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Thomas G. Franti

University of Nebraska - Lincoln, thomas.franti@unl.edu

Dean E. Eisenhauer

University of Nebraska - Lincoln, deisenhauer1@unl.edu

Mary Carla McCullough

University of Nebraska - Lincoln, mmccullough2@unl.edu

L. M. Stahr

University of Nebraska - Lincoln, lstahr2@unl.edu

Mike Dosskey

USDA National Agroforestry Center, mdosskey@fs.fed.us

See next page for additional authors

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Authors

Thomas G. Franti, Dean E. Eisenhauer, Mary Carla McCullough, L. M. Stahr, Mike Dosskey, D. D. Snow, Roy F. Spalding, and Alan L. Boldt

Watershed Scale Impacts of Buffers and Upland Conservation Practices on Agrochemical Delivery to Streams

T.G. Franti¹, D.E. Eisenhauer¹, M.C. McCullough¹, L.M. Stahr¹, M.G. Dosskey², D.D. Snow,
R.F. Spalding, and A. L. Boldt¹

ABSTRACT

Conservation buffers are designed to reduce sediment and agrichemical runoff to surface water. Much is known about plot and field scale effectiveness of buffers; but little is known about their watershed scale impact. Our objective was to estimate the watershed scale impact of grass buffers by comparing sediment and agrichemical losses from two adjacent 141-165 hectare watersheds, one with conservation buffers and one without. Rainfall derived runoff events from 2002-2003 were monitored for water runoff, TSS, phosphorous and atrazine loss. A conservation-watershed included 0.8 km of grass buffers and 0.8 km of riparian forest buffer, ridge-tilled corn, corn-beans-alfalfa rotation, terraces and grassed waterways. A control-watershed had no buffers, disk-tilled, continuous corn and grassed waterways. The same application rate and method for atrazine to corn was used in each watershed. Total rainfall during the April-June monitoring period was similar in 2002 and 2003; however, the conservation-watershed produced only 27 mm of runoff, compared to 47 mm from the control. Over two years, TSS and phosphorous losses per hectare were reduced by 97% and 95%, respectively, in the conservation-watershed. Atrazine loss per hectare was 57% less in the conservation watershed. A separation technique showed that for 2002 other conservation practices reduced TSS by 84% and buffers reduced TSS by an additional 13% compared to the control. Similarly, other conservation practices reduced atrazine losses by 29% and buffers accounted for an additional 31%. On a watershed scale buffers can add benefit to a conservation system.

Keywords. Conservation buffers, runoff, atrazine, sediment, phosphorous, watershed

INTRODUCTION

Soil erosion and subsequent sediment delivery and transport of agrichemicals, particularly atrazine, to streams continues to be a water quality problem in corn producing regions of the Midwest and Great Plains. Degradation of water quality in the Missouri River and its tributaries has been attributed to runoff contaminated with pesticides, sediment and nutrients from agricultural land in the Midwest (Clark et al., 1999; Barbash et al., 1998; Goolsby et al., 1995; Goolsby et al., 1991). In Nebraska, elevated herbicide levels in the Platte River (Snow and Spalding, 1988; USGS, 1998) and its eastern tributaries—Clear Creek, Shell Creek, Salt Creek and the Elkhorn River—are the result of a “Spring flush” in which agrichemicals are washed from treated fields shortly after application (Spalding and Snow, 1989; USGS, 1996). In particular, concentrations of 82 mg L⁻¹ atrazine and 44 mg L⁻¹ metolachlor have been measured in the Clear Creek tributary at its confluence with the Platte River (USGS, 1996).

¹ T.G. Franti, Associate Professor, tfranti@unl.edu; D.E. Eisenhauer, Professor, deisenhauer1@unl.edu; M.C. McCullough, former Research Engineer, mmccullough2@unl.edu; L.M. Stahr, Research Engineer, lstahr2@unl.edu; D.D. Snow, Assistant Professor, dsnow1@unl.edu; R.F. Spalding, Professor; rspalding2@unl.edu; A.L. Boldt, research engineer, aboldt1@unl.edu, University of Nebraska-Lincoln.

² M.G. Dosskey, Riparian Ecologist, mdosskey@fs.fed.us, USDA Agriforestry Center, Lincoln, NE.

Conservation buffers have long been used for erosion and surface water pollution control in agricultural watersheds. Buffers can filter out a major proportion of sediment and other contaminants eroded from row-cropped fields before runoff enters a major waterway. Research regarding the efficacy of buffers in controlling surface water contamination from agricultural runoff has been reviewed by Barling and Moore (1994), Haycock et al. (1997), Lowrance et al. (1995), Muscutt et al. (1993) and Dosskey (2000). Numerous studies have examined the efficacy of buffers to remove contaminants (Arora et al., 1996; Dillaha et al., 1989; Magette et al., 1989; Patty et al., 1997; Robinson et al., 1996 and Schmitt et al., 1999). Most research to date has examined losses during a small number of runoff events from test plots with small field area to buffer area ratios. The range of contaminant reductions varies with factors such as buffer width and field-area to buffer-area ratio which creates differences in water and sediment loading to the buffers. Very little information is currently available on actual reduction of contaminant levels in streams with the use of conservation buffers. In addition, there has been very little assessment of buffer performance at the watershed scale.

Our objective was to estimate the watershed scale impact of grass buffers by comparing sediment and agrichemical losses from two adjacent 141-165 hectare watersheds, one with conservation buffers and one without.

METHODS

Monitoring of rainfall-derived runoff was conducted in two adjacent subwatersheds which are part of the Clear Creek Watershed, a tributary to the Platte River in central Nebraska (Figure 1). The subwatersheds were situated on alluvial terrace deposits between a nearly level but dissected upland plain and the Platte River bottomlands. A 165-hectare conservation-watershed (Figure 1) was adjacent to Clear Creek and included several conservation practices (Table 1), including 0.80 km of long-term riparian forest, and 5 riparian grass buffers planted in 1999-2000, totaling an additional 0.8 km of buffer. The riparian grass buffers were designed and installed to NRCS standards, with a native grass mix, and ranged in width from 13.7 m to 18.3 m to maintain a 30:1 field area to buffer area ratio. With the addition of the grass buffers an estimated 75-80% of all cropland runoff from the conservation watershed passes through a riparian forest or grass buffer. Runoff from all corn areas passed through a grass buffer.

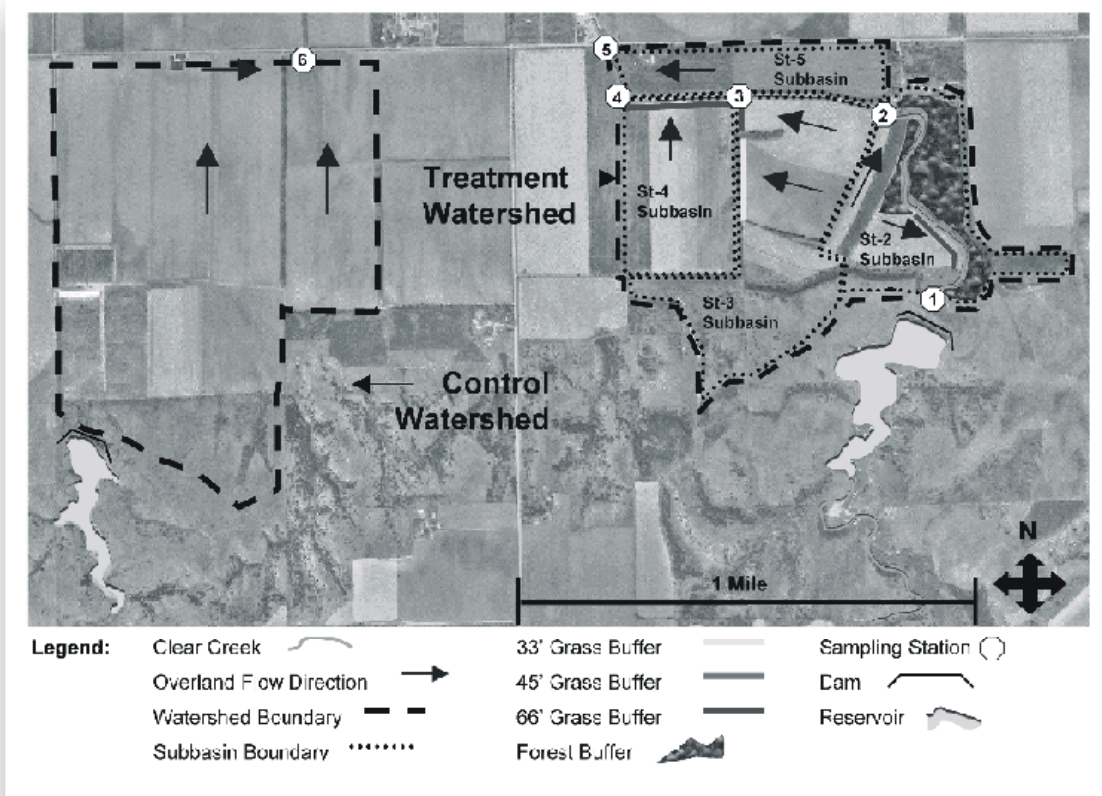


Figure 1. Clear Creek Watershed Study Site.

The control watershed had no conservation buffers. This watershed included 113 ha of continuous corn in a disk tillage system compared to 45 ha of ridge-tilled corn in a corn-bean-alfalfa rotation in the conservation watershed. Sediment and agrichemical losses were compared on a per unit area basis.

Table 1. Watershed Characteristics

Feature	Conservation Watershed	Control Watershed
Area	165 ha	141 ha
Grass Buffers ¹	0.8 km	None
Forest Buffer	0.8 km	None
Conservation Terraces	Yes	No
Grassed Waterways	Yes	Yes
Feedlot	No	11 ha
Crop Rotation	Corn-Soybeans-Alfalfa	Continuous Corn
Corn Area	45 ha	113 ha
Pasture	13 ha	8 ha
Total Cropped	155 ha	134 ha

¹ Planted in 1999 and 2000

Soils in both subwatersheds were Hord Silt loam, on 0-1% slopes. Each subwatershed was furrow irrigated, with one center pivot irrigation system in the control watershed. Each subwatershed has some area of permanent pasture. The control watershed also contains a beef cattle feedlot. (Table 1)

Atrazine was band applied to corn in both watersheds at the same rate, using the same commercial product, and was applied each year prior to when runoff monitoring began. In 2002

atrazine was applied as Bicep II Magnum at a rate of 2.2 kg ha⁻¹ (a.i.). In 2003 atrazine was applied as Guardsman Max at a rate of 0.81 kg ha⁻¹ (a.i.).

Rainfall-derived runoff was monitored at the outlet of each watershed (Station 5 and 6) during April-June of 2002 and 2003 (Fig. 1). Stream flow monitoring and water sampling was done using ISCO bubble meters and samplers programmed to sample for 24 hours after stream flow began. Samples were retrieved and samplers restarted if runoff events lasted longer than 24 hours. Water samples were tested for atrazine concentration using solid phase extraction and gas chromatography coupled mass spectrometry (GC/MS) with ¹³C ring-labeled internal standards for quantification of isotope dilution (Cassada et al. 1994). Method detection limits for atrazine and its degradation products in runoff samples is near 0.05 µg L⁻¹. Sediment concentration was analyzed gravimetrically as total suspended solids dried at 103-105 °C (APHA, 1998). Phosphate concentration was determined using ion chromatography to measure orthophosphate (soluble phosphorus). The method reporting limits for phosphate are 0.10 mg L⁻¹.

Upstream of each subwatershed is a small flood control dam. Only one runoff event in 2002 caused flow from the dam in the conservation watershed. No flow occurred from the dam in the control watershed. Discharge monitoring and water sampling was done at the conservation watershed dam so a hydrograph and mass loss separation could be done between the total flow measured and that contributed from the conservation watershed.

Channel flow conditions at Station 6 (Figure 1) changed in the spring of 2003, which resulted in our sampler being improperly programmed and only collecting one water sample for each of two events in 2003. Discharge monitoring for other events was unaffected. Therefore, there was insufficient data to calculate the total mass loss of contaminants for these two events. To estimate the mass loss, we assumed that the ratio of total mass loss divided by total volume was proportional to the mass loss divided by volume at the time of the first sample of an event, as represented by the equation:

$$\frac{m_t}{V_t} = k \frac{m_1}{V_1} \quad [\text{Equa. 1}]$$

Where k = coefficient

m_t = total mass loss of contaminant (kg)

V_t = total volume of water (L)

m_1 = mass loss at time of first water sample (kg)

V_1 = volume of water at time of first water sample (L)

We estimated the total mass loss for the events in 2003 by computing k-values using the 2002 data, and by rearranging Equation 1 as:

$$k = \frac{m_t}{m_1} \frac{V_1}{V_t} \quad [\text{Equa. 2}]$$

For each contaminant, the k-value was determined as the average of the k-values from four events: May 6, May 11, May 23 and May 26, 2002.

Table 2. Average k-values for 2002

	P	TSS	Atrazine
Average k-value, 2002	1.82	0.35	0.47
Standard Deviation	0.50	0.037	0.15

Total mass loss was then determined for the two events in 2003 by rearranging Equation 2 as:

$$m_t = k m_1 \frac{V_t}{V_1} \quad [\text{Equa. 3}]$$

For each event in 2003, the values for m_1 , V_1 and V_t were known, and the k-value from 2002 was assumed constant for 2003.

The discharge and mass loading monitored in the conservation watershed was impacted by all the conservation practices employed. Therefore, a method was needed to separate out the impacts of other conservation practices and estimate the impact of the riparian grass buffers. The field-scale effects of the buffers were known from Helmers (2003), where he measured trapping efficiency from both rainfall runoff and irrigation runoff. Mean trapping efficiency for sediment was estimated at 80%, and the infiltration ratio for rainfall runoff events was 37%, i.e., the buffer captured 37% of the water that entered it.

Using this information on buffer performance and assuming loading is linear with runoff depth, a separation calculation was used to estimate the impact of buffers and other conservation practices on reducing TSS, phosphate and atrazine mass loss (Figure 2 and 3). The separation calculation assumed that for TSS and phosphorous the loading leaving the buffers (measured at station 5) was reduced by 80% from that entering. Because an estimated 90% of atrazine runoff is in solution the atrazine trapping efficiency was assumed to equal the infiltration ratio; therefore, loading leaving the buffers was reduced by 37% from that entering. The loading entering the buffers is the loading effected by other conservation practices. This was compared to the loading from the control watershed (measured at station 6) which was not effected by conservation practices.

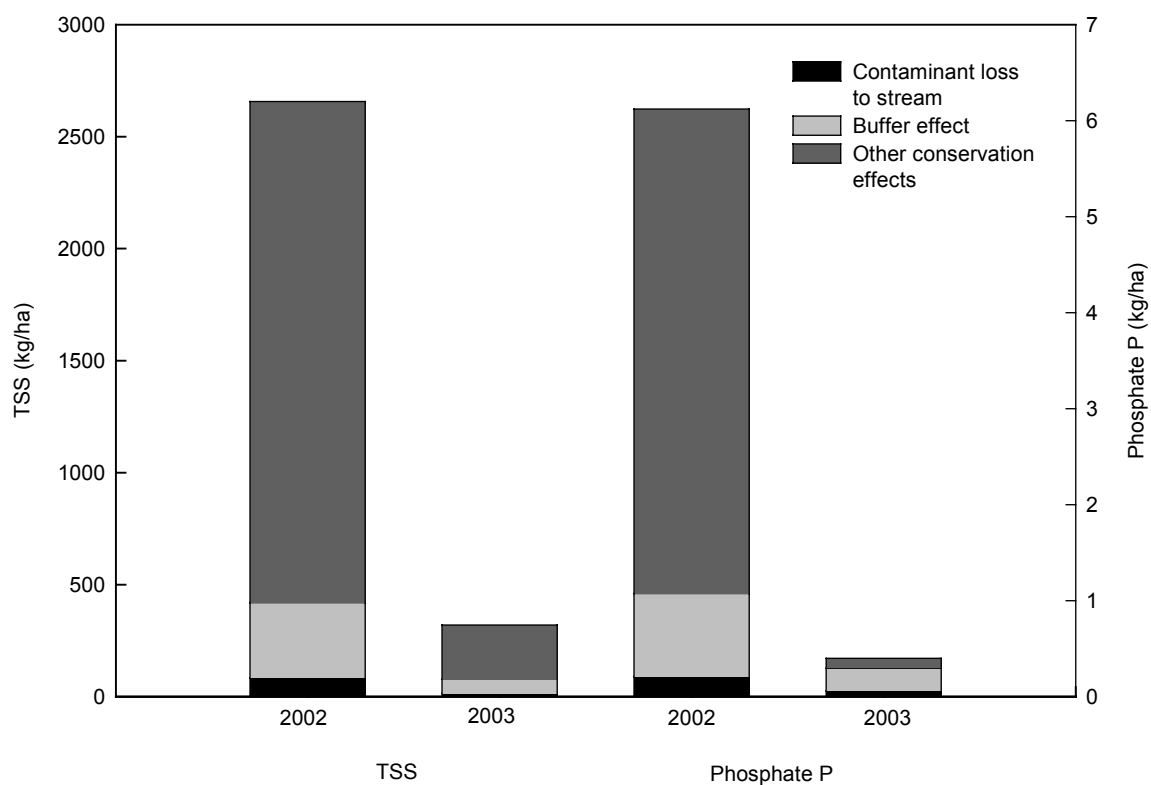


Figure 2. Effects of conservation buffers and other conservation practices on reduction of TSS and phosphorus.

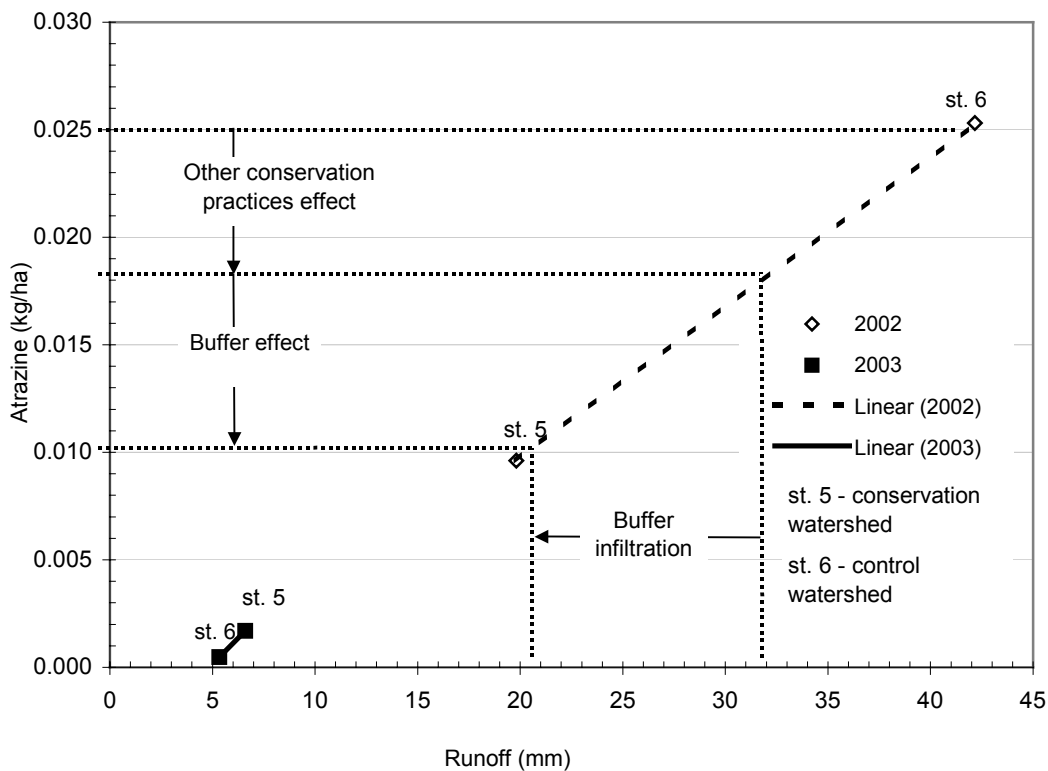


Figure 3. Effects of conservation buffers and other conservation practices on reduction of atrazine.

RESULTS

Five sampling events occurred in 2002 and four events in 2003. During the sampling period, 233-240 mm and 210-218 mm of rainfall occurred in 2002 and 2003, respectively. This resulted in a 2-year total of 27 mm of runoff from the conservation watershed, compared to 47 mm from the control watershed (Table 3). This reduction in runoff was from the combined impact of conservation tillage, conservation terraces, crop diversity and buffers.

Table 3. Contaminant Loss Results

Watershed	Year	Rainfall during sampling period, mm	Runoff mm	TSS kg ha ⁻¹	P kg ha ⁻¹	Atrazine kg ha ⁻¹	Atrazine Percent loss % ¹
Conservation (Station 5)	2002	233	20	84	0.21	0.0096	0.43
	2003	210	6.6	15	0.059	0.0017	0.21
Control (Station 6)	2002	240	42	2,657	6.12	0.025	1.1
	2003	218	5.3	321	0.40	0.00047	0.058

¹ percent of applied

Mass loss of TSS, phosphorus and atrazine was computed on a per unit area basis. TSS and phosphorus losses were based on the watershed area and atrazine loss was based on the corn area, because atrazine was only applied to corn (Table 1). In 2002, losses of all contaminants were greater in the control watershed. In 2003 losses of TSS and phosphorus were greater in the control watershed, but loss of atrazine was less.

In 2002 and 2003, respectively, atrazine loss based on total applied mass was 0.43% and 0.21% in the conservation watershed, and 1.12% and 0.058% in the control watershed. Losses in the range of 0.21% to 1.12% are typical values; however, 0.058% is lower than expected. This

suggests that atrazine loss in 2003 may be under-estimated for the control watershed. This is likely a result of the failed sampling during two events in 2003. Total mass loss was only an estimate based on equation (1) for contaminants in 2003, and for atrazine this estimate may be low.

Comparing two-year total mass loss of contaminants from the contrasting watersheds shows that TSS was reduced by 97% in the conservation watershed. Similarly, atrazine loss was reduced by 57%.

Table 4. Combined Contaminant loss for 2002-2003

Mass Loss (kg ha ⁻¹)	Control Watershed	Conservation Watershed	Reduction from all Conservation Impacts	Estimated Reduction by Grass Buffers ¹	Estimated Reduction by Other Conservation Practices
TSS	2,980	99	97%	14%	83%
Phosphorus	6.52	0.269	96%	17%	79%
Atrazine	0.025	0.011	57%	27%	30%

The grass buffers in the conservation watershed are part of a conservation system. The measured reduction from the impact of this system can be separated into the impact of the buffers and the impact of other conservation practices. Losses of runoff water, TSS and atrazine from the control watershed are unaffected by conservation practices. These losses represent the worst-case scenario. Using these losses for a starting point a separation calculation was used to estimate the impacts of the grass buffers alone and the impact of other conservation practices (Figure 2 and 3). Based on the separation analysis, the watershed scale impact of other conservation practices to reduce TSS was 83%, and for grass buffers, the impact was 14%. For atrazine losses, the watershed impact of other conservation practices was 30%, and the buffer impact was 27%.

For the two years of this study the impact of other conservation practices was much greater to reduce TSS (83%) and phosphorus loss (79%) compared to the impact of grass buffers (Table 4). The watershed impact of the grass buffers alone is estimated at 14% reduction for TSS and 17% for phosphorous. Buffers had a similar effect (27%) to other conservation practices (30%) in reducing atrazine runoff (Table 4). Conservation practices and buffers reduce atrazine loss by reducing total runoff amounts (45%). Within a conservation system, grass buffers can provide a significant additional impact in reducing TSS, phosphorous and atrazine

CONCLUSION

Conservation buffers are part of a conservation system that could include crop residue management, crop rotation, conservation terraces, and integrated uses of herbicides. The impact of riparian buffers to reduce TSS, phosphorus and atrazine loss was determined by comparing two years of runoff losses from a conservation watershed and a control watershed. The control watershed had few conservation practices, and continuous corn cropping, while the adjacent conservation watershed had 1.6 km of riparian grass and forest buffers, crop rotation (corn-beans-alfalfa) and conservation tillage (ridge-till). For the two years of the study, TSS and phosphorus losses per hectare were reduced by 97% and 96% in the conservation watershed compared to the control watershed. This was partially a result of a 45% reduction in the amount of water runoff from the conservation watershed. Atrazine was applied to corn at the same rate in each watershed; however, atrazine loss per hectare of corn was 57% less in the conservation watershed.

Previous plot studies (Helmets, 2003) had shown the trapping effectiveness for TSS of the grass buffers to be 80%, with an infiltration ratio (water captured in the buffer) of 37% for rainfall

runoff events. Using this data, the impact of the grass buffer was separated from the impact of other conservation practices.

For the two years studied, other conservation practices (ridge-tillage, crop rotation, terraces and waterways) reduced total suspended solids by 83% compared to the control watershed, and buffers reduced TSS an additional 14%. For 2002, other conservation practices reduced atrazine mass loss by 29% and buffers accounted for an additional 31%. Thus, within a conservation system grass buffers can provide a significant benefit to reducing sediment and agricultural losses to surface water.

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