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Effects of Best-Management Practices in Eagle and Joos Valley Creeks in the Waumandee Creek Priority Watershed, Wisconsin, 1990–2007

By David J. Graczyk, John F. Walker, Roger T. Bannerman, and Troy D. Rutter

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	megagram (Mg)
ton per year (ton/yr)	0.9072	megagram per year (Mg/yr)
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$°F=(1.8\times°C)+32$

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

0

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Abstract

In many watersheds, nonpoint-source contamination is a major contributor to water-quality problems. In response to the recognition of the importance of nonpoint sources, the Wisconsin Nonpoint Source Water Pollution Abatement Program (Nonpoint Program) was enacted in 1978. This report summarizes the results of a study to assess the effectiveness of watershed-management practices for controlling nonpoint-source contamination for the Eagle Creek and Joos Valley Creek Watersheds. Streamflow-gaging stations equipped for automated sample collection and continuous recording of stream stage and discharge were installed in July 1990 at Eagle and Joos Valley Creeks and were operated through September 2007. In October 1990, three rain gages were installed in each basin and were operated through September 2007. Eligible, contracted, and installed Best-Management Practices (BMPs) for Eagle and Joos Valley Creeks were tracked throughout the study period. In 2001, a majority of the goals set by the Wisconsin Department of Natural Resources and the local Land Conservation Department had been achieved for the two study watersheds.

The distributions of the rainstorms that produced surface runoff and storm loads were similar in the pre- and post-BMP periods for both Eagle and Joos Valley Creeks. The highest annual streamflow occurred at both sites in water year 1993, which corresponds to the greatest above normal precipitation at the rain gages in both watersheds. The minimum streamflow occurred in water year 2007 at both sites. For both Eagle and Joos Valley Creeks the median concentrations of suspended solids and total phosphorus at base flow were lower during the post-BMP period compared to the pre-BMP period and were statistically significant at the 0.05 significance level. The decrease in concentrations of ammonia nitrogen at both sites was not statistically significant at the 0.05 significance level. Multiple linear regression analyses were used to remove the affect of climatologic conditions and seasonality from computed storm loads. For both Eagle and Joos Valley Creeks, the median storm loads for suspended solids, total phosphorus, and ammonia nitrogen were lower during the post-BMP period compared to the pre-BMP period. The decreases in pre- and post-BMP storm-load regression residuals for both Eagle and Joos Valley Creeks were statistically significant for all three constituents at the 0.05 significance level and indicate an apparent improvement in water-quality in the pre- and post-BMP periods. . Because the pre- and post-BMP periods constituted different hydrologic conditions, separate pre- and post-BMP regressions were used to predict the theoretical pre- and post-BMP storm loads. The resulting percent reductions for suspended solids, total phosphorus, and ammonia nitrogen were 89, 77, and 66 respectively for Eagle Creek and 84, 67, and 60 respectively for Joos Valley Creek. The differences in the pre- and post-BMP residuals, theoretical loads and improvement in the base flow water quality indicate these differences and improvement, in part, may be owing to changing land practices and herd reductions in the watersheds.

Introduction

In many watersheds, nonpoint-source contamination is a major contributor to water-quality problems. In response to the recognition of the importance of nonpoint sources, the Wisconsin Nonpoint Source Water Pollution Abatement Program (Nonpoint Program) was enacted in 1978. When first introduced, the Nonpoint Program identified problems in 130 of the 330 watersheds in Wisconsin. For a given watershed, various management options, termed best-management practices (BMPs), are available for funding support through the Nonpoint Program. For example, practices in rural areas include conservation tillage, contour strip-cropping, streambank protection, and various barnyard-runoff controls. Using priority watersheds as a unit for consideration, the Nonpoint Program provides matching funds for voluntary implementation of various BMPs.

Until the late 1980's, very little data existed to demonstrate the effectiveness of BMPs for improving water quality in Wisconsin's priority watersheds. The Wisconsin Department of Natural Resources (WDNR) and the U.S. Geological Survey (USGS) developed and began a comprehensive, multi-disciplinary evaluation-monitoring program in October 1988 to assess the effectiveness of the Nonpoint Program (Wierl and others, 1996). The evaluation-monitoring program includes biological and stream-habitat monitoring by the WDNR and water-quality monitoring by the USGS. Eight watersheds were chosen for the evaluation-monitoring program. Results from three of the watersheds—Brewery, Garfoot, and Otter Creeks—have been published previously (Graczyk and others, 2003; Corsi and others, 2005).

The USGS, in cooperation with the WDNR, conducted a study in the Waumandee Creek Priority Watershed, western Wisconsin, from October 1990 to September 2007 to assess the hydrology, biology, habitat, and water quality before, during, and after implementation of BMPs.

Streamflow and water quality were collected continuously at Eagle and Joos Valley Creeks, two subbasins within the Waumandee Creek Watershed.

The period October 1990 to September 1993 is considered the pre-implementation period in the Eagle Creek Watershed. The period October 1990 to September 1992 is considered the pre-implementation period in the Joos Valley Creek Watershed. No BMPs were installed in either basin during the pre-BMP periods. BMPs were initiated in 1993 within the Eagle Creek Watershed and in 1992 within the Joos Valley Creek Watershed. The period October 1993—September 2002 is considered a transitional period in the Eagle Creek Watershed, with BMPs being installed periodically throughout the period in Eagle Creek. The period October 1992—September 2002 is considered a transitional period in the Joos Valley Creek Watershed, with BMPs being installed periodically throughout the period. In October 2000, sufficient BMPs were installed in each basin to begin the post-implementation period. Data were collected through September 2007; thus, the period October 2000—September 2007 is considered the post-BMP period for both watersheds.

Purpose and Scope

This report summarizes the results of a study to assess the effectiveness of watershed-management practices for controlling nonpoint-source contamination for the Eagle Creek and Joos Valley Creek Watersheds. Concentrations of selected water-quality constituents at base flow and storm loads for the defined pre-BMP period will be compared and contrasted to the base-flow concentrations and storm loads for the defined post-BMP period.

Physical Setting

Eagle and Joos Valley Creeks are tributaries to Waumandee Creek and are located in Buffalo County in western Wisconsin (fig. 1). Joos Valley Creek is a tributary to Eagle Creek.

Eagle Creek is currently (2010) classified as a Class III trout fishery (no natural reproduction, stocking needed to maintain the fishery); Joos Valley Creek supports a warm-water forage fishery (Wisconsin Department of Natural Resources, 1990). Both streams have the potential to improve physical and biotic conditions that may improve the fish resources (Wisconsin Department of Natural Resources, 1990). Eagle Creek has the potential to be classified as a Class II cold-water trout fishery (a stream in which some natural trout reproduction occurs but artificial propagation is needed to maintain a trout fishery), and Joos Valley Creek has the potential to be reclassified to a Class III coldwater trout fishery (Wisconsin Department of Natural Resources, 1990). From 1972 to 2007, 35,000 yearling Brown Trout were stocked in Eagle Creek (Wisconsin Department of Natural Resources, 2008 [**incomplete citation in reference list**]).

FIGURE 1. LOCATION OF THE WAUMANDEE CREEK WATERSHED IN BUFFALO COUNTY, WIS., AND DATA COLLECTION SITES. [NEAR HERE]

Eagle Creek drains 14.3 mi^2 upstream from the streamflow-gaging station, and the stream channel is 7.41 mi long from the station to the stream headwaters with a main channel slope of 70 ft/mi. The soils of Eagle Creek primarily are silt loams; a majority of these soils are well drained with some poorly drained alluvial soils on level lands adjacent to the Eagle Creek (Rappold and others, 1997). The topography typically is rolling with narrow steep ridges and rounded ridge tops (Rappold and others, 1997).

Joos Valley Creek drains 5.9 mi^2 upstream from the streamflow-gaging station. The stream channel is 5.90 mi long from the station to the stream headwaters and has been channelized in some parts; the slope of the channel is 86 ft/mi. The soils of the Joos Valley Creek Watershed are silt loams that are well drained with the level lands near the stream consisting of alluvial deposits that are not well drained (Rappold and others, 1997).

Data-Collection Network

Streamflow-gaging stations equipped for continuous recording of stream stage and discharge were installed in July 1990 at Eagle and Joos Valley Creeks (fig. 1). Measurements of streamflow were made according to standard USGS methods (Rantz and others, 1982). Discharge measurements were made every 4 to 6 weeks, and more frequently during high flows, to define a stage-discharge relation for each site.

Each gaging station was equipped with a stage-activated, refrigerated water sampler for automatic collection of water samples representing medium to high flows. A data logger was programmed to collect a sample with each 0.2 ft increase in stage once the stream stage reached an initial sampling threshold. On the falling limb of the hydrograph, a sample is collected with each 0.4 ft decrease in stage. The sampling strategy was designed to maximize the number of samples collected, with the majority of samples collected on the rising limb of the hydrograph when the concentration of constituents of interest changes the most. The samples, which were chilled to 4° C after collection, were analyzed for suspended solids, total phosphorus, and ammonia nitrogen. Samples collected were selected for analysis to represent variation in water quality over the stream hydrograph.

Manual fixed-interval water samples were collected every 2 weeks in the spring, summer, and fall and once a month in the winter. Samples were integrated over the depth and width of the stream by use of a hand-held sampler (Edwards and Glysson, 1988). The fixed-interval samples were analyzed for suspended solids, total phosphorus, and ammonia nitrogen.

All the constituents were analyzed by the Wisconsin State Laboratory of Hygiene according to standard methods (American Public Health Association, 1998; Wisconsin State Laboratory of Hygiene, 2008).

In October 1990, three rain gages were installed in each basin (fig. 1). One rain gage was at the stream gage; the other two rain-gage locations were selected by trial and error to result in approximately equal Thiessen polygon areas. Thiessen polygons represent the areas in closest proximity to each rain gage; the average precipitation for a rain-gage network can be computed as a weighted average using the Thiessen polygon areas as the weighting factor (Viessman and others, 1977). Precipitation was collected in an 8-in. collector that drained into a tipping-bucket rain gage. Each tip represented 0.01 in. of rain; all rainfall data were recorded every 5 minutes. The rain gages were calibrated once per year using a NovaLynx rain gage calibrator (Novalynx Corporation, 2007).

Land-Use and Best-Management Practices Inventory

Inventory of the rural watersheds began in 1990 to provide information on land-use and land-treatment changes that may affect water quality. A geographic information system (GIS) database retains the land-use and BMP inventories. Basin boundaries, hydrography, roads, streams, woodlots, rain gages, and BMPs were digitized from 1:24000 topographic maps. Detailed descriptions of each watershed and the BMP program are reported in Rappold and others (1997) and Wierl and others (1996). Eligible, contracted, and installed BMPs for Eagle and Joos Valley Creeks are summarized in Table 1. Total land use and land cover for Eagle and Joos Valley Creeks is shown in figure 2. In the two watersheds combined, 43 percent of the land is cropland and 41 percent of the land is woodland (Rappold and others, 1997). The remaining portions of the watersheds are in pasture, grazed woodlots, and other land uses. Annual updates of practices were obtained by contacting the Buffalo County Land Conservation Office. Barnyard-runoff control systems are installed to reduce the amount of organic matter reaching the stream by improving the cattle lots and adding filter strips. Streambank protection reduces the amount of sediment reaching the stream by limiting cattle access. Streambanks can be stabilized by various practices, including fencing and installation of watering areas in the stream. Upland-control practices reduce the amount of sediment and phosphorus by use of a combination of cropland and manure management on highly erodible lands.

TABLE 1. SUMMARY OF ELIGIBLE, CONTRACTED, AND IMPLEMENTED RURAL BEST-MANAGEMENT PRACTICES IN NONPOINT-SOURCE EVALUATION MONITORING WATERSHEDS. [NEAR HERE]

FIGURE 2. LAND USE/LAND COVER, EAGLE CREEK AND JOOS VALLEY CREEK WATERSHEDS. [NEAR HERE]

In 2001, a majority of the goals set by the WDNR and local Land Conservation Department had been achieved in the Eagle and Joos Valley Creeks Watershed. Additional practices could be implemented for several years but a majority of sources of nonpoint pollution have been controlled by the practices that already have been implemented. The land-use tracking was discontinued when the post-monitoring phase was completed.

Hydrologic Conditions During the Study Period

Precipitation

The 30-year normal annual precipitation for non-freezing periods (October–November and March–September) is 30.53 in. at the National Oceanic and Atmospheric Administration (NOAA) weather station at Mondovi, Wis. (National Oceanic and Atmospheric Administration, 2007), approximately 20 mi north of the study area. The 30-year normal annual precipitation for non-freezing periods is 28.95 in. at the NOAA weather station at La Crosse, Wis. (National Oceanic and Atmospheric Administration, 2007), approximately 35 mi south of the study area. The average non-freezing precipitation for the two NOAA stations is 29.94 in. and will be considered the long-term normal for the study period during non-freezing periods.

Precipitation at the approximate center of the Eagle Creek Watershed (rain gage E-2) was above the 30-year normal for 4 years (figure 3: 1992, 1993, 2004, and 2007) and below the 30-year normal for 7 years (figure 3 1991, 1994–96, 2003, 2005, and 2006). The 1993 precipitation at rain gage E-2 was 7.41 in. (25 percent) above the 30-year long-term normal. The 1995–96 precipitation was 10.55 in. (-35 percent) and 10.78 in. (-36 percent) below the 30-year long-term non-freezing precipitation, respectively.

FIGURE 3. YEARLY PRECIPITATION AT EAGLE AND JOOS VALLEY CREEKS AND AVERAGE NOAA LONG TERM NORMAL AT BUFFALO COUNTY, WI. [NEAR HERE]

Precipitation at the approximate center of the Joos Valley Creek Watershed (rain gage J-2) was above the long-term 30-year normal for 4 years (figure 3: 1991–93 and 2004) and was below the 30-year normal for 7 years (figure 3: 1994–96, 2003, and 2005–07). Precipitation in water year 1993 was 6.54 in. (22 percent) above the long-term normal and was 14.96 in. (-50 percent) below the long-term normal in water year 1996.

Total storm precipitation in the Eagle Creek Watershed is summarized for periods in which constituent loads were calculated in figure 4. During the pre-BMP period, constituent loads were calculated for 28 storms, with total storm precipitation ranging from 0.5 to 4.2 in. (fig. 4). During the post-BMP period, constituent loads were calculated for 34 storms, with the total storm precipitation ranging from 0.2 to 4.2 in. (fig.4). During the post-BMP period there was a somewhat higher percentage of storms less than around 1.25 in., which was compensated for by a slightly higher percentage of storms in the pre-BMP period ranging from 1.25 to around 2 in. The occurrence of storms exceeding 2 in. is roughly the same between the two periods.

FIGURE 4. CUMULATIVE DISTRIBUTION OF PRECIPITATION EVENTS AT EAGLE CREEK, BUFFALO COUNTY, WIS., FOR PERIODS IN WHICH STORM LOADS WERE CALCULATED. [NEAR HERE]

Total storm precipitation in the Joos Valley Creek Watershed is summarized for periods in which constituent loads were calculated in figure 5. In the pre-BMP period, 21 storms had loads calculated with total storm precipitation ranging from 0.3 to 4.3 in. (fig.5). During the post-BMP period, constituent loads were calculated for 34 storms with the total storm precipitation ranging from 0.2 to 5.1 in. (fig.5). During the pre-BMP period there was a somewhat higher percentage of storms less than around 1.75 in., which was compensated for by a slightly higher percentage of storms in the post-BMP period ranging from 1.75 to 2.25 in. The occurrence of storms exceeding around 2 in. is roughly the same between the two periods.

FIGURE 5. CUMULATIVE DISTRIBUTION OF PRECIPITATION EVENTS AT JOOS VALLEY CREEK, BUFFALO COUNTY, WIS., FOR PERIODS IN WHICH STORM LOADS WERE CALCULATED. [NEAR HERE]

For the most part, the distributions of the rainstorms that produced surface runoff and storm loads were similar in the pre- and post-BMP periods for both Eagle and Joos Valley Creeks. At both sites, the post-BMP periods had more precipitation events that produced runoff and storm loads than the pre-BMP periods. The median precipitation of monitored storms was 1.25 in. at Eagle Creek and 1.23 in. at Joos Valley Creek in the pre-BMP period. In comparison, the median precipitation of monitored storms was 1.32 in. at Eagle Creek and 1.37 in. at Joos Valley Creek in the post-BMP period.

Streamflow

Streamflow data collected as part of this study were used to determine the hydrologic conditions at Eagle and Joos Valley Creek gaging stations (fig. 1). In addition, the streamflow data were needed to determine the nutrient and solids loads at Eagle and Joos Valley Creek gaging stations. Base flow represents sustained groundwater discharge to the stream channel. Daily mean streamflows were separated into daily mean base-flow and stormflow contributions by use of the fixed-interval method (Sloto and Crouse, 1996). HYSEP is a computer program that is used to separate a streamflow hydrograph into slow-response flow (base flow) and quick-response flow (runoff). The fixed-interval method assigns the lowest discharge in a calculated time interval to all days in that interval starting with the first day of the period of record. The assigned values are then connected to define the base-flow hydrograph. Runoff—the difference between the annual mean discharge and base flow—is water that flows over the land surface and through the shallow groundwater system and enters the stream relatively quickly. Daily streamflow data for the gaging stations for each year of the study period are published in "Water Resources Data, Wisconsin, Water Years 1991–95 (Holmstrom and others, 1992–96) and Water Years, 2003–07 (Waschbusch and others, 2004–2008).

At Eagle Creek, the mean annual streamflow for the study period was 9.14 ft^3/s; the mean annual streamflow during the pre-BMP period was 10.1 ft^3/s, which was 11 percent greater than the mean annual streamflow for the study period; and the mean annual streamflow during the post-BMP period was 7.92 ft^3/s, which was 13 percent less than the mean annual streamflow for the study period (table 2). The highest annual streamflow was 13.5 ft^3/s in water year 1993 in the pre-BMP period, and the lowest annual streamflow was 6.31 ft^3/s in water year 2006 in the post-BMP period (fig. 6). The minimum streamflow for 7 consecutive days—which is an indication of low flow—was 3.2 ft^3/s for the study period in water year 2007 (post-BMP period) (table 2 and figure 6). The mean base flow for the study period was 7.91 ft^3/s (87 percent of the annual flow; table 2). The mean base flow in the pre-BMP period was 8.68 ft^3/s (86 percent of the annual streamflow; table 2). The mean base flow during the post-BMP period was 6.86 ft^3/s (87 percent of the annual streamflow; table 2), which was 13 percent less than the mean base flow for the study period. Runoff at Eagle Creek was the highest in water year 1993 (2.25 ft^3/s), which also was the highest for the study period. The peak discharge recorded was 2,400 ft^3/s on August 14, 1995, in the transitional period (Holmstrom and others, 1996).

TABLE 2. SUMMARY OF STREAMFLOW CHARACTERISTICS FOR EAGLE CREEK AND JOOS VALLEY CREEK, PRE- AND POST BMP PERIOD. [NEAR HERE]

FIGURE 6. STREAMFLOW CHARACTERISTICS FOR EAGLE CREEK, BUFFALO COUNTY, WI. [NEAR HERE]

At Joos Valley Creek, the mean annual streamflow for the study period was 3.99 ft^3/s; the mean annual streamflow in the pre-BMP period was 4.29 ft^3/s, which was 8 percent greater than the mean annual streamflow for the study period (table 2). The mean annual streamflow during the post-BMP period was 3.50 ft^3/s, which is 12 percent less than the mean annual streamflow for the study period (table 2). The highest annual streamflow was 5.81 ft^3/s in water year 1993 during the pre-BMP period, and the lowest annual streamflow was 2.64 ft^3/s in water year 2006 during the post-BMP period (fig. 7). The minimum 7-day low flow was 0.57 ft^3/s for the study period and occurred in the post-BMP period. The minimum 7-day low flow in the pre-BMP period was 1.60 ft^3/s. The mean base flow for the study period was 3.37 ft^3/s (85 percent of the annual streamflow; table 2 and fig. 7). The mean base flow for the pre-BMP period was 3.72 ft^3/s (87 percent of the annual streamflow; table 2). The mean base flow for the post-BMP period was 2.88 ft^3/s (83 percent of the annual streamflow; table 2). Overland runoff was the highest in water year 2004, 0.90 ft^3/s (fig. 7). The maximum instantaneous peak flow was 1,480 ft^3/s and occurred on August 14, 1995 (Holmstrom and others, 1996).

FIGURE 7. STREAMFLOW CHARACTERISTICS FOR JOOS VALLEY CREEK, BUFFALO COUNTY, WI. [NEAR HERE]

The highest annual streamflow occurred at both sites in water year 1993, which also corresponds to the greatest above normal precipitation at the rain gages in both watersheds. The minimum streamflow occurred in water year 2007 at both sites. The greatest below normal precipitation occurred in water year 2006, and this may have resulted in the low flows in water year 2007.

Water Quality Before and After Implementation of Best-Management Practices

Base-Flow Concentrations

Base-flow water quality generally reflects groundwater quality because base flow of a stream largely is a result of groundwater discharge to the stream. Consequently, base-flow water quality may be affected by land-use practices that affect groundwater. Concentrations of nutrients, for example, may become elevated above background concentrations in groundwater as a result of agricultural activities.

Comparisons of the base-flow water-quality concentrations during the pre- and post-BMP periods may indicate changes owing to the BMPs. A nonparametric Wilcoxon rank-sum test can be used to determine whether significant differences are present between two independent periods (pre- and post-BMP). The null hypothesis is that the median of the selected constituents at base flow during the pre-BMP period are the same as those in the post-BMP period. The alternative hypothesis is that the median concentrations at base flow in the post-BMP period are less than those during the pre-BMP period. If the null hypothesis is rejected in favor of the alternative hypothesis, then the reduction is considered statistically significant and could be a result of changes in land-use practices in the watershed.

Water-quality samples were collected at base-flow conditions during the pre-and post-BMP periods. Daily mean discharge was separated into overland flow and base flow to determine whether a sample collected was during a base-flow period. If the ratio of mean daily base flow to mean daily discharge was 0.95 or greater (95 percent or more base flow), then the day was considered a potential base-flow sample day. In addition, an overland-flow time lag was calculated. The time lag was equal to the drainage area raised to the 0.2 power and rounded up to the next day (Viessman and others, 1977). The time lag was used to eliminate samples collected on the falling limbs of hydrographs that may represent runoff water quality rather than base-flow water quality. The overland-flow time lag was determined to be 2 days for both Eagle and Joos Valley Creeks. If a potential base-flow sample was collected within 2 days of the hydrograph peak, this sample was not considered to be a base-flow sample. The Wilcoxon rank-sum nonparametric test was applied to the pre- and post-BMP concentrations for the base-flow samples (table 3). Concentrations of the base-flow samples for Eagle and Joos Valley Creeks are shown in figure 8 and figure 9. Also shown on these figures is the median for each constituent by water year.

TABLE 3. RESULTS OF THE WILCOXON RANK-SUM TEST ON THE MEDIAN CONCENTRATIONS OF SUSPENDED SOLIDS AND NUTRIENTS AT BASE FLOW, PRE- AND POST-BMP PERIODS, EAGLE CREEK AND JOOS VALLEY CREEK, WI. [NEAR HERE]

FIGURE 8. CONCENTRATIONS AND WATER-YEAR MEDIANS OF SUSPENDED SOLIDS AND NUTRIENTS IN BASE-FLOW SAMPLES DURING THE DATA-COLLECTION PERIOD AT EAGLE CREEK, BUFFALO COUNTY, WI. [NEAR HERE]

FIGURE 9. CONCENTRATIONS AND WATER-YEAR MEDIANS OF SUSPENDED SOLIDS AND NUTRIENTS IN BASE-FLOW SAMPLES DURING THE DATA-COLLECTION PERIOD AT JOOS VALLEY CREEK, BUFFALO COUNTY, WI. [NEAR HERE]

For both Eagle and Joos Valley Creeks, the median concentrations of suspended solids and total phosphorus during base-flow conditions decreased between the pre- and post-BMP periods (table 3). These decreases were statistically significant at the 0.05 level (table 3). The concentrations of suspended solids decreased 75 and 71 percent at Eagle and Joos Valley Creeks, respectively. Concentrations of total phosphorus during base-flow conditions decreased 33 percent at Eagle Creek and 38 percent at Joos Valley Creek from the pre- to the post-BMP period. The decrease in the concentration of ammonia nitrogen was not statistically significant at the 0.05 level.

Distribution and Seasonality of Loads

Daily mass and storm-period loads were computed for suspended solids and total phosphorus; mass loads for ammonia nitrogen were computed for storm periods only. At Eagle Creek, 18, 17, and 19 percent of the suspended solids transported during the study period occurred during May, March, and April, respectively. This represents 54 percent of the suspended solids load transported during the study period. A total of 2 percent of the suspended solids transported during the study period occurred during October, December, and January (fig. 10). During March, May, and April, 21, 15, and 14 percent, respectively, of total phosphorus were transported. This represents 50 percent of the total phosphorus load transported during the study period. A total of 3 percent of total phosphorus transported during the study period occurred during October, December, and January (fig. 10).

FIGURE 10. AVERAGE MONTHLY DISTRIBUTION OF TOTAL PHOSPHORUS AND SUSPENDED SOLIDS LOADS AT EAGLE CREEK, BUFFALO COUNTY, FOR WATER YEARS 1991-1994 AND 2003-2007. [NEAR HERE]

At Joos Valley Creek, 18, 16, and 17 percent of the suspended solids load transported during the study period occurred during March, April, and June, respectively (fig.11). This represents 51 percent of the suspended solids transported during the study period. During October, January, and December, the least amount of suspended solids were transported, representing less than 1 percent of the total suspended solids transported during the study period. During March, May, and June, 25, 14, and 13 percent, respectively, of total phosphorus were transported (fig.11). A total of 2 percent of total phosphorus transported during the study period occurred during October, December, and January.

FIGURE 11. AVERAGE MONTHLY DISTRIBUTION OF TOTAL PHOSPHORUS AND SUSPENDED SOLIDS LOADS AT JOOS VALLEY CREEK, BUFFALO COUNTY FOR WATER YEARS 1991-1994 AND 2003-2007. [NEAR HERE]

At Eagle Creek, 34 percent of the suspended solids load was transported on 1 day during the study period (table 4 and fig. 12). Twenty seven percent of the total phosphorus load during the study period was transported in 1 day. Similar results can be found at Joos Valley Creek, with 43 percent of suspended solids load and 33 percent of total phosphorus load transported in 1 day (table 4 and fig.13). At both sites, more than 70 percent of the suspended solids and total phosphorus loads were transported in 7 days during the study period.

TABLE 4. PERCENT DAILY CONTRIBUTION OF TOTAL PHOSPHORUS AND SUSPENDED SOLIDS FOR EAGLE CREEK AND JOOS VALLEY CREEK, BUFFALO WI. [NEAR HERE]

FIGURE 12. DAILY DISTRIBUTION OF TOTAL PHOSPHORUS AND SUSPENDED SOLIDS LOADS AT EAGLE CREEK, BUFFALO COUNTY FOR WATER YEARS 1991-1994 AND 2003-2007. [NEAR HERE]

FIGURE 13. DAILY DISTRIBUTION OF TOTAL PHOSPHORUS AND SUSPENDED SOLIDS LOADS AT JOOS VALLEY CREEK, BUFFALO COUNTY, FOR WATER YEARS 1991-1994 AND 2003-2007. [NEAR HERE]

Loads were separated into storm loads and base-flow loads. On average for the study period, 87 percent of the streamflow was comprised of base flow, with the remaining 13 percent comprised of stormflow at Eagle Creek (fig. 14). For Joos Valley Creek, 85 percent of the annual streamflow was comprised of base flow, with the remaining 15 percent comprised of stormflow (fig. 14). While the majority of the streamflow was comprised of base flow, the majority of the suspended solids and total phosphorus loads was transported by stormflow. At Eagle Creek, 89 percent of the annual average suspended solids load was transported during storms (fig. 14). Similar results were found for total phosphorus; 80 percent of the annual average total phosphorus was transported as stormflow (fig. 14). At Joos Valley Creek, 90 percent of the annual average suspended solids was transported during stormflows, and 84 percent of the average annual total phosphorus was transported during stormflows (fig. 14).

FIGURE 14. ANNUAL CONTRIBUTIONS OF STORMFLOW AND BASE-FLOW PERIODS TO STREAMFLOW, SUSPENDED SOLIDS AND TOTAL PHOSPHORUS LOADINGS AT EAGLE CREEK AND JOOS VALLEY CREEK, BUFFALO COUNTY, WI FOR WATER YEARS 1991-2007. [NEAR HERE]

Storm Loads

Fixed-interval sampling, particularly at a monthly frequency, may not show changes resulting from BMP implementation (Walker and Graczyk, 1993; Walker, 1994) because a great deal of the annual suspended solids and nutrient transport occurs during storms. Consequently, mass transport resulting from individual storms was analyzed further to determine the effects of BMP installation. Instantaneous mass transport of a particular constituent was determined by multiplying streamflow by the concentration of the constituent and a conversion factor (Porterfield, 1972). The integration method was then used to determine the mass transport of each constituent for each storm (Porterfield, 1972), expressed as a storm load. Concentration at the beginning of a storm was estimated from samples collected during previous base-flow periods between storms. Concentration at the end of the storm was estimated from samples collected immediately after the end of the storm. Some concentration data for individual storms were estimated by the relation between concentration and streamflow. Estimated data samples within a storm period were kept to a minimum.

The storm loads and median storm loads for all three constituents for the pre- and post-BMP periods are listed in table 5 and figures 15 and 16, respectively. In many cases, the variability in the storm loads is large enough to mask potential differences in the pre- and post-BMP periods. The two periods were compared statistically by means of the Wilcoxon rank- sum test described previously (table 5). For both Eagle and Joos Valley Creeks, the median storm loads for all three constituents was lower during the post-BMP period compared to the pre-BMP period (table 5, figures 15 and 16). With the exception of ammonia nitrogen at Eagle Creek, all of these decreases were statistically significant at the 0.05 level (table 5, significance level for median storm loads).

TABLE 5. RESULTS OF THE WILCOXON RANK-SUM TEST COMPARING STORM LOADS AND STORM-LOAD RESIDUALS FOR PRE- AND POST-BMP PERIODS. [NEAR HERE]

FIGURE 15. SUSPENDED SOLIDS, TOTAL PHOSPHORUS AND AMMONIA NITROGEN STORM LOADS AND MEDIAN STORM LOADS DURING THE PRE- AND POST-BMP PERIODS AT JOOS VALLEY CREEK IN BUFFALO COUNTY, WI. [NEAR HERE]

FIGURE 16. SUSPENDED SOLIDS, TOTAL PHOSPHORUS AND AMMONIA NITROGEN STORM LOADS AND MEDIAN STORM LOADS DURING THE PRE- AND POST-BMP PERIOD AT EAGLE CREEK IN BUFFALO COUNTY, WI. [NEAR HERE]

In many cases, the variability in the storm loads is large enough to mask potential differences in the pre- and post-BMP periods. In addition, because the pre- and post-BMP periods arise from different hydrologic conditions, differences in the hydrologic conditions could result in differences in storm loads that are not a result of the management practices. To overcome these difficulties, one approach is to perform regressions relating the storm loads to variables representing climatic and seasonal conditions. If the independent variables represent the natural climatologic and seasonal conditions, then the variability remaining in the regression residuals represents the combination of lack-of-fit for the regression model and changes induced by the BMPs. In theory, it should be possible to detect smaller differences between the pre- and post-BMP periods compared to detecting differences in the storm loads because the regression, by design, reduces variability in the data.

A number of independent variables were selected, most of which were based on various measures of precipitation for each distinct rainstorm. These included total rainfall (P), the 15- and 30-minute maximum intensities (I_{15} and I_{30}), and the Universal Soil Loss Equation (USLE) erosivity index (EI) (Wischmeier and Smith, 1978). Additional precipitation-based measures included the 1-, 3-, and 5-day antecedent precipitation (API_1, API_3, and API_5, respectively), which is computed as the total rainfall for the 1, 3, and 5 days prior to the beginning of each storm, respectively. Terms combining total rainfall and the antecedent precipitation also were considered (for example, $P+API_1$). Finally, two seasonal terms were included to allow for variations arising solely based on the time of year. The seasonal terms were based on the serial date of the storm (T), using a period of 1 year and both sine and cosine terms to allow for amplitude and phase-shift estimation.

Preliminary regression results indicated that for many of the constituents and storms, simple linear regressions resulted in the prediction of negative storm loads. Because this would result in erroneous conclusions when comparing pre- and post-BMP periods, the final regressions were based on a logarithmic transformation of the storm loads, thus assuring that negative loads cannot be predicted.

For each constituent, stepwise regressions were done using the independent variables described above (table 6). For each regression, additional variables were considered if the improvement in the resulting regression was considered large enough to warrant the use of additional variables. In addition, various regression plots were examined to verify that the underlying assumptions of regression analysis were not violated. For cases where only one of the seasonal sine/cosine terms was statistically significant, both terms were included in the final regression to assure proper characterization of the amplitude and phase shift of the combined seasonal term.

TABLE 6. REGRESSION RESULTS FOR STORM LOADS AT EAGLE AND JOOS VALLEY CREEKS, WI. [NEAR HERE]

The storm loads and median storm loads for all three constituents for the pre- and post-BMP periods are listed in table 5 and figures 15 and 16, respectively. The two periods were compared statistically by means of the Wilcoxon rank- sum test described previously. The test was applied to the storm loads and the regression residuals (table 5). If the regressions represent the variability owing to natural factors, a difference in the regression residuals could be attributed directly to a difference owing to the BMPs.

For both Eagle and Joos Valley Creeks, the median storm loads for all three constituents was lower during the post-BMP period compared to the pre-BMP period (table 5, figs. 15 and 16). With the exception of ammonia nitrogen at Eagle Creek, all of these decreases were statistically significant at the 0.05 level (table 5, significance level for median storm loads). However, because the pre- and post-BMP periods represented potentially different hydrologic conditions, these decreases are not necessarily the result of the implementation of BMPs in the watersheds. Because the storm-load residuals represent variability in the loads not explained by climatic and seasonal influences, differences in the residuals between the two periods are a better indication of the effects of BMP implementation. The decreases in pre- and post-BMP storm-load residuals for both Eagle and Joos Valley Creeks were statistically significant for suspended solids, total phosphorus, and ammonia nitrogen at the 0.05 level (table 5, significance level for storm-load residuals). Therefore, the differences in pre- and post- BMP storm loads likely are owing to the BMPs installed.

The difference between pre- and post-BMP median storm loads does not reflect the percent reduction in the individual storm loads largely because the pre- and post-BMP periods constituted different hydrologic conditions. Using separate pre- and post-BMP regressions, it is possible to predict the theoretical pre- and post-BMP storm loads for different values of the independent variables. For these conditions, the difference in the loads predicted by the pre- and post-BMP regressions represents the theoretical reduction in load. Separate regressions were determined for the pre- and post-BMP periods using the same set of independent variables determined previously (table 6). The resulting pre- and post-regressions were applied to the conditions represented by all the monitored storms, and median values for a complete set of pre- and post-BMP conditions were determined. The resulting average percent reductions based on the median values for the entire study period are given in table 7.

TABLE 7. AVERAGE PERCENT REDUCTIONS PREDICTED ACROSS ALL MONITORED STORMS USING SEPARATE PRE- AND POST-BMP REGRESSIONS TO ESTIMATE LOADS. [NEAR HERE]

Effects of Best-Management Practices in Eagle and Joos Valley Creeks

Eagle and Joos Valley Creeks are affected by a mixture of BMPs, and each BMP has varying success in controlling different aspects of the water quality, habitat, and biology of the streams. A similar mixture of BMPs is used in most Wisconsin Priority Watershed Projects that involve agricultural land uses. BMPs can be divided into five main categories: animal waste-management systems, streambank protection, fencing, nutrient management, and upland-management practices (table 1). A description of the BMPs and their potential effects on water quality was summarized in the results from an earlier evaluation-monitoring project (Graczyk and others, 2003). The same five categories of BMPs were used in two earlier evaluation-monitoring projects with some improvements in water quality (Graczyk and others, 2003; Corsi and others, 2005).

Effects of Best-Management Practices on Water Quality

Sampling results indicate a change in water quality in Joos Valley and Eagle Creeks when comparing base-flow concentrations and average loads in the pre- and post-BMP periods (tables 3 and 7). Median concentrations of suspended solids in base flow for Joos Valley and Eagle Creeks decreased 71 and 75 percent, respectively, while the median concentration of total phosphorus in base flow decreased 38 and 39 percent, respectively, and was statistically significant. There was a reduction of concentration of ammonia in base flow but this difference was not statistically significant. The reduction in average loads for suspended solids, total phosphorus, and ammonia nitrogen, as predicted by the pre- and post-BMP regression equations, ranged from 60 to 89 percent (table 7). The large reduction in median base-flow concentration and average loads observed in Joos Valley and Eagle Creeks should be reflective in high levels of implementation of BMPs. The levels of implementation of BMPs was less in the Joos Valley and Eagle Creek Watersheds as compared to previously studied watersheds (table 8). In most cases, the level of implementation in Joos Valley and Eagle Creek Watersheds was about two-thirds less than other watersheds studied.

TABLE 8. PERCENT OF ELIGIBLE BMPS IMPLEMENTED IN THREE EVALUATION-MONITORING STUDIES. [NEAR HERE]

Protecting the area in and around the two creeks was especially important, because the Buffalo County Land Conservation Department staff observed cows pasturing next to the channels or standing in the water along both creeks (T. Schultz, Land Conservation Buffalo County, WI. oral commun., 2009). Streambank erosion was especially severe along Joos Valley Creek where the cows were allowed to trample most of the banks. Streambank erosion, pasturing, and grazing in woodlots were considered major sources of suspended solids in the two study areas (Wisconsin

Department of Natural Resources, 1990). Implementation of the main BMP categories certainly contributed to the water-quality improvements in Joos Valley and Eagle Creeks. This fact alone does not seem to explain, however, why the reduction of median base-flow concentrations and loads is so high when the level of implementation of other BMPs is relatively low.

To help understand the reasons for the large improvements in water quality in Joos Valley and Eagle Creeks, the Buffalo County Land Conservation Department staff reviewed landowner records for any other changes not included in the main BMP categories. The most important item found in the records was the decrease in the number of farms without cows. Of the 25 farms that had cows at the beginning of the Waumandee Priority Watershed Project, only 7 farms had cows by the end of the project (T. Schultz, Land Conservation Buffalo County, WI., oral commun., 2009). Because the average herd size in the remaining seven farms did not increase appreciably, a loss of 18 farms with cows means a very large decrease in the number of cows in the study areas. Without the cows trampling the banks and grazing adjacent to the creek, the net effect on the stream water quality could be as effective as the implemented streambank protection and fence installation. Removing a large number of cows from the watershed also could explain the decrease in base-flow concentrations. Without the cows to re-suspend bottom sediments, the turbidity is reduced and so is the concentration of phosphorus associated with the solids. Improvements in base-flow quality for Garfoot Creek also were attributed to restricting access of the cows to the channel (Graczyk and others, 2003).

A reduction in the number of cows also would reduce pollutant loads from important sources further from the creeks. Upland pastures and woodlots would have time to return to more natural conditions, so they could no longer be an important source of suspended solids and total phosphorus. With fewer cows, less manure is stored in the barnyards and spread onto the fields.

The importance of reducing manure in the runoff is reflected in the large reduction in ammonia loads. Less manure in the runoff from the barnyards and fields also would reduce the loads of suspended solids and total phosphorus. A dramatic reduction in the number of cows likely played a substantial role in the observed improvements in water quality, because the presence of cows can affect the sources of pollutants, both around a stream channel and some distance from the channel.

Although reducing the number of cows in a watershed appears to contribute to improved water quality, it is not consistent with efforts to promote sustainable farming practices. It is possible that the reduction of cows in the watershed acted as a surrogate for the ability of fencing and streambank protection to improve water quality. Greater efforts to reduce the cows' access to the stream, use of proper manure and nutrient management, appropriate sites for grazing, and proper upland-management practices might produce water-quality benefits that are similar to those observed in this study.

Comparison of Results to the Pollutant Reduction Goals for the Waumandee Priority Watershed Project

The Nonpoint Source Control Plan for the Waumandee Priority Watershed Project (Wisconsin Department of Natural Resources, 1990) describes pollution-reduction goals and water-resource objectives for each of the 12 subwatersheds comprising the Waumandee Watershed. The study areas for Joos Valley and Eagle Creeks are in the Eagle Valley subwatershed. They occupy the upper half of the subwatershed and represent about 48 percent of the total subwatershed area. The pollutant-reduction goals for the Eagle Valley subwatershed are as follows:

- Reduce upland sediment loads for the entire subwatershed by 50 percent. The sources targeted for reducing the sediment load include cropland, pastures, and grazed woodlots.

- Reduce streambank erosion along Eagle Creek by 80 percent. This targets the entire length of Eagle Creek, not just the 7.41 mi in the study area.
- Reduce streambank erosion along Joos Valley and Baertch Valley Creeks by 60 percent.
- Reduce the top 70 percent of organic load from barnyards draining to Eagle Creek. Phosphorus runoff during the 10-year, 24-hour rainfall is an indication of organic load and bacteria entering the creek, so the reduction in organic load is the same as an equivalent reduction in phosphorus. This targets the entire length of Eagle Creek, not just the 7.41 mi in the study area.
- Reduce the top 50 percent of the organic load from barnyards draining to Joos Valley Creek.

The sediment and phosphorus reduction goals selected for the Eagle Creek subwatershed seem to have been achieved in the two study areas. The estimated reductions in average loads for suspended solids exceed the percentage-reduction goals for both the uplands and streambank erosion (table 9). This comparison is not entirely valid, however, because the suspended solids reductions measured in the study areas combine the effects of controlling both sources of sediment. A more useful comparison is to combine the reduction goals for uplands and streambank erosion into one goal; this can be done by using the annual sediment loads presented in the Waumandee Priority Watershed Plan. After multiplying the annual sediment loads predicted for each source by the desired percent reduction, the combined sediment-reduction goal for the entire subwatershed is 2,328 ton/yr (table 9). This represents a 58-percent reduction in the annual sediment load for the subwatershed. Since the measured percent suspended solids reductions are over 80 percent, the combined goal of 58 percent for the subwatershed easily is achieved in the two study areas.

TABLE 9. SEDIMENT REDUCTION GOALS FOR STREAMBANK EROSION AND UPLANDS IN THE EAGLE VALLEY SUBWATERSHED. [NEAR HERE]

If the only source of phosphorus in the study areas was the barnyards, the phosphorus-reduction goals for the barnyards were achieved in the two study areas. The reduction goals for organics are the same as for phosphorus, since the calculation for barnyard loads is done in terms of phosphorus. It is not clear if the measured reduction in total phosphorus is a result of barnyard work or the control of some other source, such as streambank erosion or proper spreading of manure. While it is not entirely possible to determine if the phosphorus goals for the subwatershed were achieved, it is obvious that a very large reduction in total phosphorus occurred in the two study areas.

Summary

Streamflow-gaging stations equipped for automated sample collection and continuous recording of stream stage and discharge were installed in July 1990 at Eagle and Joos Valley Creeks and operated through September 2007. In October 1990, three rain gages were installed in each basin and operated through September 2007. Eligible, contracted, and installed best-management practices (BMPs) for Eagle and Joos Valley Creeks were tracked throughout the study period. In 2001, a majority of the BMP-implementation goals set by the Wisconsin Department of Natural Resources (WDNR) and local Land Conservation Department had been achieved for the two study watersheds.

The distributions of the rainstorms that produced surface runoff and storm loads were similar in the pre- and post-BMP periods for both Eagle and Joos Valley Creeks. The highest annual streamflow occurred at both sites in water year 1993, which also corresponds to the greatest above-normal precipitation at the rain gages in both watersheds. The minimum streamflow occurred in water year 2007 at both sites. For both Eagle and Joos Valley Creeks, the median concentrations of suspended solids and total phosphorus during base flow were lower during the post-BMP period than the pre-BMP period. The decrease in the concentrations of ammonia nitrogen at both sites was not statistically significant at the 0.05 significance level. For both Eagle and Joos Valley Creeks, the median storm loads for suspended solids, total phosphorus, and ammonia nitrogen were lower during the post-BMP period than the pre-BMP period. Multiple linear-regression analysis was used to remove the affect of climatologic conditions and seasonality from computed storm loads. The decreases in pre- and post-BMP storm-load regression residuals for both Eagle and Joos Valley Creeks were statistically significant for suspended solids, total phosphorus, and ammonia nitrogen at the 0.05 significance level. Therefore, it is likely that the differences in pre- and post-BMP storm loads were owing to the BMPs installed during the study.

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