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EFFECT OF BMP IMPLEMENTATION ON STORM FLOW QUALITY OF TWO NORTHWESTERN ARKANSAS STREAMS

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ABSTRACT. *The effectiveness of management practices in improving quality of runoff from agricultural land areas has been reported based primarily on results from plot- and field-scale studies. There is limited information available on watershed scales, particularly when the dominant agricultural land use is pasture. The objective of this study was to determine whether a program of Best Management Practice (BMP) implementation in the Lincoln Lake watershed of northwestern Arkansas was effective in reducing storm stream flow concentrations and mass transport of nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN), ortho-phosphorus (PO_4-P), total phosphorus (TP), chemical oxygen demand (COD), and total suspended solids (TSS). Storm flow quality of the two main tributaries to Lincoln Lake was monitored from September 1991 to April 1994. Significant decreases (from 23 to 75% per year) in both concentrations and mass transport of NO_3-N, NH_3-N, TKN, and COD occurred concurrently with BMP implementation. The decreases in nitrogen and COD concentrations and mass transport are attributed to BMP implementation, and the BMP most responsible for these decreases is most likely nutrient management.* ***Keywords.*** *Water quality, Nonpoint source pollution, Best management practices.*

Agricultural activities such as row crop production (e.g., Baker and Laflen, 1982) and animal manure application (e.g., McLeod and Hegg, 1984; Pote et al., 1994) have been demonstrated to increase runoff concentrations of pollutants such as nitrogen (N), phosphorus (P), organic matter, sediment, and/or bacteria relative to ambient levels. Excessive inputs of such pollutants to downstream waters can accelerate eutrophication (see, for example, Sharpley et al., 1994) and, under severe circumstances, even pose a health hazard to animals and humans.

A significant amount of research has been devoted to the goal of identifying management options that minimize transport of pollutants from agricultural land areas, consistent with practical and economic considerations. Examples of such management options that have been developed, tested and implemented include no-till (Mueller et al., 1984) and grassed buffer zones (e.g., Dillaha et al., 1989). Effective management options that meet criteria similar to those defined by Bailey and Waddell (1979) may be designated by government agencies as "Best Management Practices" (BMPs). Cost sharing is sometimes available from government agencies to agricultural producers who voluntarily implement BMPs.

While BMPs have the potential for reducing pollutant losses from agricultural land areas, it is a challenge to estimate, before its implementation, the impact of a particular BMP if it is applied under conditions other than those under which it was developed and tested. It is even more difficult still to predict the integrated effects of implementing many BMPs at different locations within a watershed of thousands of hectares. The uncertainty regarding water quality effects of BMP implementation under untested conditions and watershed scales has been noted by Park et al. (1994) and Walker (1994).

Data on how BMP implementation on the watershed scale affects water quality is necessary in several regards. If public funds are being used to share costs of BMP implementation, then the water quality effects of BMP implementation should be assessed to determine whether any measurable benefit is occurring. Such data could similarly be used to help form judgments on whether the costs of BMP implementation are justified by the water quality benefits. Information on water quality effects of BMP implementation can also be used to improve mathematical models, so that they are better tools for accurately predicting the effects of BMP implementation. Output from reliable simulation models could then be used as a substitute for observed data in economic and other analyses.

Few studies on BMP effectiveness on watershed scales have been reported. Park et al. (1994) monitored a 1464 ha watershed, in which the primary agricultural activities were row crop production, in eastern Virginia both before and after implementing no-till, critical area treatment, and some structural BMPs. The BMPs were reported to reduce N and P concentrations in stream samples by 20 and 40%, respectively. Walker and Graczyk (1993) monitored two watersheds (14.0 and 27.2 km^2) in southern Wisconsin in which conservation reserve, contour stripcropping,

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minimum tillage, changing crop rotation, and barnyard treatment were implemented. The BMPs were found to reduce mass transport of NH_3-N and suspended solids for one watershed, and the authors speculated that significant reductions in the other watershed might have been detected had more data been available.

The objective of this study was to assess the impact of BMP implementation in a northwest Arkansas watershed on storm-flow stream quality. Storm flows were emphasized in this study because they are typically more sensitive to nonpoint source pollution, and they contribute much more to annual pollutant export than base flows. This study differs from recent similar work by examining different land uses and BMPs than have been reported. The major land use in this study (aside from forest, on which no BMPs were applied) was pasture, and the key BMP was nutrient management (defined in more detail later). The difference in land uses is significant in view of differences in the hydrology and water quality dynamics of the two types of agricultural production systems (e.g., Edwards et al., 1996).

METHODS AND MATERIALS

SITE CHARACTERISTICS

The study area was the Lincoln Lake watershed, which is located in northwest Arkansas, north of the city of Lincoln (36°00′ N, 94°25′ W). The mean annual rainfall is 1120 mm, and the mean annual temperature is 14.1°C (National Climatic Data Center, 1994). The Lincoln Lake watershed drains a total of approximately 3240 ha. Elevations within the watershed range from approximately 365 to 487 m, and the mean elevation is 429 m.

Fifteen soil series occur in the watershed, but only five series (Captina, Enders, Enders-Allegheny, Hector-Mountainburg, and Linker) cover nearly 70% of the total area (Harper et al., 1969). The Captina and Enders series are described as having moderately good drainage; the Allegheny and Linker series have good drainage, and the Hector-Mountainburg complex has good to somewhat excessive drainage (Harper et al., 1969).

The major land uses in the watershed are pasture (56% overall) and deciduous forest (34% overall). The dominant agricultural activities in the watershed are beef cattle and confined animal (predominately poultry) production. There are also apple orchards, dairy facilities, and other agricultural operations within the watershed, but the quantity and areal extent of these operations are small in comparison to grazing and confined animal production. The confined animal operations result in a large (as much as 17 Mg/ha of pastureland area) amount of manure available for land application (Soil Conservation Service and University of Arkansas Cooperative Extension Service, 1990).

IMPLEMENTATION OF BMPS

The Soil Conservation Service and University of Arkansas Cooperative Extension Service (1990) reported that Lincoln Lake was eutrophic, and lake production was limited by N inputs. Both algal blooms and complaints regarding the palatability of water after treatment for drinking purposes were common. These factors and a concern regarding the role of agricultural activities (especially land application of manures) prompted the Natural Resources Conservation Service (NRCS; formerly named the Soil Conservation Service, or SCS) and the University of Arkansas Cooperative Extension Service (CES) to develop and implement a program to help producers implement BMPs. The NRCS took responsibility for direct technical assistance to producers who wished to implement BMPs, while the CES conducted public educational activities. The program began in 1990, but producer participation in the program was relatively small until the following year.

Nutrient management, pasture and hayland management, waste utilization, dead poultry composting, and waste storage structure construction (pond/lagoon for liquid manure or stacking shed for dry manure), were the major BMPs implemented. The first three BMPs listed were almost always simultaneously implemented on a particular land area. Detailed records on the land areas (in the case of the first three BMPs) and sites (for the last two BMPs) on which BMPs were implemented were maintained by the NRCS.

The SCS (1992) defined nutrient management as "managing the amount, form, source, placement, and timing of applications of plant nutrients". In the context of animal manure application, the major benefits that would be expected from implementing nutrient management include reduced concentrations of N and unoxidized organic matter. Since manure application rates are based on meeting plant N requirements, generally leading to over-fertilization in terms of plant P requirements, no reductions in concentrations of phosphorus (P) would be expected. Phosphorus would thus accumulate in the soil, even though perhaps at a slower rate, for N-based manure application rates. The increasing soil P concentrations could, in turn, cause even higher P concentrations in runoff.

Waste utilization involves "using agricultural waste or other waste on land in an environmentally acceptable manner while maintaining or improving soil and plant resources" (SCS, 1987a). Waste utilization is closely related to nutrient management in terms of potential water quality benefits in the sense that nutrient management principles are involved in determining waste application parameters such as amount and timing.

The third areal BMP, pasture and hayland management, consists of "proper treatment and use of pastureland or hayland" (SCS, 1987b) and includes guidelines for beginning and ending grazing, harvesting forage, and controlling weeds. Pasture and hayland management can improve water quality through reduced losses of nutrients, solids, and organic matter associated with maintaining desirable soil cover and structure.

Dead poultry composting, described by SCS (1990), is a point BMP that was designed to replace other means of disposing of dead poultry, such as pits. Dead poultry composting could be expected to affect water quality by reducing N and organic matter loadings to subsurface water relative to those associated with unlined disposal pits. The impact of composting might thus be more pronounced for base flows than for storm flows.

A waste storage structure, described by SCS (1977), is used for temporary storage of agricultural wastes until land-application or other means of disposal. A waste storage structure can be viewed as having the potential to cause the same benefits as nutrient management, since the structure can provide manure users with the flexibility to time applications appropriately.

The key BMP among those described above is nutrient management. The most practical use of the majority of agricultural by-products (whether manure or composted dead animals) is likely land application, and nutrient management leads to selection of the best application parameters.

STORM FLOW MONITORING STRATEGY

As described earlier, the BMPs were implemented in response to the quality of Lincoln Lake. The effectiveness of BMP implementation, however, was assessed through monitoring the main tributaries (Moore Creek and Beatty Branch) to the lake rather than monitoring the lake itself. The reason for monitoring the tributaries in preference to the lake was to avoid any effects that nutrients stored in the lake might have on lake monitoring. Stored nutrients could have delayed any measurable response in water quality, even if the BMPs were effective in reducing nutrient inputs. Monitoring the tributaries was judged as providing the highest potential for rapidly and accurately assessing BMP effectiveness with respect to storm flow pollutant load reduction. This strategy would also allow BMP effectiveness to be assessed independently of the pre-existing status of the lake, making the results of wider general use.

Moores Creek and Beatty Branch were monitored at one site each (referred to as MA and BA, respectively). The total drainage areas of these two tributaries are 2120 ha for Moores Creek and 1120 ha for Beatty Branch. Both sites were located as close to the lake as possible. The locations of the monitoring sites and their corresponding sub-watersheds are shown in figure 1. The sub-watershed area associated with the MA site was approximately 1800 ha, or 85% of the total area drained by Moores Creek. Approximately 800 ha, or 71% of the total Beatty Branch drainage area, drained past site BA. Land use was determined for the sub-watershed associated with each monitoring site as given in table 1.

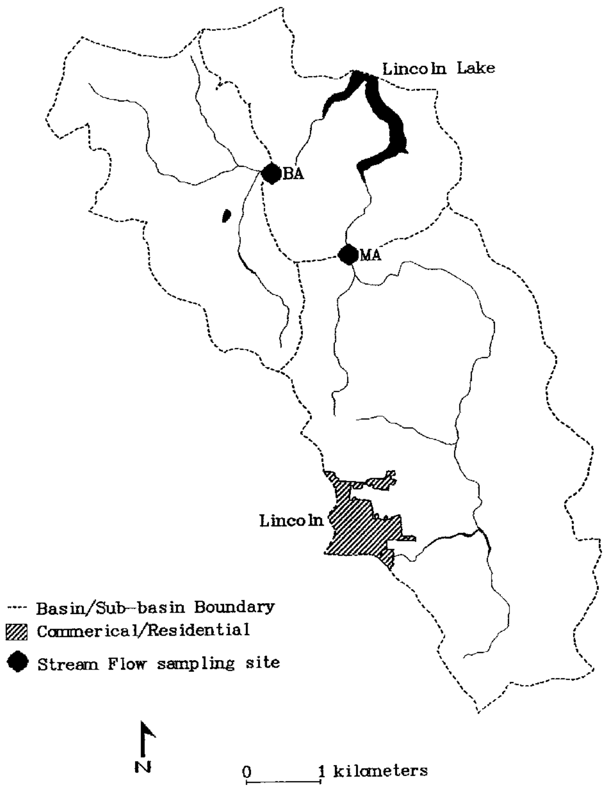

Figure 1–Stream sampling sites and corresponding sub-watersheds.

MONITORING EQUIPMENT AND PROCEDURES

Each site had instrumentation installed to measure stream stage and to collect water samples during storm events. A pressure transducer (model PCDR950, Druck, Inc.) was secured to a concrete flagstone and placed in the streambed at each site to measure stage. The output from the pressure transducers was measured and recorded at 5-min intervals by data loggers (model CR10 measurement and control modules, Campbell Scientific, Inc.). Automatic water samplers (model 800SL portable liquid sampler, American Sigma) collected samples during storm events. The sample intakes were secured to trees at the edges of the streambeds in the immediate vicinity of the pressure transducers. The sampler tubing and pressure transducer wiring were shielded with plastic conduit and buried from the streambeds to the instrument shelters. The instrument shelters were constructed of wood and sealed to prevent water entry. The pressure transducers and water samplers were interfaced so that sampling (1-L sample volume) initiated upon detection of a storm event and continued at 2-h intervals until the storm event had ended. All instruments were powered by batteries and were operational on a near-continuous basis throughout the project duration. The monitoring equipment was installed and fully operational by 23 September 1991, and monitoring continued until 30 April 1994.

Rating curves for the MA and BA monitoring stations were developed by measuring discharge at a range of stages using procedures described by U.S. Geological Survey (USGS) (1969). The rating curves were then constructed according to techniques recommended by USGS (1984). The slope-conveyance method was used to extend the rating curve for stages above which discharge measurements were available.

Water samples were collected not later than 24 h following each storm event. Samples were transported to the Arkansas Water Resources Center Water Quality Laboratory, prepared for analysis, and analyzed for nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN), orthophosphorus (PO_4-P), total phosphorus (TP), chemical oxygen demand (COD) and

Table 1. Land uses within monitored site watersheds

	Site	
	MA	BA
Category	Areal Coverage (%)	
Pasture	61.8	56.5
Orchards	2.5	0.5
Poultry houses	1.6	0.4
Other agricultural	0.1	1.4
Residential	5.4	0.0
Commercial	1.7	0.0
Water	0.0	0.0
Forest	25.9	39.5
Other	1.0	1.7

total suspended solids (TSS). Standard methods of analysis (Greenberg et al., 1992) were used in all analyses. Ion chromatography was used in analyses of NO_3-N and PO_4-P. The ammonia selective electrode method was used to determine NH_3-N. The macro Kjeldahl method was used in TKN analyses. Total P was determined by the ascorbic acid colorimetric method following sulfuric acid-nitric acid digestion. The closed reflux, colorimetric method was used for COD determinations.

Due to resource constraints, it was not possible to analyze all runoff samples collected. Therefore, a subset of runoff samples was selected for analysis from each storm event so that the rising and falling limbs as well as the peak of the runoff hydrograph were represented. Flow-weighted event means of analysis parameters were computed by integrating with respect to time the products of analysis parameter concentrations and flow rates and then dividing the result by the total runoff amount, determined by integrating runoff rate with respect to time. Event mass transport of analysis parameters was computed as the integral, with respect to time, of the products of analysis parameter concentrations and runoff rates with appropriate conversions for consistency of units.

Two tipping bucket rain gages were installed and used to record occurrences and amounts of rainfall. One gage was located in the extreme northern portion of the Lincoln Lake watershed, while the other was in the extreme southern portion.

DATA ANALYSIS

In contrast to other reports of BMP effectiveness studies (e.g., Park et al., 1994), there were no distinct pre- and post-implementation data sets on stream quality that could be directly compared. The data in this study were instead collected simultaneously with BMP implementation. BMP effectiveness in this situation can be assessed by analyzing the data for trends, provided nothing else with the potential for causing the trends occurred. The approach to assessing BMP effectiveness in this study was thus to assess trends in the data with respect to time, considering time as a surrogate for other measures of BMP implementation.

Before beginning the analysis for trends, one-way analysis of variance (ANOVA) was used to determine whether there were any seasonal effects in the data. The seasons were defined as fall, October-December; winter, January-March; spring, April-June; and summer, July-September. When seasonal effects were not significant, natural logarithms of observed parameter concentrations and mass transport were regressed only against time past the beginning of monitoring. The regression was performed to determine whether there were any statistically significant trends in the data as evidenced by regression line slopes that were significantly different from zero. The natural logarithms of concentration and mass transport data were used in preference to the original data because (a) the concentration and transport data have a lower bound of zero, (b) the untransformed data generally had skewed distributions, and (c) first-order models provided a better fit to the data than linear models.

In cases where seasonal effects on concentration or mass transport were significant, the data were fitted to the model:

$$\ln(Y) = b_1 + b_2 t + b_3 \sin \frac{2\pi t}{365} + b_4 4 \cos \frac{2\pi t}{365} \qquad (1)$$

where Y is the dependent variable (concentration or mass transport of a particular parameter), t is time (d) since monitoring began, and $b_1, \ldots, b_4$ are regression coefficients. This process enabled the trends with regard to time to be assessed independently of seasonal effects on concentrations and mass transport. Separation of seasonal effects from time trends was necessary because the monitoring duration was not an integer multiple of 365 d. Otherwise, a seasonal dependent variable might mistakenly be assessed as having a time trend if, for example, monitoring began during the season of highest values and ended during the season of lowest values.

RESULTS AND DISCUSSION

Daily rainfall recorded by the two rain gages installed within the watershed was 21% higher, on average, than normal for Fayetteville, Arkansas (approximately 25 km distant, the nearest weather station with available daily rainfall data). Monthly mean (arithmetic mean of the two rain gages within the watershed) rainfall and runoff (mean of sites MA and BA) are given in figure 2.

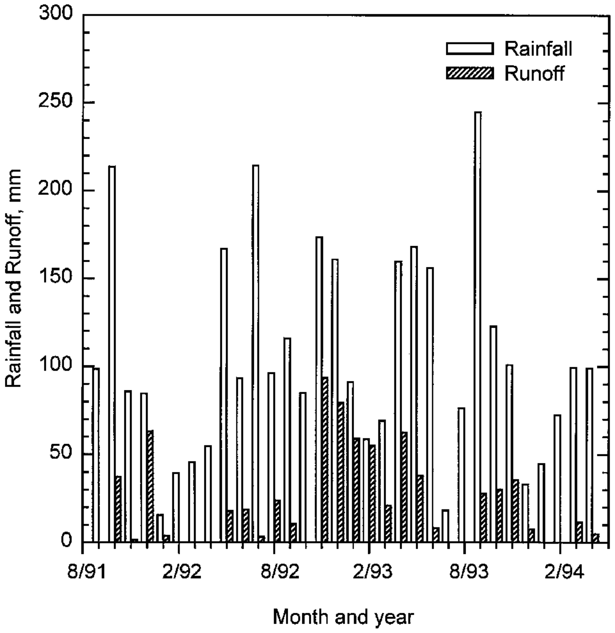

Figure 2–Mean (of two stations) monthly rainfall and runoff.

BMP IMPLEMENTATION

Proportions of available land (pastureland use) having BMPs implemented are given in figure 3. These data reflect only land area for which the areal BMPs (nutrient management, waste utilization, and pasture and hayland management) were implemented, since the point BMPs (dead bird composting and waste storage structure) are not readily associated with a land area. Proportions of available land on which BMPs were implemented ranged from 39%

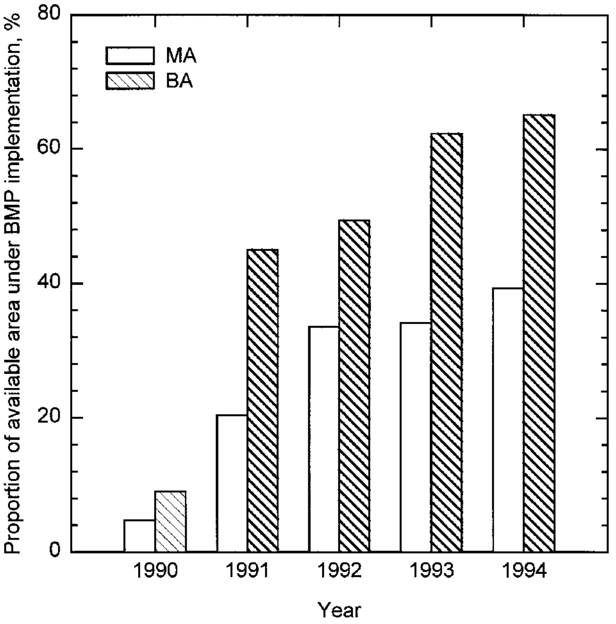

Figure 3–Proportions of potential land area with BMPs implemented.

Table 2. Event mean storm flow concentrations of analysis parameters for the MA watershed

Parameter*	Fall	Winter	Spring	Summer	Overall
			(mg/L)		
NO_3-N					
Mean	1.36a‡	0.65b	0.58b	0.98ab	0.95
SD†	0.90	0.19	0.23	0.61	0.70
NH_3-N					
Mean	0.08b	0.09b	1.28a	0.13b	0.41
SD	0.09	0.11	2.44	0.08	1.35
TKN					
Mean	1.25b	1.34b	7.13a	1.81b	2.92
SD	0.59	0.75	7.74	0.71	4.74
PO_4-P					
Mean	0.17b	0.09b	0.15b	0.25a	0.16
SD	0.08	0.07	0.08	0.12	0.09
TP					
Mean	0.28b	0.34ab	0.43ab	0.55a	0.37
SD	0.13	0.25	0.22	0.27	0.22
COD					
Mean	NS§	NS	NS	NS	53.4
SD	NS	NS	NS	NS	42.6
TSS					
Mean	NS	NS	NS	NS	61.4
SD	NS	NS	NS	NS	69.6

* NO_3-N, nitrate nitrogen; NH_3-N, ammonia nitrogen; TKN, total Kjeldahl nitrogen; PO_4-P, ortho-phosphorus; TP, total phosphorus; COD, chemical oxygen demand; TSS, total suspended solids.

† Standard deviation.

‡ Within-row seasonal means followed by the same letter are not significantly ($p < 0.05$) different.

§ Seasonal effects on concentrations were not significant

(site MA) to 65% (site BA) at the end of the monitoring period (fig. 3). In general, the land areas on which the BMPs were implemented were uniformly distributed throughout the monitored areas. The only exception was the southernmost 20% of site BA's drainage area, which had a relatively high (84%) proportion of land area with BMP implementation.

Six waste storage structures and eight dead bird composters were constructed within site MA's monitored area. Both the waste storage structures and composters were distributed uniformly within the MA site drainage area. Only one dead poultry composter (no waste storage facilities) was constructed within site BA's monitored area. That composter was located on the extreme northwestern boundary of the drainage area.

WATER QUALITY PARAMETER CONCENTRATIONS

Flow-weighted mean concentrations of analysis parameters are given in tables 2 and 3 for the MA and BA watersheds, respectively. Concentrations of N and P generally followed seasonal patterns. Concentrations of NH_3-N (MA) and TKN were highest during spring, and NO_3-N concentrations were highest in summer and fall, suggesting that spring-applied manure might be contributing significantly to storm flow N concentrations.

In general, there were no significant differences in concentrations between the two sampling sites. The single exception was TP, which was significantly ($p < 0.05$) higher for the MA site than for the BA site. The difference in TP concentrations might have been due to differences in land use; the MA watershed had greater proportions of pasture, poultry houses, commercial and residential area than the BA watershed (table 1).

Comparing the data of table 2 to information reported by Edwards et al. (1994), storm flow and base flow concentrations of NO_3-N, NH_3-N, and TKN were similar. Storm flow concentrations of PO_4-P, TP, COD and TSS, however, were from two to six times greater than corresponding base flow concentrations, indicating a relatively important role of storm runoff in transport of these materials.

Significant ($p < 0.08$) decreasing trends in concentrations of NO_3-N, NH_3-N, TKN, and COD were noted for both the MA and BA sites, while concentrations of PO_4-P and TP were stable during monitoring. These trends are demonstrated in figures 4 and 5. Concentrations of TSS increased significantly during monitoring for the BA site. Rates of change for the analysis parameters, calculated from the slopes of the regression lines relating natural logarithms of concentrations to time, are given in table 4.

The trends in concentrations of NO_3-N, NH_3-N, and TKN are generally consistent with BMP implementation. The decreasing trends in COD concentrations might be due in part to decreased inputs of unoxidized N (i.e., related to BMP implementation). The reason for the increasing trend in TSS concentrations observed at the BA site is unknown. Construction of logging roads upstream of the monitoring site occurred near the end of monitoring and could have produced higher TSS concentrations without a large impact on N or P, but there is insufficient information to advance this activity as the reason. No significantly decreasing trends in stream flow P concentrations were expected as a result of implementing the three areal BMPs. As discussed earlier, nutrient management and waste utilization can lead to P accumulation in the soil when these practices are based on meeting plant N requirements. The expected trends, if any were present and detectable given the relatively short monitoring duration, would therefore be increases in stream flow P concentrations.

Table 3. Event mean storm flow concentrations of analysis parameters for the BA watershed

Parameter*	Fall	Winter	Spring	Summer	Overall
	(mg/L)				
NO_3-N					
Mean	1.40a	0.60b	0.36b	0.97ab	0.80
SD†	0.96	0.30	0.14	1.08	0.77
NH_3-N					
Mean	NS	NS	NS	NS	0.10
SD	NS	NS	NS	NS	0.19
TKN					
Mean	1.30b	2.01ab	7.73a	1.72ab	3.76
SD	0.50	3.70	8.60	0.22	6.02
PO_4-P					
Mean	0.18a	0.06b	0.10b	0.20a	0.13
SD	0.06	0.05	0.07	0.13	0.09
TP					
Mean	0.29b	0.20b	0.29b	0.44s	0.29
SD	0.11	0.09	0.11	0.12	0.13
COD					
Mean	NS	NS	NS	NS	51.8
SD	NS	NS	NS	NS	43.0
TSS					
Mean	49.3ab	23.3b	46.0ab	79.2a	46.0
SD	42.5	29.0	39.5	18.4	38.7

* NO_3-N, nitrate nitrogen; NH_3-N, ammonia nitrogen; TKN, total Kjeldahl nitrogen; PO_4-P, ortho-phosphorus; TP, total phosphorus; COD, chemical oxygen demand; TSS, total suspended solids.

† Standard deviation.

‡ Within-row seasonal means followed by the same letter are not significantly ($p < 0.05$) different.

§ Seasonal effects on concentrations were not significant.

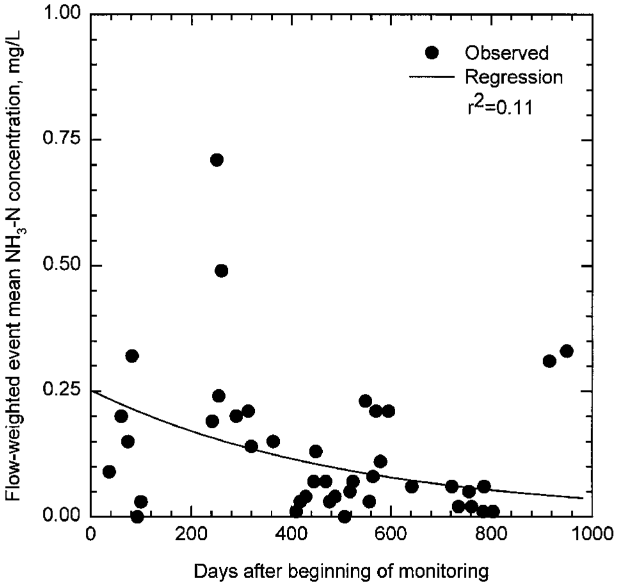

Figure 4–Event NH_3-N concentrations at the MA site. Coefficient of determination applies to regression of natural logarithms of NH_3-N concentration against days after beginning of monitoring.

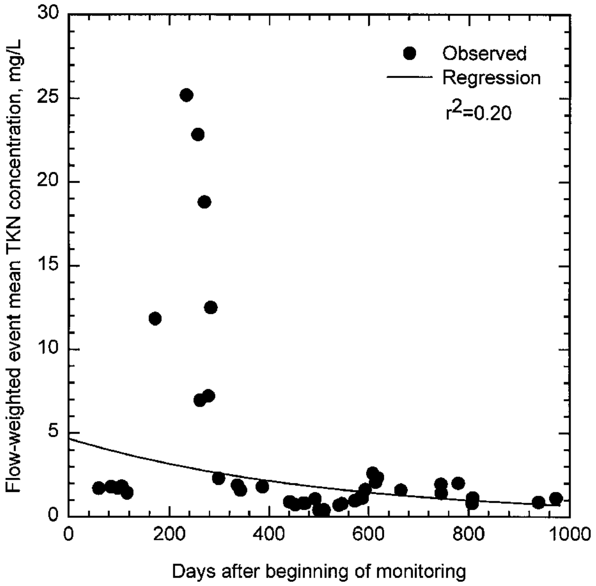

Figure 5–Event TKN concentrations at the BA site. Coefficient of determination applies to regression of natural logarithms of TKN concentration against days after beginning of monitoring.

Table 4. Annual changes in concentrations of analysis parameters

Site	NO_3-N	NH_3-N	TKN	PO_4-P	TP	COD	TSS
	(%/year)						
MA	–23.6	–52.9	–40.4	NC*	NC	–34.8	NC
BA	–22.5	–37.1	–55.9	NC	NC	–23.8	71.6

* No significant trend ($p > 0.10$).

WATER QUALITY PARAMETER MASS TRANSPORT

Analysis parameter losses for the two sites are summarized in tables 5 and 6. The influences of season on event mean mass transport were generally the same as on concentrations (tables 2 and 3). This finding was expected, since mean event flow rates exhibited no dependence on season. The exceptions were that season did not significantly affect event mean mass transport of TP on watershed MA or mass transport of TKN, TP and TSS for watershed BA, whereas season had a significant impact on the event mean concentrations (tables 2 and 3). This discrepancy is attributed to variability in storm event flow rates, which increased the variability of mass transport relative to concentrations. There were no differences in mean event mass transport between the MA and BA sites.

Mean annual mass transport is given in table 7. As indicated in table 7, losses during storm flows in all cases constituted the majority of total losses. Losses of PO_4-P, TP, COD, and TSS were more closely associated with storm events than losses of N species, indicating a relatively limited occurrence of transport via subsurface flows for those parameters. The seasonal distributions of flow volume and mass transport are given in table 8. The greatest flow volumes occurred in fall, which corresponded with the greatest mass transport of NO_3-N, TKN, and COD. In the cases of other parameters, however, the greatest mass transport did not necessarily match with the timing of highest event mean concentration. This indicates

Table 5. Event mean storm flow transport of analysis parameters for the MA watershed

	Season				
	Fall	Winter	Spring	Summer	Overall
Parameter*	(kg/ha)				
NO$_3$-N					
Mean	0.37a‡	0.12ab	0.07b	0.13ab	0.20
SD†	0.41	0.04	0.04	0.18	0.29
NH$_3$-N					
Mean	0.02b	0.02b	0.12a	0.01b	0.05
SD	0.03	0.01	0.23	0.01	0.13
TKN					
Mean	0.31b	0.23b	0.75a	0.22b	0.40
SD	0.28	0.13	0.82	0.15	0.51
PO$_4$-P					
Mean	0.05a	0.01b	0.02ab	0.04ab	0.04
SD	0.05	0.01	0.03	0.03	0.04
TP					
Mean	NS§	NS	NS	NS	0.08
SD	NS	NS	NS	NS	0.07
COD					
Mean	NS	NS	NS	NS	11.0
SD	NS	NS	NS	NS	13.3
TSS					
Mean	NS	NS	NS	NS	12.8
SD	NS	NS	NS	NS	16.8

* NO$_3$-N, nitrate nitrogen; NH$_3$-N, ammonia nitrogen; TKN, total Kjeldahl nitrogen; PO$_4$-P, ortho-phosphorus; TP, total phosphorus; COD, chemical oxygen demand; TSS, total suspended solids.

† Standard deviation.

‡ Within-row seasonal means followed by the same letter are not significantly ($p < 0.05$) different.

§ Seasonal effects on concentrations were not significant.

Table 6. Event mean storm flow transport of analysis parameters for the BA watershed

	Season				
	Fall	Winter	Spring	Summer	Overall
Parameter*	(kg/ha)				
NO$_3$-N					
Mean	0.45a	0.14b	0.05b	0.15b	0.20
SD†	0.46	0.09	0.05	0.24	0.31
NH$_3$-N					
Mean	NS	NS	NS	NS	0.02
SD	NS	NS	NS	NS	0.02
TKN					
Mean	NS	NS	NS	NS	0.56
SD	NS	NS	NS	NS	0.73
PO$_4$-P					
Mean	0.05a	0.01b	0.02b	0.04ab	0.03
SD	0.04	0.01	0.03	0.03	0.03
TP					
Mean	NS	NS	NS	NS	0.06
SD	NS	NS	NS	NS	0.06
COD					
Mean	NS§	NS	NS	NS	10.0
SD	NS	NS	NS	NS	9.5
TSS					
Mean	NS	NS	NS	NS	9.0
SD	NS	NS	NS	NS	11.0

* NO$_3$-N, nitrate nitrogen; NH$_3$-N, ammonia nitrogen; TKN, total Kjeldahl nitrogen; PO$_4$-P, ortho-phosphorus; TP, total phosphorus; COD, chemical oxygen demand; TSS, total suspended solids.

† Standard deviation.

‡ Within-row seasonal means followed by the same letter are not significantly ($p < 0.05$) different.

§ Seasonal effects on concentrations were not significant.

Table 7. Mean annual mass transport*of analysis parameters

	Parameter						
	NO$_3$-N	NH$_3$-N	TKN	PO$_4$-P	TP	COD	TSS
Site	(kg/ha/year)						
MA	3.44 (78%)	0.47 (71%)	6.84 (74%)	0.61 (92%)	1.27 (90%)	163.7 (87%)	182.0 (94%)
BA	3.19 (78%)	0.26 (71%)	8.64 (74%)	0.48 (92%)	0.95 (90%)	154.9 (87%)	140.3 (94%)

* Values in parentheses are corresponding proportions of total annual mass transport (Edwards et al., 1994).

that if pollutant mass loadings to a downstream water body are of concern, then some seasons will play a greater role than others in determining those loadings, and that concentrations or flow alone might not be sufficient to identify the most important seasons for mass loading.

Annual trends in analysis parameter losses are summarized in table 9 and are demonstrated in figures 6 and 7. Trends in analysis parameter mass transport mirrored those in concentrations with the exception of TSS at the BA monitoring site. As described earlier, TSS concentrations at the BA site demonstrated an increasing trend with regard to time, but mass transport exhibited no significant trend with regard to time.

BMP Effectiveness

The improving trends in NO$_3$-N, NH$_3$-N, TKN, and COD concentrations and transport are not attributed to trends in flow. Flow had an increasing trend during monitoring, which could be expected to promote a deteriorating trend in terms of transport. The trends in water quality can thus be attributed to activities within the watershed. There were no known activities with the potential for improving stream flow quality except for SCS and CES efforts, so the observed trends are attributed to changes in agricultural practices that occurred concurrently with programs conducted by SCS and CES.

The findings of this study should not be interpreted as implying a direct relationship between proportion of area having BMP implemented and water quality improvement. Activities on a relatively small proportion of the total area can have a disproportionately large impact on water quality, depending on what was being done prior to BMP implementation, proximity to the monitoring station, and other such factors. Another factor that should be considered is that educational activities of the CES are not directly reflected in the data regarding BMP implementation. There could have been a significant number of persons who changed their management practices as a result of CES activities but did not have a formal farm plan developed with NRCS assistance. In this case, water quality could have been positively affected by activities not accounted for by NRCS.

The data do not enable a direct assessment of what management practice(s) had the greatest impact on stream quality. Some deductions based on the data, however, might

Table 8. Seasonal distribution of mass transport (%)

Water- shed	Para- meter*	Season			
		Fall	Winter	Spring	Summer
MA	Flow	51.7	19.6	20.0	8.7
	NO_3-N	57.4	11.5	18.1	12.9
	NH_3-N	33.4	4.4	54.2	8.0
	TKN	57.7	6.0	24.0	12.4
	PO_4-P	38.5	11.3	24.5	25.7
	TP	35.6	9.9	28.1	26.4
	COD	50.0	8.8	22.0	19.3
	TSS	28.4	13.0	29.7	28.9
BA	Flow	41.9	24.7	25.7	7.8
	NO_3-N	59.4	12.5	23.7	4.4
	NH_3-N	52.2	16.2	28.0	3.6
	TKN	66.9	9.3	18.0	5.8
	PO_4-P	27.4	19.8	38.6	14.3
	TP	24.0	19.2	43.6	13.2
	COD	44.4	11.9	35.5	8.2
	TSS	17.6	27.5	43.2	11.7

* NO_3-N, nitrate nitrogen; NH_3-N, ammonia nitrogen; TKN, total Kjeldahl nitrogen; PO_4-P, ortho-phosphorus; TP, total phosphorus; COD, chemical oxygen demand; TSS, total suspended solids.

Table 9. Annual changes in mass transport of analysis parameters

	Parameter						
Site	NO_3-N	NH_3-N	TKN	PO_4-P (%/year)	TP	COD	TSS
MA	–34.0	–47.2	–50.0	NS*	NS	–44.0	NS
BA	–58.4	–62.4	–74.7	NS	NS	–60.6	NS

* No significant change with respect to time ($p > 0.10$).

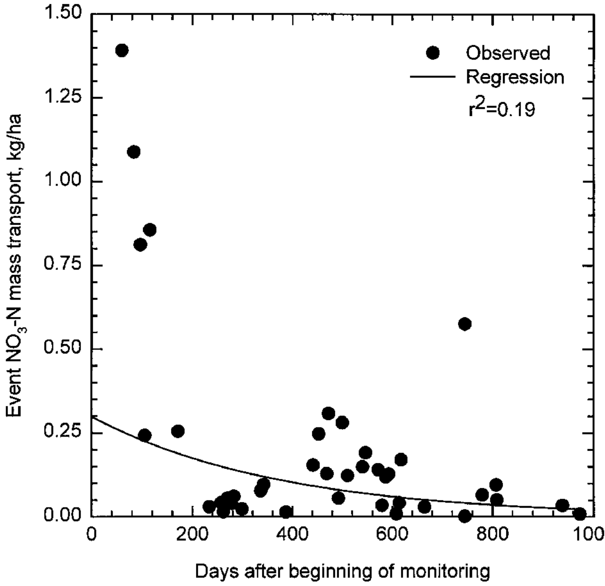

Figure 6–Event NO_3-N mass transport at the BA site. Coefficient of determination applies to regression of natural logarithms of NO_3-N mass transport against days after beginning of monitoring.

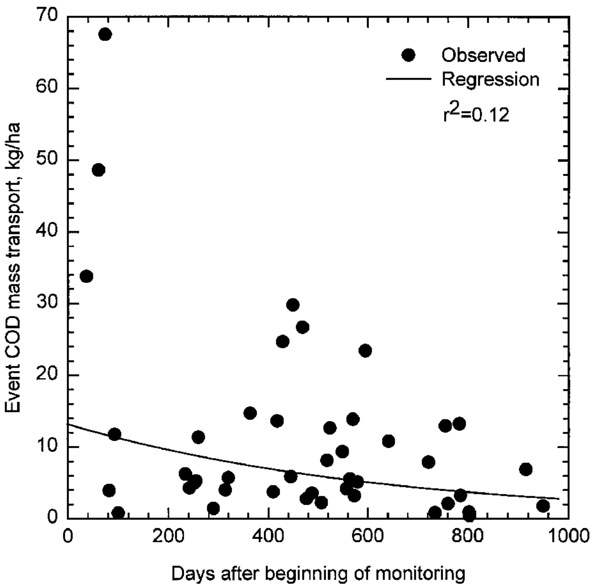

Figure 7–Event COD mass transport at the MA site. Coefficient of determination applies to regression of natural logarithms of COD mass transport against days after beginning of monitoring.

clarify the potential impacts of practices that were installed during the monitored period. The water quality trends at the BA site appear to reflect the implementation of nutrient management, waste utilization, and pasture and hayland management, because only one dead poultry composter was installed within the BA drainage watershed during the monitored period. Composters installed prior to monitoring might have caused delayed water quality improvements, but there is no information to indicate whether any composters were installed prior to monitoring. Eight dead poultry composters were installed within the MA drainage watershed, as pointed out earlier, in addition to the implementation of the three areal BMPs. The water quality improvements observed at the MA site, however, could have resulted without dead bird composter installation, since very similar results were observed at the BA site (which had only one composter installed during monitoring).

The findings of this study with respect to reduced N concentrations are generally compatible with those reported for similar studies. Walker and Graczyk (1993) reported that BMP implementation decreased NH_3-N (as found in this study) and suspended sediment concentrations on one of two monitored streams. Park et al. (1994) found reductions in TKN (as in this study), sediment, and TP concentrations as well as decreases in runoff, attributed to BMP implementation. Differences between this and the other studies could be due to land use and the specific BMPs implemented. No reductions in TSS were found in this study. Concentrations of TSS even at the beginning of monitoring, however, were quite low in comparison to those typically reported for row-cropped lands. Furthermore, the BMPs implemented in this study were not oriented toward reducing erosion to the same degree as in the other studies. Differences with regard to P concentrations between this study and that of Park et al. (1994) could be related to the role of sediment in P transport. It is known (e.g., Sharpley et al., 1993) that for land areas with high sediment losses (e.g., row-cropped land), more P transport via sediment occurs than for land areas with low sediment losses (e.g., pasture land). The TP reductions reported by Park et al. (1994) could therefore have been related to sediment reductions. The lack of TP reductions in this study might have been related to a low proportion of sediment-bound P and no reduction in TSS concentrations. Soil P concentrations could also have been occurring during monitoring, which would not have promoted reductions in stream flow TP concentrations.

SUMMARY AND CONCLUSIONS

Water quality was monitored from September 1991 to April 1994, concurrent with agricultural BMP implementation, on the two main tributaries to Lincoln Lake, Arkansas. Both concentrations and mass transport of NO_3-N, NH_3-N, TKN, and COD during storm flows exhibited significant decreasing trends during monitoring at both sites. Given that these findings are consistent with the impacts that the major BMPs were expected to produce, and considering that there were no other reported water quality-related activities within the watershed, the findings can be attributed to BMP implementation. The land uses and specific BMPs involved in this study are different from those reported in other studies (Park et al., 1994; Walker and Graczyk, 1993). However, the results of this and the earlier studies are consistent in their findings of water quality improvements associated with BMP implementation.

Significant trends in pollutant concentrations were detected after less than three years' monitoring, which is a considerably shorter duration than is often suggested (≥ five years). It should not be inferred, however, that three years or less is a sufficient monitoring duration for measuring a positive response to BMP implementation. The response duration between BMP implementation and changes in stream quality can logically be considered related to the degree to which stream quality has been negatively impacted, residual pollution, and the directness of the relationships between the BMPs and pollutant sources, not to mention the myriad of environmental factors. It is possible that for this study, conditions were optimal for detecting a stream quality response to BMP implementation in a relatively short period. Conditions might not be as favorable for similar studies. Planned monitoring durations should thus be conservative and adjusted based on site-specific results.

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