchment slope, which have been shown to influence surface-runoff depths (Dodds, 1997).

Average monthly surface-runoff values ranged between 0.1 and 4.3 cm at the selected sites within the Illinois River Basin (Table 2). On average, the highest amounts of surface runoff occurred from winter through spring (November-June), and the lowest amounts of surface runoff occurred from summer through early fall (July-October; Table 2; Fig. 1). For example, average monthly surface-runoff depth ranged from 1.1 to 4.3 cm across all nine sub-basins in May, whereas surface-runoff depth ranged from 0.2 to 0.5 cm across all nine sub-basins in August (Table 2). These data show the contrasting amounts of surface runoff that occur during these time periods. Estimated monthly surface-runoff depth as a fraction of average monthly rainfall near Fayetteville, Ark. ranged from 3.6 - 23.4%

(Table 3), where the lower percentages occurred from summer through early fall (July-October).

Some sub-basins of the Illinois River Basin had lower depths of surface runoff than those observed in the Eucha-Spavinaw Basin, while other sub-basins of the Illinois River Basin had higher amounts of surface runoff than observed in the Eucha-Spavinaw Basin. The annual average surface-runoff depth at the Eucha-Spavinaw Basin was 11.9 cm (DeLaune et al., 2006), while the sub-basins of the Illinois River Basin ranged from 9.5 to 28.2 cm (Table 2). DeLaune et al. (2006) used historical streamflow data from one site in the Eucha-Spavinaw Basin and if surface-runoff depth was estimated at more sites, then spatial variations in surface-runoff depth similar to that observed in the Illinois River Basin would most likely be found. Although surface-runoff depths varied spatially throughout the Illinois River Basin, the temporal pattern of surface-runoff depth was very similar across all nine sub-basins and even the Eucha-Spavinaw Basin.

The variations in monthly surface-runoff depth found in this study of the Illinois River Basin are important for determining when to land-apply poultry litter in order to reduce the risk of NPS-P loading into waterways. Because lower depths of surface runoff occur from July through October, this time frame would represent the time frame with the least risk of P transport in surface runoff and thus is preferable for land applications of poultry litter. The typical practice of land-applying poultry litter occurs in the spring for forage management, but this practice involves applying poultry litter during times of increased surface runoff and thus greater risk of phosphorus transport from the landscape. The use of actual streamflow data over an extended period of time with consistent hydrograph-separation techniques was essential to estimate surface-runoff depth and to determine the temporal patterns of surface runoff in the Illinois River Basin.

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Table 1. U.S. Geological Survey (USGS) descriptive information about selected sites in the Illinois River Basin, Arkansas and Oklahoma, including USGS station number, sub-basin name, county, state, latitude, longitude, drainage area of sub-basin (km2), and period of record.

USGS #	Name	County	State	Latitude	Longitude	Area (km^2)	Period of record
07194800	Illinois River at Savoy	Washington	AR	36°06'11"	94°20'39"	433	1979-2004
07194880	Osage Creek near Cave Springs	Benton	AR	36°16'53"	94°13'40"	90	1990-2004
07195000	Osage Creek near Elm Springs	Benton	AR	36°13'19.45"	94°17'11.69"	337	1950-2004
07195400	Illinois River Hwy 16	Benton	AR	36°08'40.97"	36°08'40.97"	1319	1979-2004
07195430	Illinois River South of Siloam Springs	Benton	AR	36°06'33.32"	94°32'04.3"	1490	1995-2004
07195800	Flint Creek at Springtown	Benton	AR	36°15'19.73"	94°26'02.19"	37	1961-2004
07195855	Flint Creek near west Siloam Springs	Delaware	OK	36°12'58"	94°36'15"	155	1979-2004
07196900	Baron Fork at Dutch Mills	Washington	AR	35°52'48"	94°29'11"	105	1958-2004
07249985	Lee Creek near Short	Sequoyah	OK	35°31'09"	94°27'58"	1088	1930-2004

Table 2. Average monthly surface-runoff depth (cm) and annual total surface-runoff depth (cm) as calculated using USGS daily streamflow data and hydrograph separation using the Base Flow Index software program at selected sites in the Illinois River Basin, Arkansas and Oklahoma.

USGS #	Name	County	State	Latitude	Longitude	(km^2)	
07194800	Illinois River at Savoy	Washington	AR	36°06'11"	94°20'39"	433	1979-2004
07194880	Osage Creek near Cave Springs	Benton	AR	36°16'53"	94°13'40"	90	1990-2004
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07249985	Lee Creek near Short	Sequoyah	OK	35°31'09"	94°27'58"	1088	1930-2004

Table 3. Average monthly and annual rainfall (cm) as measured in Benton County, Ark., and the percentage of rainfall estimated as average monthly and annual surface runoff.

Month	Average rainfall (cm)	% of rainfall estimated as surface runoff
January	5.7	19.8
February	6.4	23.4
March	11.2	17.1
April	10.6	22.8
May	13.3	16.1
June	13.2	13.6
July	8.1	11.5
August	8.5	3.6
September	12.0	5.7
October	9.1	8.5
November	12.2	14.6
December	8.9	18.1
Annual	119.2	14.2

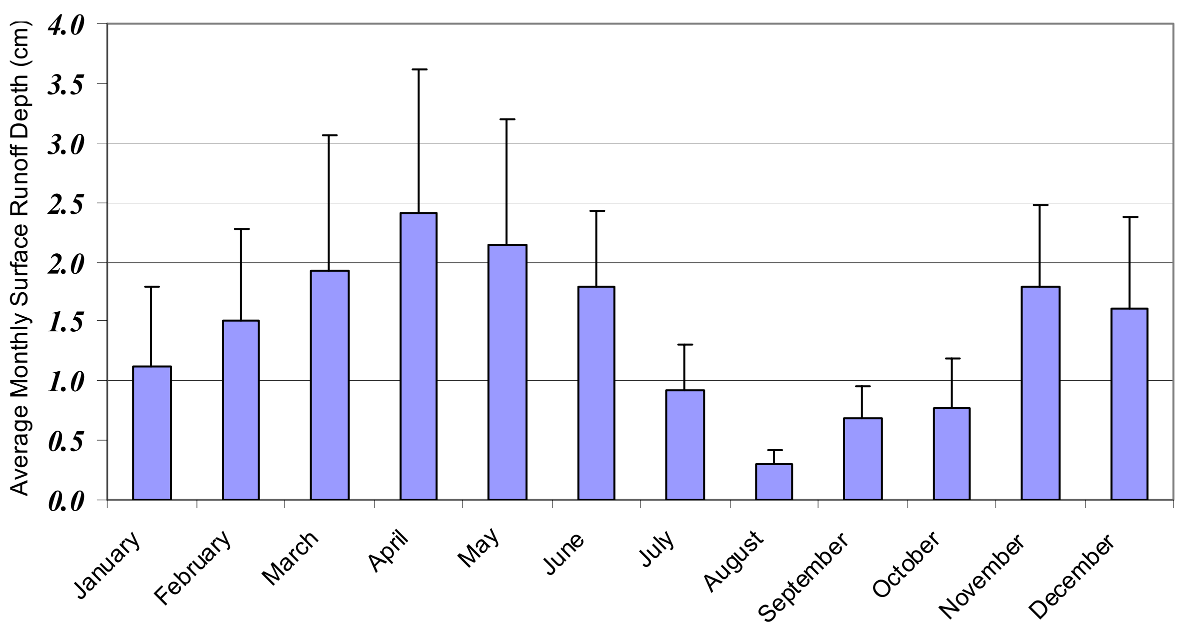

Fig. 1. Average monthly surface-runoff depth (cm) and standard error as calculated using daily streamflow data and hydrograph separation using the Base Flow Index software program for nine sub-basins within the Illinois River Basin, Arkansas and Oklahoma.