Prepared in cooperation with the Wisconsin Department of Natural Resources

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

Scientific Investigations Report 2011–5119

U.S. Department of the Interior
U.S. Geological Survey

Cover. Downstream view of the streamflow-gaging station at Eagle Creek.
Photograph by 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).

Abbreviations

BMPs	Best-management practices
EI	Erosivity index
GIS	Geographic Information System
NOAA	National Oceanic and Atmospheric Administration
Nonpoint Program	Wisconsin Nonpoint Source Water Pollution Abatement Program
USGS	U.S. Geological Survey
USLE	Universal Soil Loss Equation
WDNR	Wisconsin Department of Natural Resources

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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 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 watershed and were operated through September 2007. Best-Management Practices (BMPs) were installed during 1993 to 2000 in Eagle and Joos Valley Creeks and were tracked throughout the study period. By the year 2000, a majority of the BMPs were implemented in the two watersheds and goals set by the Wisconsin Department of Natural Resources and the local Land Conservation Department had been achieved for the two study watersheds (Wisconsin Department of Natural Resources, 1990).

The distributions of the rainstorms that produced surface runoff and storm loads were similar in the pre-BMP (1990–93) and post-BMP implementation (2000–07) periods for both Eagle and Joos Valley Creeks. The highest annual streamflow occurred at both sites in water year 1993, which corresponded to the greatest above normal nonfrozen precipitation measured at two nearby NOAA weather stations. The minimum streamflow occurred in water year 2007 at both sites. Base-flow and stormwater samples were collected and analyzed for suspended solids, total phosphorus, and ammonia nitrogen. For both Eagle and Joos Valley Creeks the median concentrations of suspended solids and total phosphorus in 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 median 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 effects 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 and were statistically significant at the 0.05 significance level. The decreases in storm-load regression residuals from the pre- to the post-BMP periods for both Eagle and Joos Valley Creeks were statistically significant for all three constituents at the 0.05 significance level and indicated an apparent improvement in water-quality in the post-BMP period. Because the rainfall characteristics for individual storms in the pre- and post-BMP periods are likely to be different, separate pre- and post-BMP regressions were used to estimate the theoretical pre- and post-BMP storm loads to allow estimates of precent reductions between the pre- and post-BMP periods. The estimated percent reductions in storm loads 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 apparent improvement in water quality is attributed to the implemented BMPs and to a reduction in the number of cattle 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 reducing nonpoint sources, the Wisconsin Nonpoint Source Water Pollution Abatement Program (Nonpoint Program) was enacted in 1978 (Wisconsin Department of Natural Resources, 1978). When first introduced, the Nonpoint Program identified problems in 130 of the 330 watersheds in Wisconsin. For a given watershed, various management actions, 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.

On the watershed scale little data exists 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, multidisciplinary 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, in western Wisconsin, from October 1990 to September 2007 to assess the hydrology and water quality before and after implementation of BMPs. Streamflow and water quality were collected at Eagle and Joos Valley Creeks, two subwatersheds within the Waumandee Creek Watershed.

Data was collected from October 1990 to September 1993, and is considered the pre-BMP period in the Eagle Creek Watershed. Data was collected from October 1990 to September 1992, and is considered the pre-BMP period in the Joos Valley Creek Watershed. No BMPs were implemented in either watershed 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 2000 is considered a transitional period in the Eagle Creek Watershed, with BMPs being implemented periodically throughout the period. The period October 1992–September 2000 is considered a transitional period in the Joos Valley Creek Watershed, with BMPs being implemented periodically throughout the period. In October 2000, sufficient BMPs were implemented in each watershed to begin the post-implementation period. Data collection began again in October 2002 and data was collected through September 2007; thus, the period October 2002–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 are compared and contrasted to the base-flow concentrations and storm loads for the defined post-BMP period. The effectiveness of implemented BMPs to improve the water quality in the watersheds is assessed. This report presents results for suspended solids, total phosphorus and ammonia nitrogen, constituents which were targeted for reduction in the priority watershed plan for the study area (Wisconsin Department of Natural Resources, 1990).

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), and 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). Joos Valley Creek supports a warm-water forage fishery, and has the potential to be reclassified to a Class III coldwater trout fishery (Wisconsin Department of Natural Resources, 1990). From 1972 to 2009, 34,894 yearling Brown Trout were stocked in Eagle Creek (Wisconsin Department of Natural Resources, 2010). Both streams have the potential to improve physical and biotic conditions that may improve the fish resources (Wisconsin Department of Natural Resources, 1990).

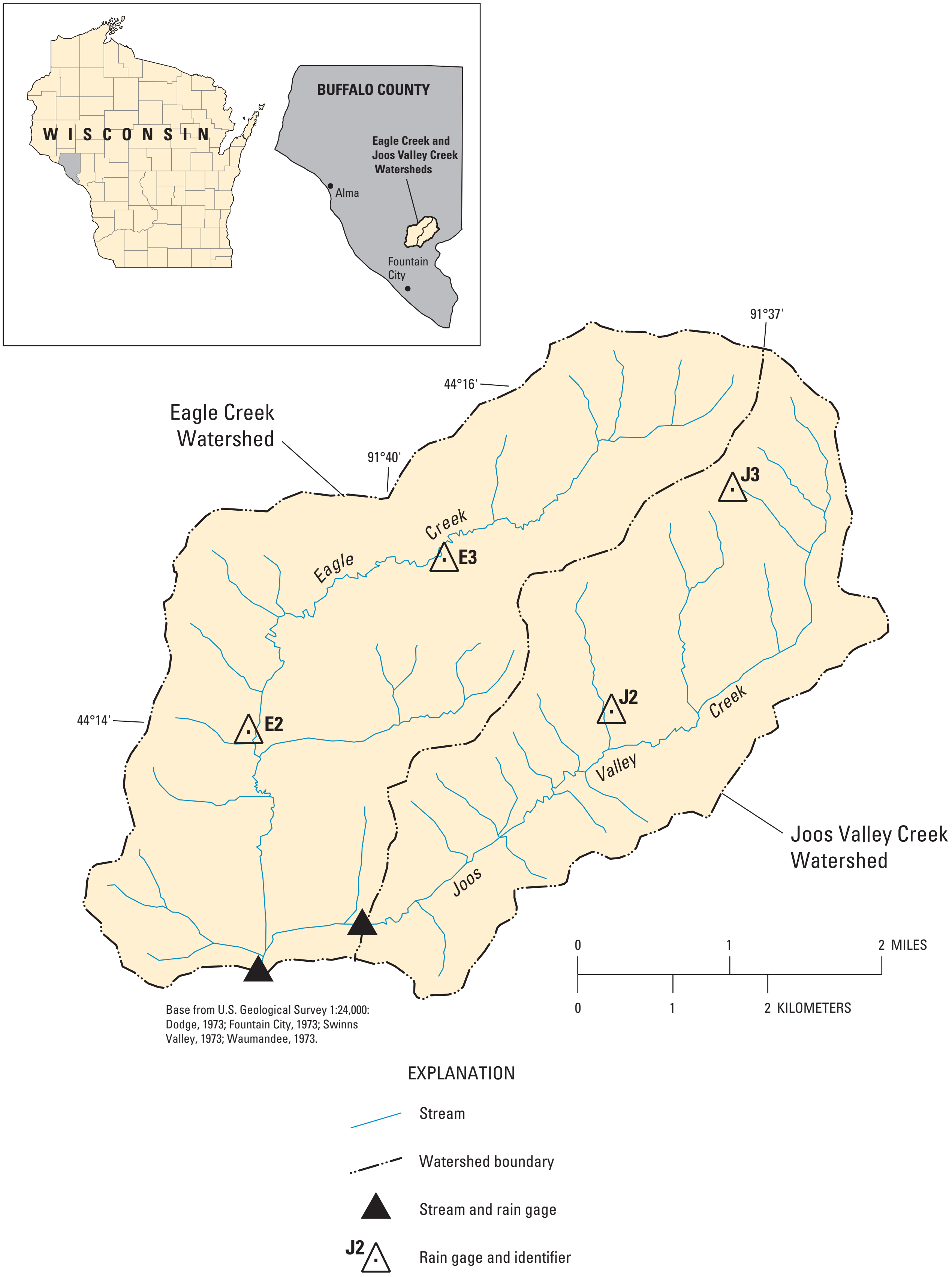
Eagle Creek drains 14.3 mi^2 upstream from the streamflow-gaging station, the stream channel is 7.41 mi long, and has a slope of 70 ft/mi. The soils of Eagle Creek primarily are silt loams; a majority of these soils are well drained with some poorly drained alluvial soils on level lands adjacent to the 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 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 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 automated collection of water samples during medium to high flows. A data logger was programmed to collect a sample with each 0.2 ft increase in stage after the stream stage reached an initial sampling threshold. On the falling limb of the hydrograph, a sample was 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



Base from U.S. Geological Survey 1:24,000:
Dodge, 1973; Fountain City, 1973; Swinns
Valley, 1973; Waumandee, 1973.

Figure 1. Location of the Eagle and Joos Valley Creek Watersheds in Buffalo County, Wis., and data-collection sites.

of interest were expected to change most rapidly. The samples, which were chilled to 4°C after collection, were analyzed for suspended solids, total phosphorus, and ammonia nitrogen. A subset of the samples that were collected during storm runoff was selected for analysis so as to represent the variation in water quality over the stream hydrograph.

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 either a hand-held sampler or a sampler suspended from the bridge (Edwards and Glysson, 1988). These samples were collected on a fixed time interval and analyzed for suspended solids, total phosphorus, and ammonia nitrogen. Concurrent manual integrated samples and automated pump samples were collected to assess the representativeness of the automated samples. In addition, sampler blanks were collected to assess possible contamination.

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, 2010).

In October 1990, three rain gages were installed in each watershed (fig. 1). One rain gage was at the stream gage; the other two rain gages were placed in locations that resulted 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).

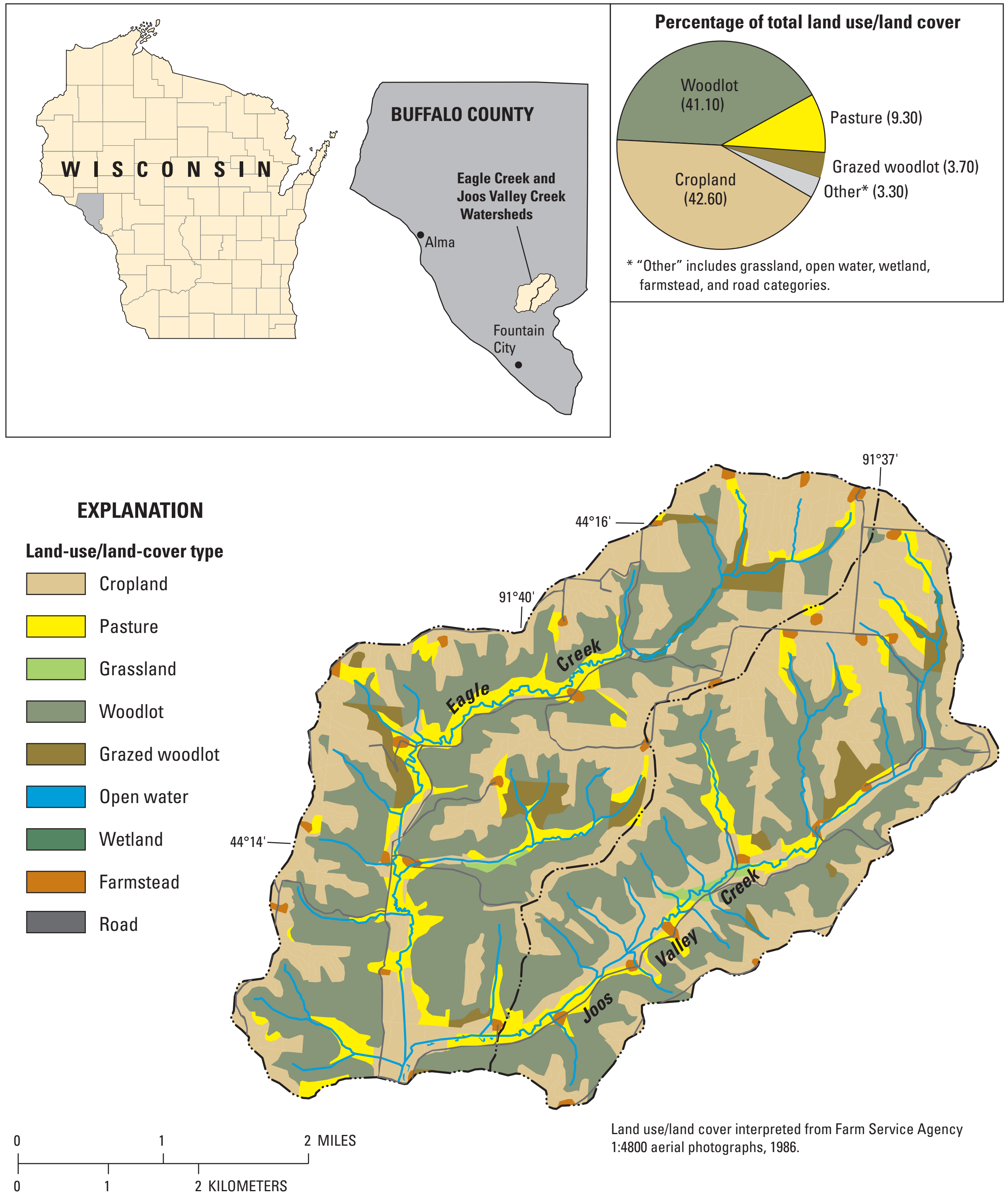
Land-Use and Best-Management Practices Inventory

Inventory of land uses and land treatment in the rural watersheds began in 1990 to provide information on changes that may affect water quality. A geographic information system (GIS) database retains the land-use and BMP inventories. Watershed boundaries, hydrography, roads, streams, woodlots, rain gages, and BMPs were digitized from 1:24000 topographic maps. Detailed descriptions of each watershed and its BMP programs are reported in Rappold and others (1997) and Wierl and others (1996). Targeted and implemented BMPs for Eagle and Joos Valley Creeks are summarized in Table 1. Total land use and land cover for Eagle and Joos Valley Creeks are 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 BMPs were obtained by contacting the Buffalo County Land Conservation Office. Barnyard-runoff control systems are implemented to reduce the amount

Table 1 . Summary of targeted and implemented rural BMPs in the Eagle and Joos Valley Creek Watersheds, Buffalo County, Wis.

[BMP, best-management practices]

Management practice	Targeted	Implemented	Targeted	Implemented
	Eagle Creek		Joos Valley Creek	
	Animal-waste management		Animal-waste management	
Manure storage (facilities)	4	3	3	0
Barnyard-runoff control systems (facilities)	11	8	7	2
	Streambank protection		Streambank protection	
Streambank protection (feet)	20,340	4,580	10,240	6,790
Fencing (feet)	12,730	1,940	10,950	1,700
Stream crossing (numbers of crossings)	7	2	2	1
Grade stablization (structures)	10	9	0	1
	Upland management		Upland management	
Nutrient management (acres)	562	470	437	0
Upland BMPs (acres)	1360	260	710	0



* "Other" includes grassland, open water, wetland, farmstead, and road categories.

Land use/land cover interpreted from Farm Service Agency 1:4800 aerial photographs, 1986.

Figure 2. Land use/land cover, Eagle and Joos Valley Creek Watersheds.

of manure 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 and 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 delivery to streams by use of a combination of cropland and manure management on highly erodible lands.

In 2000, a majority of the goals set by the WDNR and County Land Conservation Department had been achieved in the Eagle Creek and Joos Valley Creek Watersheds. Additional practices could be implemented for several years but it was believed that 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 (March–November) 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 Mondovi gage was above the 30-year normal for 3 years (fig. 3: 1992, 1993 and 2007) and below the 30-year normal for 5 years (fig. 3; 1991, 2003–05, and 2006). The 1993 precipitation was 11.88 in. (40 percent) above the 30-year long-term normal. The 2003 precipitation was 8.38 in. (28 percent) below the 30-year long-term non-freezing precipitation.

Precipitation at the La Crosse gage was above the long-term 30-year normal for 5 years (fig. 3: 1991, 1992, 1993, 2004 and 2007) and was below the 30-year normal for 3 years (fig. 3; 2003, 2005 and 2006). Precipitation in water year 1993 was 9.70 in. (32 percent) above the long-term normal.

Total event 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 precipitation events, with the total event precipitation ranging from 0.2 to 4.2 in. (fig.4). During the post-BMP period there was a somewhat higher percentage of precipitation events less than around 1.25 in., whereas during the pre-BMP period a slightly higher percentage of precipitation events in the pre-BMP period ranging from 1.25 to around 2 in. occurred. The occurrence of precipitation events exceeding 2 in. was roughly the same between the two periods.

In the Joos Valley Creek Watershed during the pre-BMP period, 21 storms had loads calculated with total event 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., whereas during the post-BMP period a slightly higher percentage of storms ranging from 1.75 to 2.25 in. occurred. The occurrence of storms exceeding around 2 in. was roughly the same between the two periods.

For the most part, the distributions of the rainstorms that were monitored and used to calculate storm loads were not dramatically different in the pre- and post-BMP periods for both Eagle and Joos Valley Creeks. At both sites, slightly more post-BMP periods were monitored compared to 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.

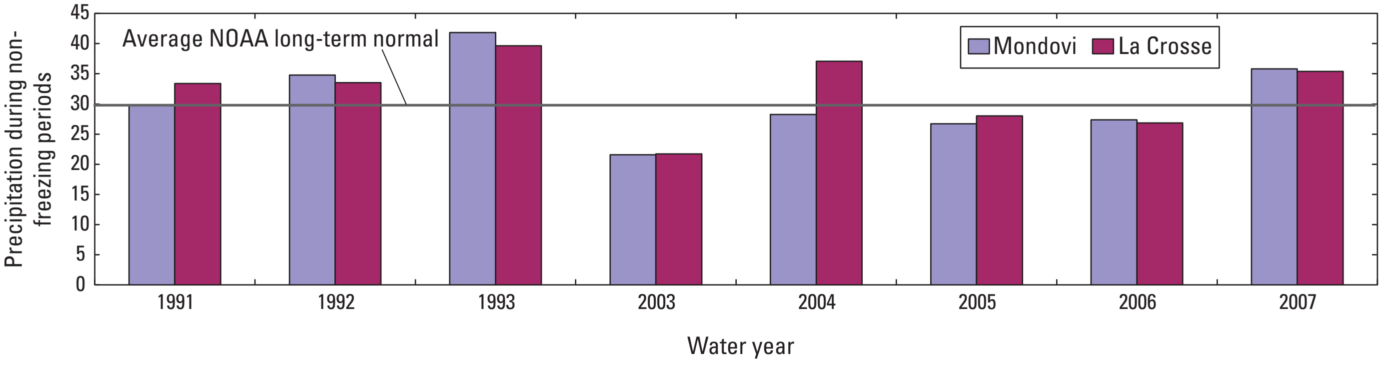


Figure 3. Yearly precipitation at Eagle and Joos Valley Creeks and average NOAA long-term normal at Buffalo County, Wis.

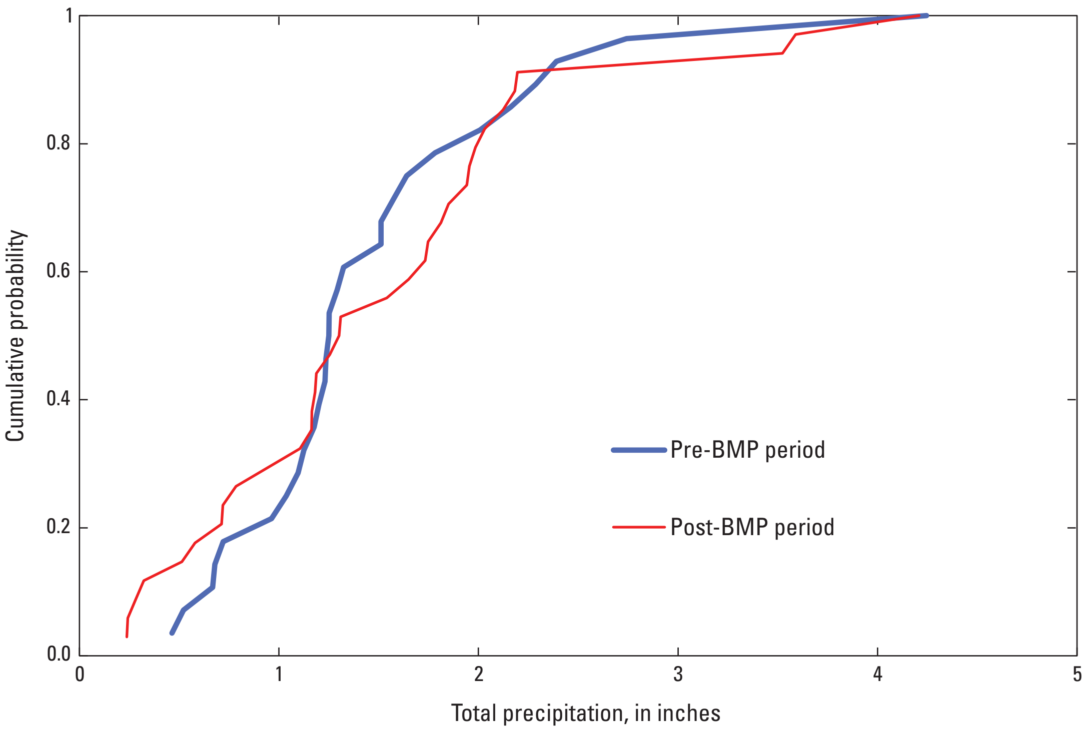


Figure 4. Cumulative distribution of precipitation events at Eagle Creek, Buffalo County, Wis., for periods in which storm loads were calculated.

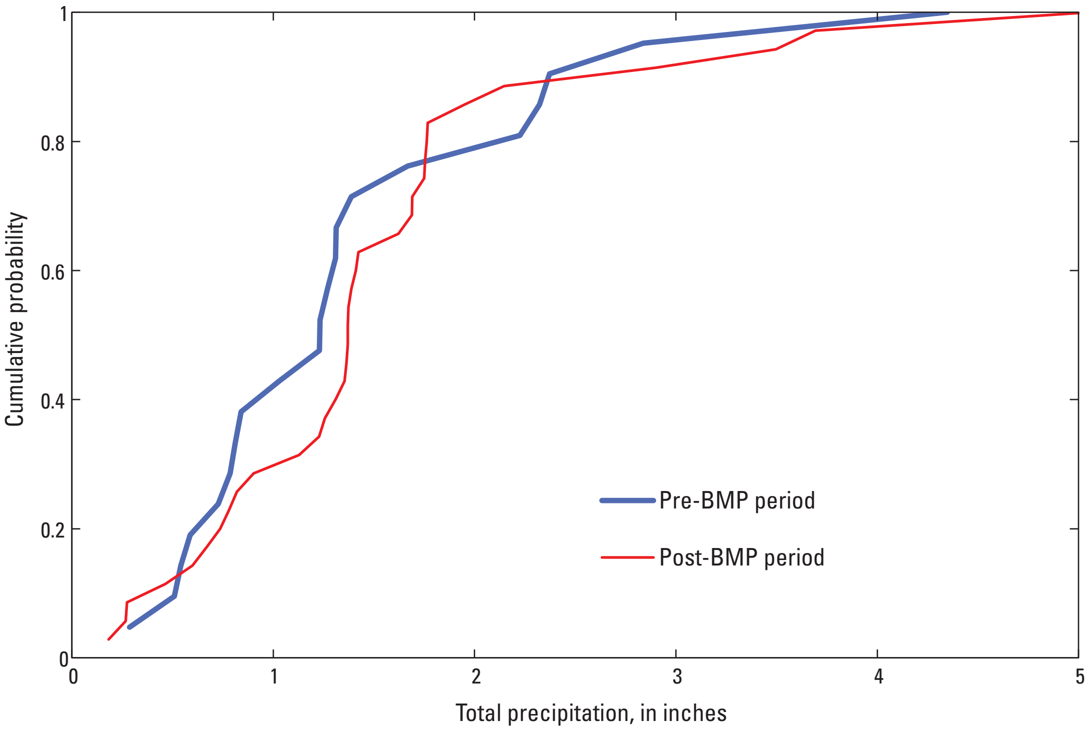


Figure 5. Cumulative distribution of precipitation events at Joos Valley Creek, Buffalo County, Wis., for periods in which storm loads were calculated.

Streamflow

Streamflow data collected as part of this study were used to determine the hydrologic conditions at Eagle Creek and Joos Valley Creek gaging stations (fig. 1). In addition, the streamflow data were needed to determine the nutrient and suspended solids loads at Eagle Creek and Joos Valley Creek gaging stations. Base flow represents sustained groundwater discharge to the stream. Daily mean streamflows were separated into daily mean base-flow and stormflow contributions by use of the fixed-interval hydrograph-separation 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 daily mean discharge and daily mean 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, 2004–08).

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; 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 during the study period —which is an indication of low flow—was 3.2 ft^3/s which occurred in water year 2007 (post-BMP period) (table 2 and fig. 6). The mean base flow for the study period was 7.91 ft^3/s (87 percent of the annual streamflow; 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).

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 7day low flow during the study period was 0.57 ft^3/s, which occurred in 2007 during 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).

Table 2. Summary of streamflow characteristics for Eagle and Joos Valley Creeks, pre- and post-BMP periods.

Streamflow characteristic (cubic feet per second, unless noted)	Eagle Creek			Joos Valley Creek		
	Pre-BMP period 10/90–9/93	Post-BMP period 10/02–9/07	Period of record	Pre-BMP period 10/91–9/92	Post-BMP period 10/02–9/07	Period of record
Mean annual streamflow	10.11	7.92	9.14	4.29	3.5	3.99
Minimum 7-day low flow	4.4	3.2	3.2	1.60	0.57	0.57
Mean base flow	8.68	6.86	7.91	3.72	2.88	3.37
Mean base flow percent[1]	86	87	87	87	83	85

[1] As a percentage of mean annual streamflow.

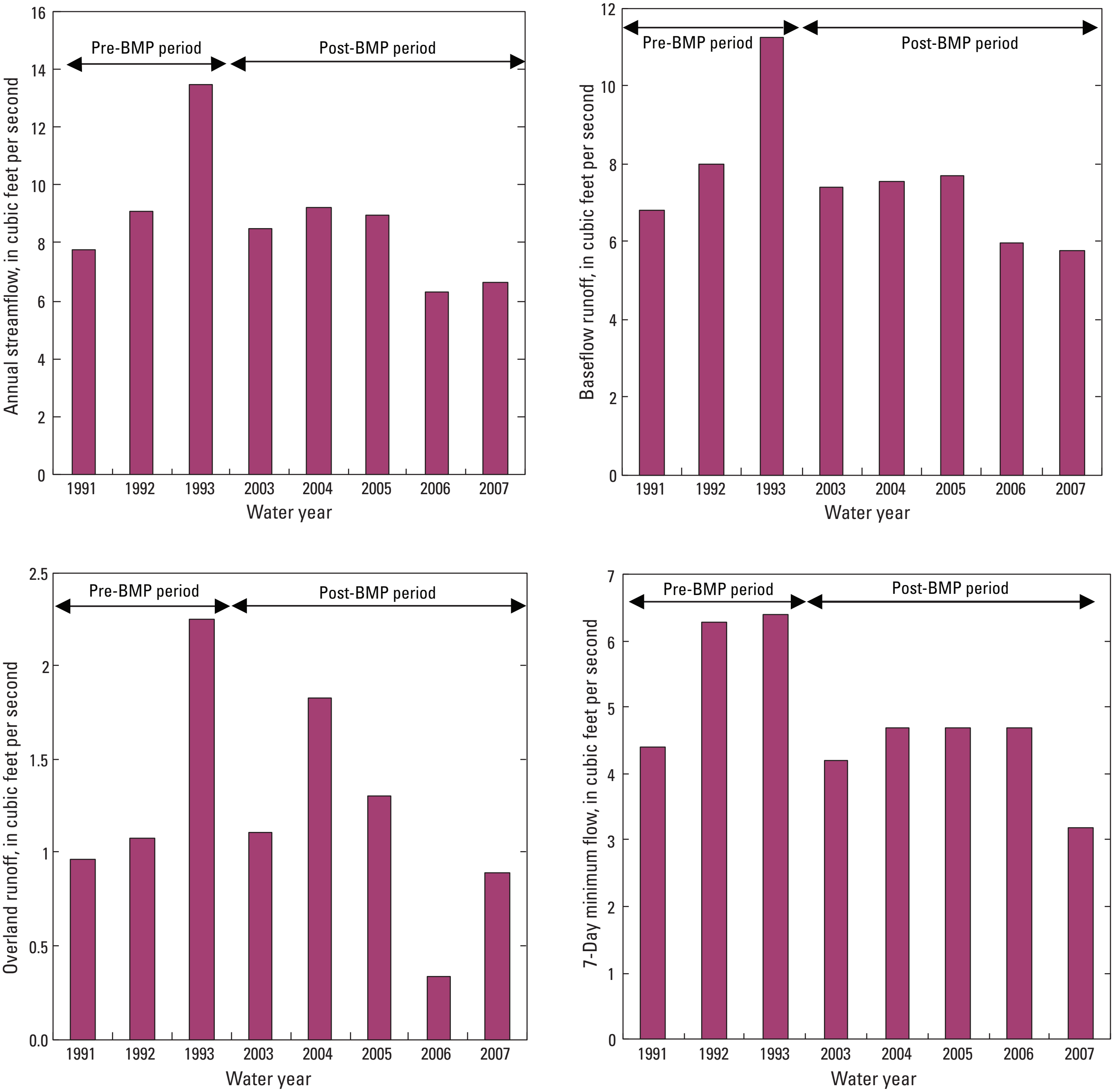


Figure 6. Streamflow characteristics for Eagle Creek, Buffalo County, Wis.

The maximum instantaneous peak flow was 1,480 ft^3/s and occurred on August 14, 1995 (Holmstrom and others, 1996).

The highest annual streamflow occurred at both sites in water year 1993, which corresponds to the greatest above normal precipitation in Eagle Creek watershed and the second greatest above normal precipitation in Joos Valley Creek Watershed. The minimum annual streamflow occurred in water year 2006 at both sites (figs. 6 and 7). 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

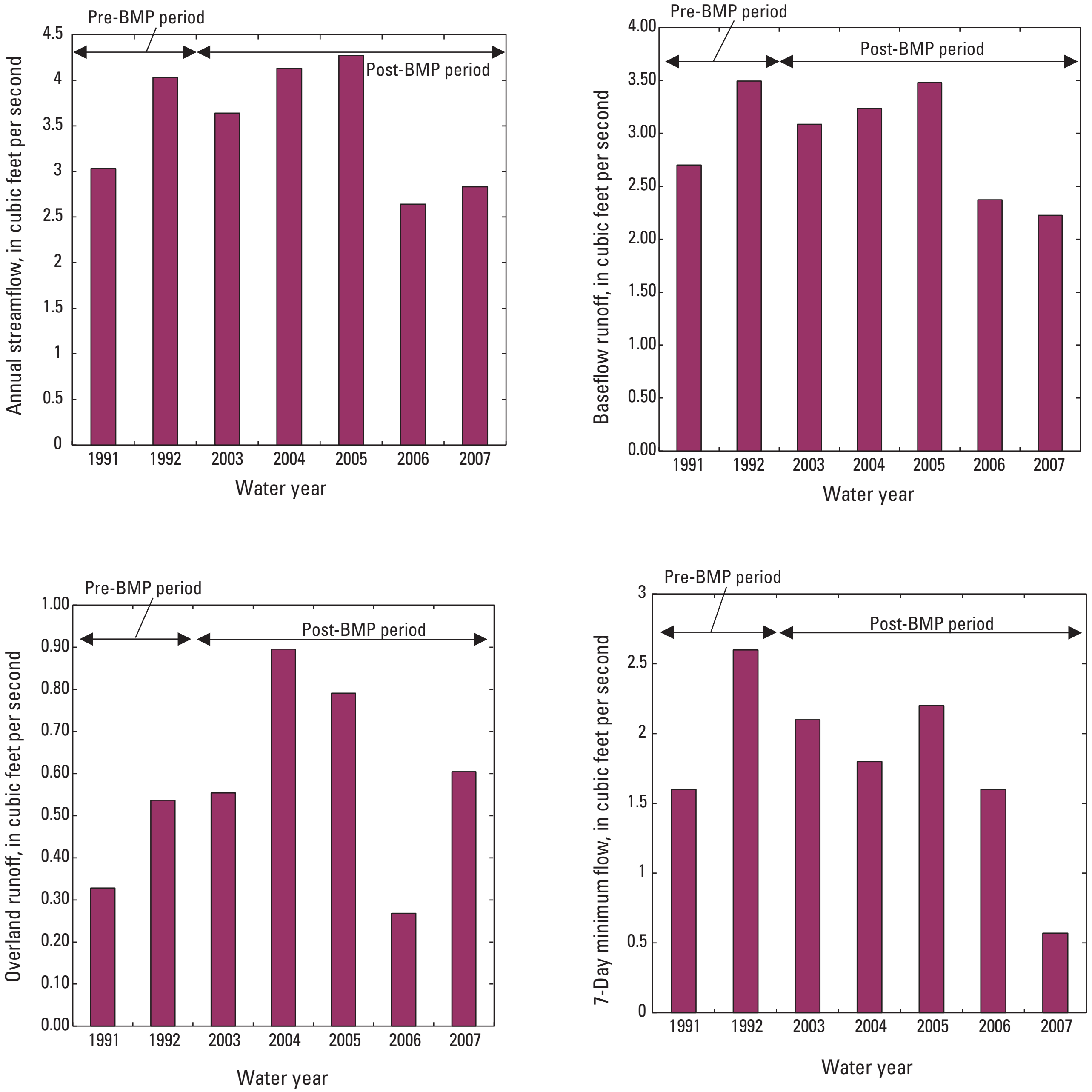


Figure 7. Streamflow characteristics for Joos Valley Creek, Buffalo County, Wis.

groundwater. Concentrations of nutrients, for example, may become elevated above background concentrations in groundwater as a result of agricultural activities (Dubrovsky and Hamilton, 2010).

Comparisons of the base-flow water-quality concentrations (suspended solids, total phosphorus and ammonia nitrogen) during the pre- and post-BMP periods may indicate changes that can be attributed to the implementation of BMPs. A nonparametric Wilcoxon rank-sum test (Helsel and Hirsch, 1992) can be used to determine whether significant differences are present between data from the two independent periods (pre- and post-BMP). The null hypothesis is that the median concentration of a selected constituent in base flow during the pre-BMP period is the same as that in base flows during the post-BMP period. The alternative hypothesis is that the median concentration in base flow during the post-BMP period is less than that 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.

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 significance level (table 3). The median 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 periods. An apparent decrease in the concentrations of ammonia nitrogen at both sites was not statistically significant at the 0.05 significance level.

Distribution and Seasonality of Loads

Daily load and storm-period loads were computed for suspended solids and total phosphorus; loads for ammonia nitrogen were computed for storm periods only. 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 GCLAS software implementation of the integration method was then

Table 3. Results of the Wilcoxon rank-sum test on the median concentrations of suspended solids and nutrients in base flow during, pre- and post-BMP periods, Eagle and Joos Valley Creeks, Wis.

[mg/L, milligrams per liter; BMP, best-management practice; < , less than; significance level =0.05]

Constituent	Pre-BMP period		Post-BMP period		Significance level
	Median concentration	Sample size	Median concentration	Sample size	
Eagle Creek					
Suspended solids (mg/L)	40.5	48	10.0	67	<0.001
Total phosphorus (mg/L)	.07	49	.047	66	<.001
Ammonia nitrogen (mg/L)	.027	49	.023	67	.350
Joos Valley Creek					
Suspended solids (mg/L)	37.5	40	11.0	67	<0.001
Total phosphorus (mg/L)	.08	36	.05	66	<.001
Ammonia nitrogen (mg/L)	.028	39	.023	67	.422

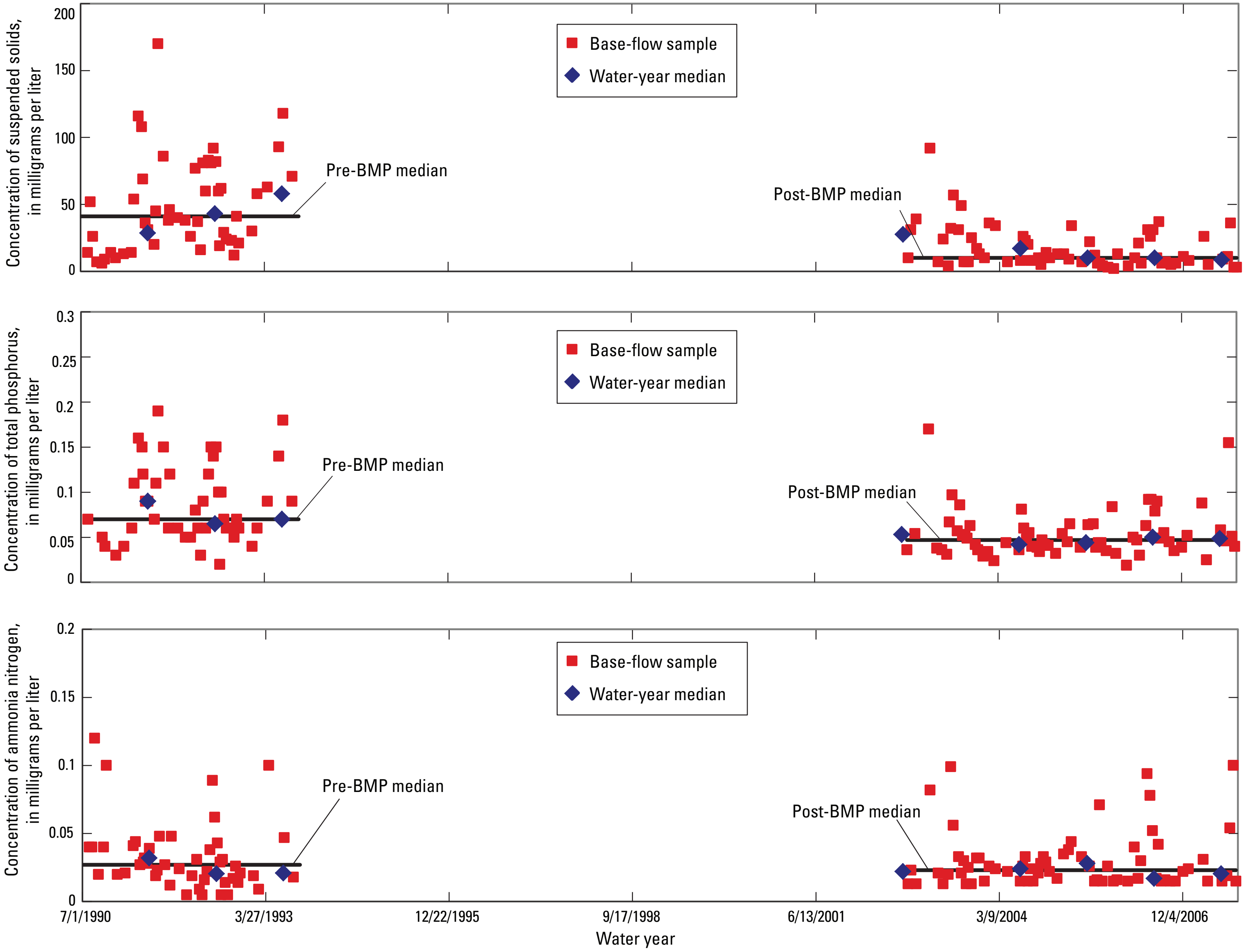


Figure 8. Concentrations and water-year medians of suspended solids and nutrients in base-flow samples during the data-collection period at Eagle Creek, Buffalo County, Wis.

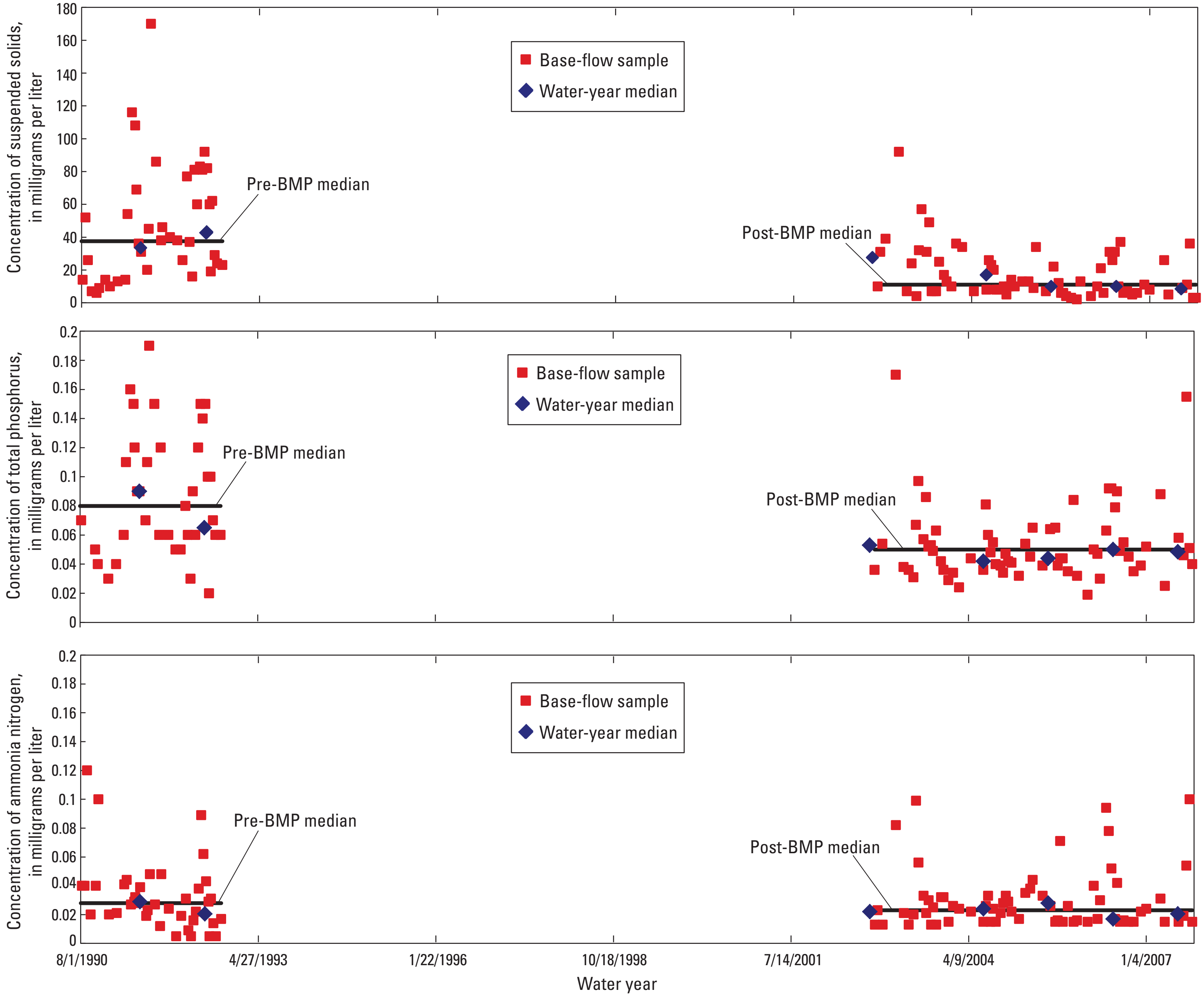


Figure 9. Concentrations and water-year medians of suspended solids and nutrients in base-flow samples during the data-collection period at Joos Valley Creek, Buffalo County, Wis.

used to determine the mass transport of each constituent for both daily and storm periods (Koltun and others, 2006). 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 concentrations within a storm period were kept to a minimum. A summary of the number of samples and estimated concentrations for the storm loads computed during the pre- and post-BMP periods is given in table 4. Daily suspended solids and total phosphorus loads 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, 2004–08).

At Eagle Creek, 54 percent of the suspended solids transported during the study period occurred during the months of March, April and May (fig.10). A total of 2 percent of the suspended solids transported during the study period occurred during the months of October, December, and January (fig. 10). A total of 50 percent of total phosphorus loads transported during the study period occurred during the months of March, April and May. A total of 3 percent of total phosphorus transported during the study period occurred during the months of October, December, and January (fig. 10).

At Joos Valley Creek, 51 percent of the suspended solids load transported during the study period occurred during the months of March, April and June (fig. 11). Less than 1 percent of the suspended solids transported during the study period occurred during the months of October, December and January. A total of 53 percent of total phosphorus loads transported during the study period occurred during the months of March, May, and June (fig.11). A total of 2 percent of total phosphorus transported during the study period occurred during the months of October, December, and January.

Table 4. Summary of number of samples and estimated concentrations used in computing storm loads during the pre- and post-BMP periods

	Suspended solids samples	Suspended solids estimates	Total phosphorus samples	Total phosphorus estimates	Ammonia nitrogen samples	Ammonia nitrogen estimates
Eagle Creek						
Minimum	1	0	1	0	1	0
Median	4	3	4	3	4	2
Maximum	19	9	21	8	20	6
Joos Valley Creek						
Minimum	1	1	1	1	1	1
Median	4	3	4	3	4	2
Maximum	18	8	18	12	18	8

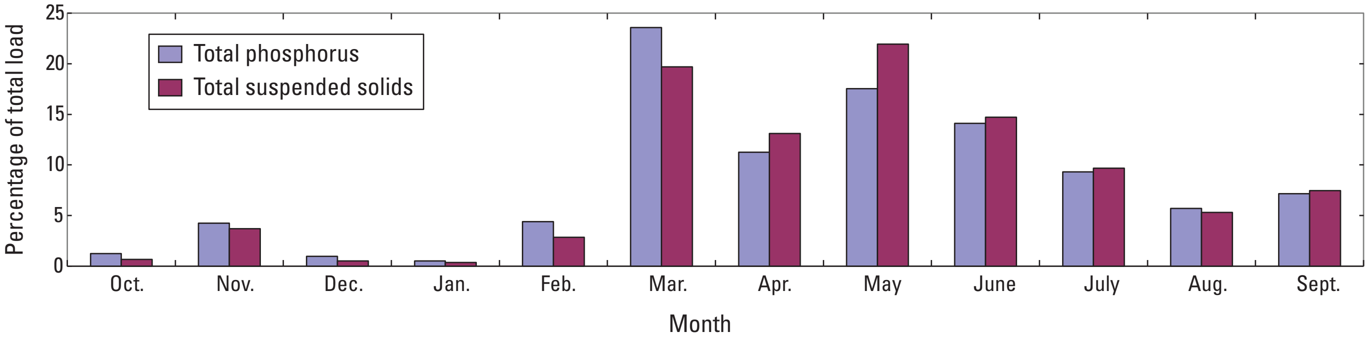


Figure 10. Average monthly distribution of total phosphorus and suspended solids loads at Eagle Creek, Buffalo County, Wis., for water years 1991–94 and 2003–07.

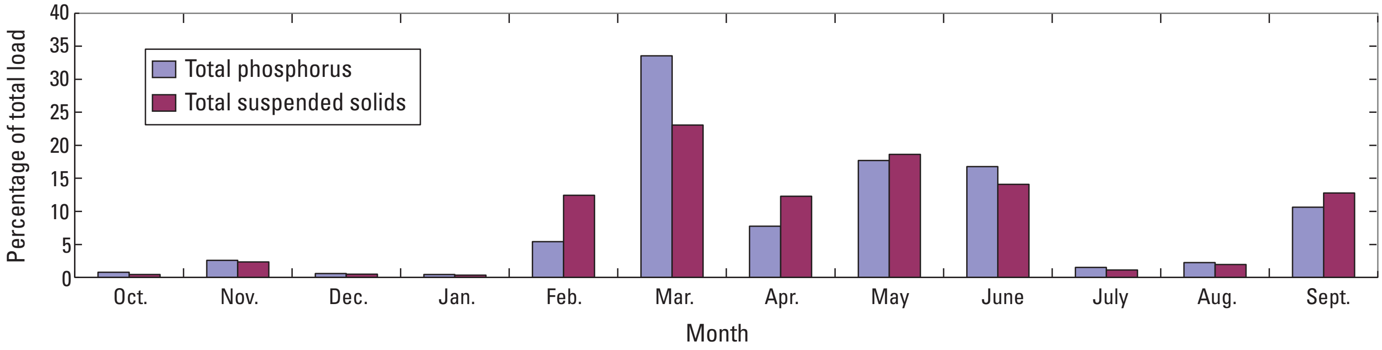


Figure 11. Average monthly distribution of total phosphorus and suspended solids loads at Joos Valley Creek, Buffalo County for water years 1991–94 and 2003–07.

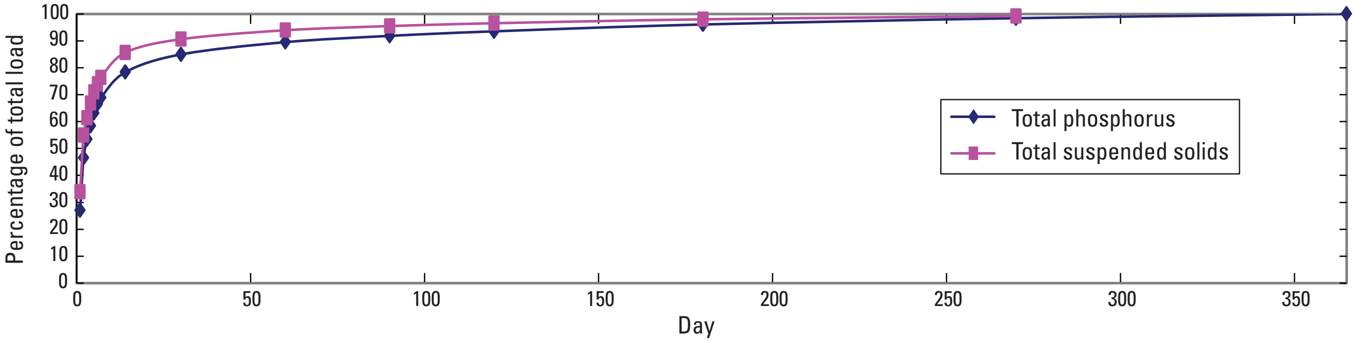


Figure 12. Daily distribution of total phosphorus and suspended solids loads at Eagle Creek, Buffalo County, Wis., for water years 1991–94 and 2003–07

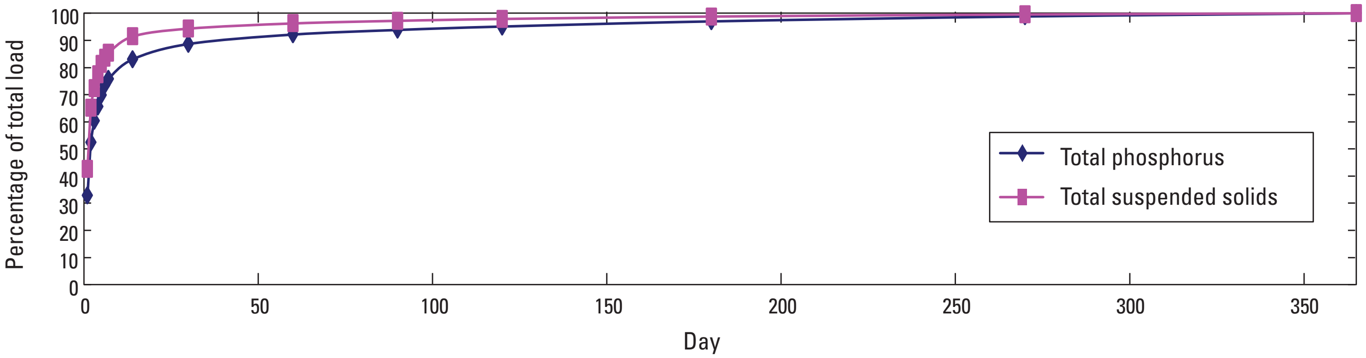


Figure 13. Daily distribution of total phosphorus and suspended solids loads at Joos Valley Creek, Buffalo County, Wis., for water years 1991–94 and 2003–07.

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 was 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 were 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).

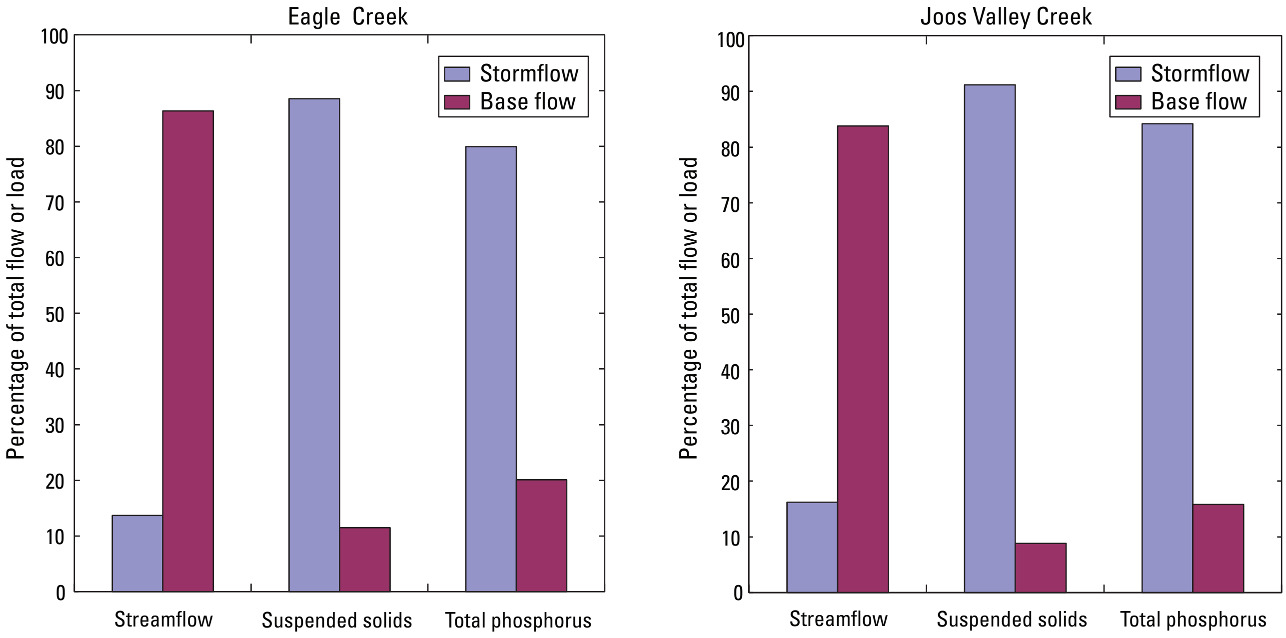


Figure 14. Annual contributions of stormflow and base-flow periods to streamflow, suspended solids and total phosphorus loadings at Eagle and Joos Valley Creeks, Buffalo County, Wis., for water years 1991–2007.

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 majority 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.

The median storm loads and storm-load regression residuals for all three constituents for the pre- and post-BMP periods are listed in table 5 and figs. 15 and 16, respectively. 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 were 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).

Although the general hydrologic conditions were similar during the pre- and post-BMP periods, different rainfall characteristics and seasonal factors could produce differences in storm loads that are not a result of the management practices. To overcome the obstacle that different rainfall characteristics and seasonal factors can complicate the interpretation of changes in data, three statistical analyses were performed: (1) development of regression equations to identify significant variables related to climatic and seasonal factors; (2) analysis of the storm-load regression residuals that were generated by these equations; and (3) development of separate pre- and post-BMP regression equations.

Regressions relating the storm loads to variables representing climatic and seasonal conditions were used to reduce the natural variability due to climatic and seasonal factors. If the independent variables represent the natural climatic and seasonal conditions, then the variability remaining in the regression residuals (the difference between the measured value and the value predicted by the regression equation) 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 (Walker, 1994).

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 (Helsel and Hirsch, 1992).

Table 5. Results of the Wilcoxon rank-sum test comparing median storm loads and storm-load residuals for pre- and post-BMP periods.

[<, less than, significance level =0.05]

	Median storm loads[1]				Storm-load residuals	
Constituent	Pre-BMP period	Post-BMP period	Z-value	Significance level	Z-value	Significance level
Eagle Creek						
Suspended solids	121	22.5	3.638	0.000	5.162	<0.001
Total phosphorus	248	75.4	3.186	.0014	4.113	<.001
Ammonia nitrogen	25.0	15.2	1.872	.0613	4.102	<.001
Joos Valley Creek						
Suspended solids	19.7	3.4	3.195	0.001	4.094	<0.001
Total phosphorus	56.7	15.3	2.588	.0097	3.851	.0001
Ammonia nitrogen	8.43	2.76	2.976	.0029	3.972	<.001

[1] Suspended-solids loads are in tons; loads of other constituents are in pounds.

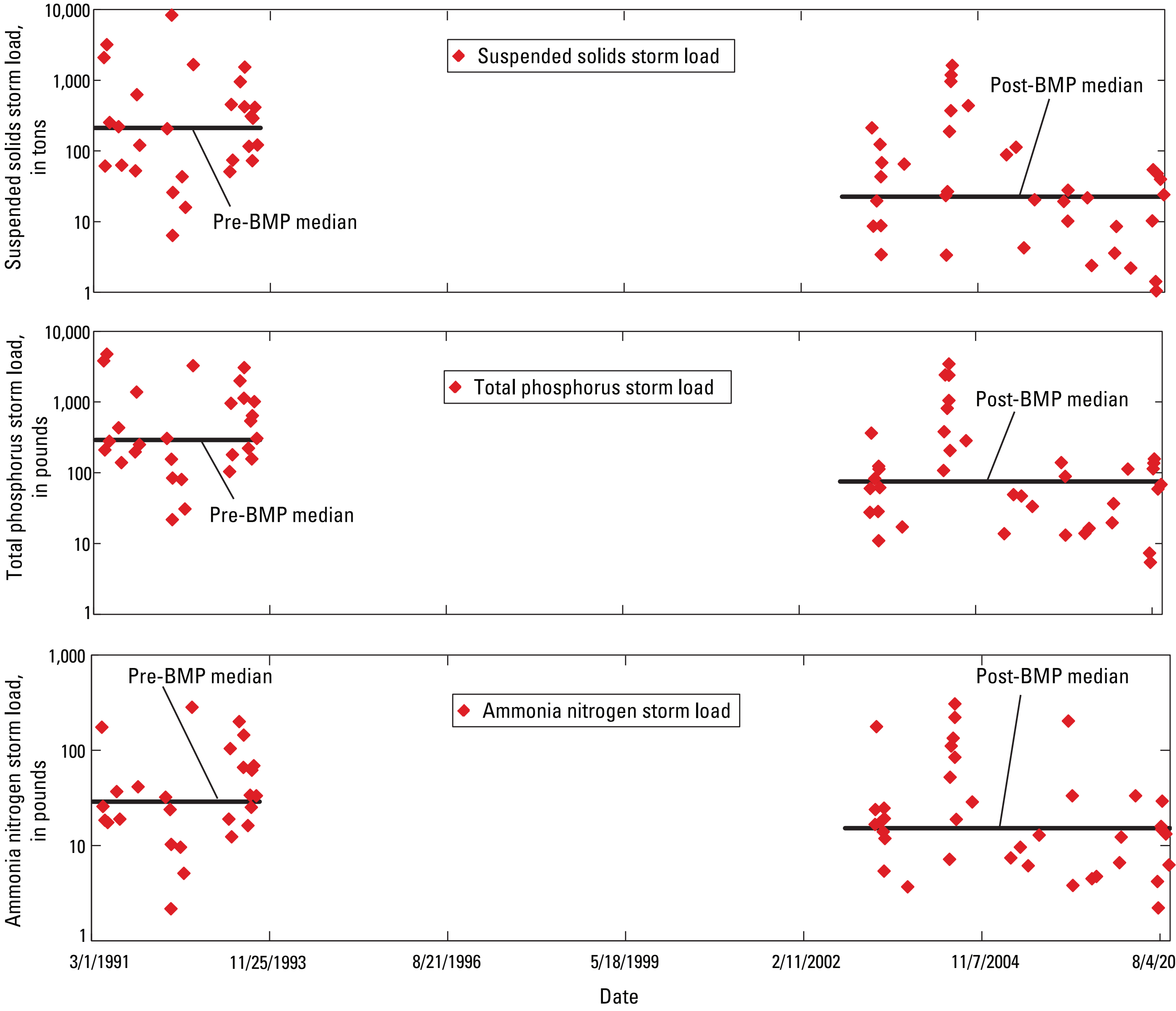


Figure 15. Suspended solids, total phosphorus and ammonia nitrogen storm loads and median storm loads during the pre- and post-BMP period at Eagle Creek in Buffalo County, Wis.

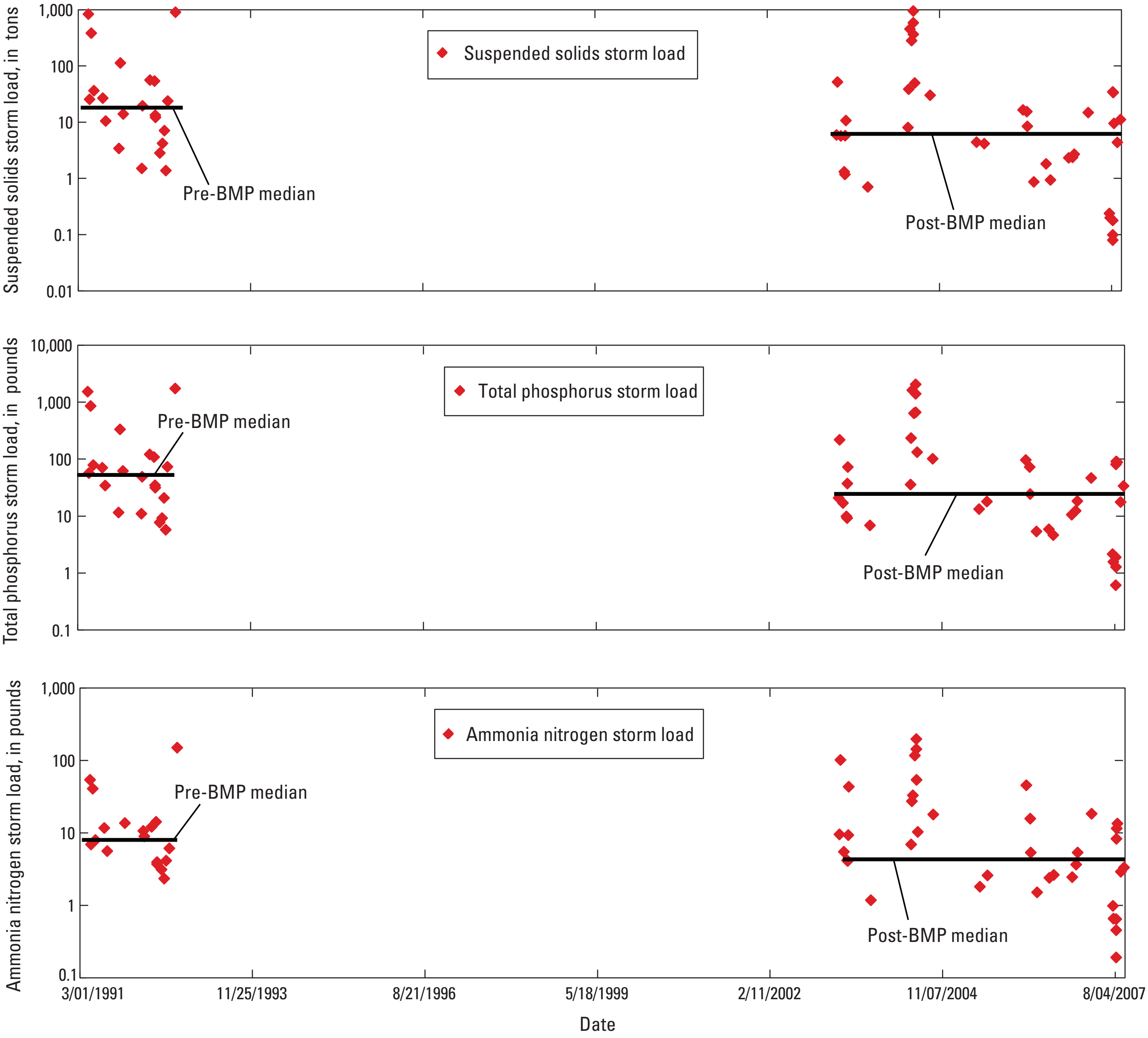


Figure 16. Suspended solids, total phosphorus and ammonia nitrogen storm loads and median storm loads during the pre- and post-BMP periods at Joos Valley Creek in Buffalo County, Wis.

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 on the combined pre- and post-BMP periods 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.

A second statistically based indication of the effects of the BMP implementation can be identified by an analysis of the differences in the storm-load regression residuals between the two periods, which would represent variability in the loads not explained by climatic and seasonal influences. 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 level (table 5, significance level for storm-load regression residuals). Therefore, the differences in pre- and post- BMP storm loads likely are owing to the BMPs implemented.

A third analysis was used to provide estimates of the percent change between the pre- and post-BMP periods. 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. Separate regressions were used because the seasonal and storm rainfall characteristics were different for the pre- and post-BMP periods. The difference in the loads predicted by the pre- and post-BMP regressions represents a theoretical reduction in load for each storm. 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 the storms in the pre- and post-BMP periods, and median values across all the storms were determined. The resulting average percent reductions were based on the median values for the entire study. In general, the likely percent reduction in suspended solids (89 and 84 percent), total phosphorus (77 and 67 percent) and ammonia nitrogen (66 and 60 percent) at Eagle and Joos Valley Creeks, respectively (table 7) are much greater than expected. Load reductions were greater in the Eagle Creek watershed than in the Joos Valley Creek watershed.

Table 6. Regression results for storm loads at Eagle and Joos Valley Creeks, Wis.

[I_n, n-maximum precipitation intensity; P, total precipitation; API_n, n-day antecedent precipitation; T, serial date of storm; EI, USLE erosivity index; R^2, fraction of the variance of response variables explained by the explanatory variables for the model; < , less than ; values in **bold** are statistically significant at the 0.05 level]

Dependent variable	Independent variables	Sample size	Significance level	Adjusted R^2	Standard error	Standard error, in percent
Eagle Creek						
Suspended solids	P, EI, sin(T), cos(T)	73	**<0.001**	0.254	1.80	295
Total phosphorus	EI	73	**<.001**	.248	1.55	225
Ammonia nitrogen	I_{15}, EI, $P+API_1$, sin(T), cos(T)	73	**<.001**	.338	1.15	142
Joos Valley Creek						
Suspended solids	$P+API_2$, sin(T), cos(T)	43	**<0.001**	0.558	1.42	195
Total phosphorus	$P+API_2$, sin(T), cos(T)	43	**<.001**	.617	1.09	132
Ammonia nitrogen	$P+API_2$, sin(T), sin(T)	43	**<.001**	.518	1.00	117

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 influencing 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 storm 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 concentrations of total phosphorus in base flow decreased 38 and 33 percent, respectively, these decreases were statistically significant. There was a reduction of concentration of ammonia in base flow but this difference was not statistically significant. The reduction in average storm 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 reductions in median base-flow concentrations and average storm loads observed in Joos Valley and Eagle Creeks should be indicative of very high levels of BMP implementation. The levels of BMP implementation were less in the Joos Valley and Eagle Creek Watersheds as compared to previously studied watersheds (table 8; Corsi and others, 2005; Graczyk and others, 2003). In most cases, the level of BMP implementation in Joos Valley and Eagle Creek Watersheds was about two-thirds less than other watersheds studied.

Protecting the area in and around the two creeks was especially important, because the Buffalo County Land Conservation Department staff observed livestock pasturing next to the channels or standing in the water along both creeks (T. Schultz, Land Conservation Buffalo County, Wis. verbal commun., 2009). Streambank erosion was especially severe along Joos Valley Creek where the livestock 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 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 BMPs is relatively modest.

Table 7. Average percent reductions predicted across all monitored storms using separate pre- and post-BMP regressions to predict storm loads.

	Median predicted loads		
Variable	**Pre-BMP**	**Post-BMP**	**Percent reduction**
	Eagle Creek		
Suspended solids (tons)	156	17.0	89
Total phosphorus (lb)	246	57.5	77
Ammonia nitrogen (lb)	36.9	12.6	66
	Joos Valley Creek		
Suspended solids (tons)	21	3.4	84
Total phosphorus (lb)	55	18.0	67
Ammonia nitrogen (lb)	11.0	4.5	60

Table 8. Percentage of eligible BMPs implemented in three priority watershed evaluation-monitoring projects, Wisconsin.

[NA, information not available]

Type of BMP	Eagle Creek[1]	Joos Valley Creek[1]	Otter Creek[2]	Garfoot Creek[3]	Brewery Creek[3]
	Animal-waste management				
Manure storage	25	100	75	NA	NA
Barnyard runoff control systems	54	57	100	70	50
	Stream bank protection				
Streambank protection	35	36	94	100	86
Fencing	36	25	100	100	0
Grade stabilization	80	0	100	100	100
	Upland management				
Nutrient management	41	0	100	26	58
Upland BMPs	19	0	54	19	22

[1] Waumandee Prority Watershed Project (current study).

[2] Sheboygan River Priority Watershed Project (Corsi and others, 2005).

[3] Black Earth Priority Watershed Project (Graczyk and others, 2003).

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 with cattle. Of the 25 farms that had livestock at the beginning of the Waumandee Priority Watershed Project, only 7 farms had cattle by the end of the project (T. Schultz, Land Conservation Buffalo County, WI., verbal commun., 2009). Because the average herd size in the remaining 7 farms did not increase appreciably, a loss of 18 farms with cattle means a very large decrease in the number of cattle in the study areas. Without the cattle 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 cattle from the watershed also could explain the decrease in base-flow concentrations of suspended solids and total phosphorus. Without the cattle 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 in the Black Earth Creek watershed also were attributed to restricting access of the livestock to the channel (Graczyk and others, 2003).

A reduction in the number of cattle 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 would no longer be an important source of suspended solids and total phosphorus. With fewer cattle, 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 cattle likely played a substantial role in the observed improvements in water quality, because the presence of cattle can affect the sources of pollutants, both around a stream channel and some distance from the channel.

Although reducing the number of cattle 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 livestock in the watershed acted as a surrogate for the ability of fencing and streambank protection to improve water quality. Greater efforts to reduce livestock 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 Creek Priority Watershed Project

The Nonpoint Source Control Plan for the Waumandee Creek 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 Creek Priority Watershed. Eagle Valley Creek is one of the 12 subwatersheds, and contains both Eagle and Joos Valley Creek. The pollutant-reduction goals for the Eagle Valley Creek 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 Creek by 60 percent.
- Reduce the organic load from the “top” 70 percent of barnyards draining to Eagle Creek. This targets the entire length of Eagle Creek, not just the 7.41 mi in the study area.
- Reduce the organic load from the “top” 50 percent of barnyards draining to Joos Valley Creek.

The organic load represents the sum of the phosphorus, nitrogen and organic material that originates from manure washed off from barnyards as a result of the 10-year, 24-hour rainfall event. 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 likely proportional to a reduction in phosphorus.

The sediment and phosphorus reduction goals selected for the Eagle Creek Watershed seem to have been achieved in the two study areas. Analytical methods for suspended solids and suspended sediment are different and the results of the two analytical methods are not comparable (Gray and others, 2000). Because the comparison is in the percentage of changes of loads and not actual loads and the erosional and transport properties are the same for both constituents, a comparison between the percentage reductions in the overall sediment loads and those of the median suspended solids loads can be considered valid. 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 BMPs on both sources of sediment.

Table 9. Sediment-reduction goals for streambank erosion and uplands in the Eagle and Joos Valley Creek subwatersheds.

Sediment source	Annual sediment load, in tons per year[1]	Reduction goal, in percent	Reduction in annual sediment load, in tons per year
Cropland	1,480	50	740
Pasture and grazed woodlots	1,210	50	605
Streambank erosion—Eagle Creek	890	80	712
Streambank erosion—Joos Valley Creek	439	60	263
Streambank erosion—Tributaries to Eagle Creek	13	60	8
Totals	4,032		2,328

[1] Wisconsin Department of Natural Resources, 1990.

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 Creek 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.

If one assumes that the major source of phosphorus in the study areas was from barnyards, then the phosphorus-reduction goals for the barnyards (50 percent) would be achieved in the two study areas, which showed total phosphorus reductions of at least 67 percent. 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 manure spreading practices. 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 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 watershed and operated through September 2007. Implemented best-management practices (BMPs) for Eagle and Joos Valley Creeks were tracked throughout the study period; BMPs were implemented during 1993-2000. In 2000, 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. Base-flow and storm-water samples were collected and analyzed for suspended solids, total phosphorus, and ammonia nitrogen. Data results were compared for the pre-BMP (1990–93) and post-BMP (2002–07) periods.

For the most part, the distributions of the rainstorms that were monitored and used to calculate storm loads were not dramatically different 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 significantly 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 analyses were used to remove the effects 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. Separate pre- and post-BMP regressions were used to estimate the likely percent reduction in suspended solids (89 and 84 percent), total phosphorus (77 and 67 percent) and ammonia nitrogen (66 and 60 percent) at Eagle and Joos Valley Creeks, respectively.

These differences in the pre- and post-BMP storm-load regression residuals were attributed to the BMPs that were implemented during the study period combined with a decrease in the number of farms with livestock, which mimicked the water-quality benefits of BMPs, such as fencing and streambank protection.

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