Wat. Sci. Tech. Vol. 28, No. 3-5, pp. 539–548, 1993.

0273–1223/93 $24·00

PRELIMINARY EVALUATION OF EFFECTS OF BEST MANAGEMENT PRACTICES IN THE BLACK EARTH CREEK, WISCONSIN, PRIORITY WATERSHED

John F. Walker and David J. Graczyk

U.S. Geological Survey, Water Resources Division, 6417 Normandy Lane, Madison, WI 53719, USA

ABSTRACT

Nonpoint-source contamination accounts for a substantial part of the water quality problems in many watersheds. The Wisconsin Nonpoint Source Water Pollution Abatement Program provides matching money for voluntary implementation of various best management practices (BMPs). The effectiveness of BMP s on a drainage-basin scale has not been adequately assessed in Wisconsin by use of data collected before and after BMP implementation.

The U.S. Geological Survey, in cooperation with the Wisconsin Department of Natural Resources, monitored water quality in the Black Earth Creek watershed in southern Wisconsin from October 1984 through September 1986 (pre-BMP conditions). BMP implementation began during the summer of 1989 and is planned to continue through 1993. Data collection resumed in fall 1989 and is intended to provide information during the transitional period of BMP implementation (1990-93) and 2 years of post-BMP conditions (1994-95).

Preliminary results presented for two subbasins in the Black Earth Creek watershed (Brewery and Garfoot Creeks) are based on data collected during pre-BMP conditions and the first 3 years of the transitional period. The analysis includes the use of regressions to control for natural variability in the data and, hence, enhance the ability to detect changes. Data collected to date (1992) indicate statistically significant differences in storm mass transport of suspended sediment and ammonia nitrogen at Brewery Creek. The central tendency of the regression residuals has decreased with the implementation of BMPs; hence, the improvement in water quality in the Brewery Creek watershed is likely a result of BMP implementation. Differences in storm mass transport at Garfoot Creek were not detected, primarily because of an insufficient number of storms in the transitional period. As practice implementation continues, the additional data will be used to determine the level of management which results in significant improvements in water quality in the two watersheds. Future research will address techniques for including snowmelt runoff and early spring storms.

KEYWORDS

Nonpoint pollution sources; water quality management; statistical methods; agricultural runoff; storm runoff; surface water; regression analysis; sediment erosion; erosion control; nutrients

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.

The U.S. Geological Survey (USGS), in cooperation with the Wisconsin Department of Natural Resources (WDNR), studied the Black Earth Creek watershed in southern Wisconsin from October 1984 through September 1986 to assess the hydrology, aquatic macrophytes, and water quality of Black Earth Creek and its tributaries. Streamflow and water-quality data were collected continuously at one site on a cold-water trout stream (Garfoot Creek near Cross Plains) and one site on a warm-water stream (Brewery Creek at Cross Plains).

The information presented in a report from that study included determination of (1) streamflow, (2) aquatic macrophyte species and biomass, (3) suspended-sediment, total phosphorus, and total nitrogen loads, (4) miscellaneous water-quality characteristics, (5) water temperatures, and (6) concentrations of dissolved oxygen (Field and Graczyk, 1990). Data from that study was used to develop a plan for the control of nonpoint-source runoff and related resource management in the Black Earth Creek watershed (Wisconsin Department of Natural Resources, 1989).

This paper summarizes the interim results of a subsequent evaluation of the effectiveness of watershed-management practices for controlling nonpoint-source contamination for two small rural watersheds. The data for water years[1] 1985-86 collected at Brewery and Garfoot Creeks are contrasted with additional data collected during the water years 1990-92. The work described in this paper was funded in part by the Wisconsin Department of Natural Resources through a grant from the Nonpoint Program.

STUDY AREA

Garfoot and Brewery Creeks, tributaries to Black Earth Creek, are in the northwestern part of Dane County (Fig. 1). Garfoot Creek has been classified by the WDNR as a class II trout stream; that is, a stream in which some natural trout reproduction occurs but artificial propagation is needed to maintain a trout fishery. Brewery Creek is a warm-water stream that has the potential to maintain a forage fish population (Wisconsin Department of Natural Resources, 1989).

Garfoot Creek drains 14.0 km^2 (5.39 mi^2) upstream from the streamflow-gaging station near Cross Plains, and the stream channel is 6.3 km (3.9 mi) long from the station to the stream headwaters. The overall channel slope is 18 m/km (97 ft/mi) and the channel slope between the 10- and 85-percent points of the main channel is 8.9 m/km (47 ft/mi). The bed material consists mainly of sand, silt, and clay, with gravel in riffle areas. Garfoot Creek flows along a wide valley floor flanked by steep valley walls. The valley floor of Garfoot Creek is mainly outwash and alluvium composed of sand, gravel, and clay (Cline, 1963). The valley walls are soil-covered sandstone, shale, and dolomite bedrock. The soils of Garfoot Creek are primarily silt loams; some of the silt loams are poorly drained, and water can pond in depressions (Glocker and Patzer, 1978). The land use is primarily agriculture (48% of the basin) and woodlands (45% of the basin) (Wisconsin Department of Natural Resources, 1989).

---

[1] A water year is the 12-month period from October 1 through September 30. It is designated by the year in which the 12-month period ends. For example, water year 1985 is the period October 1,1984 through September 30, 1985.

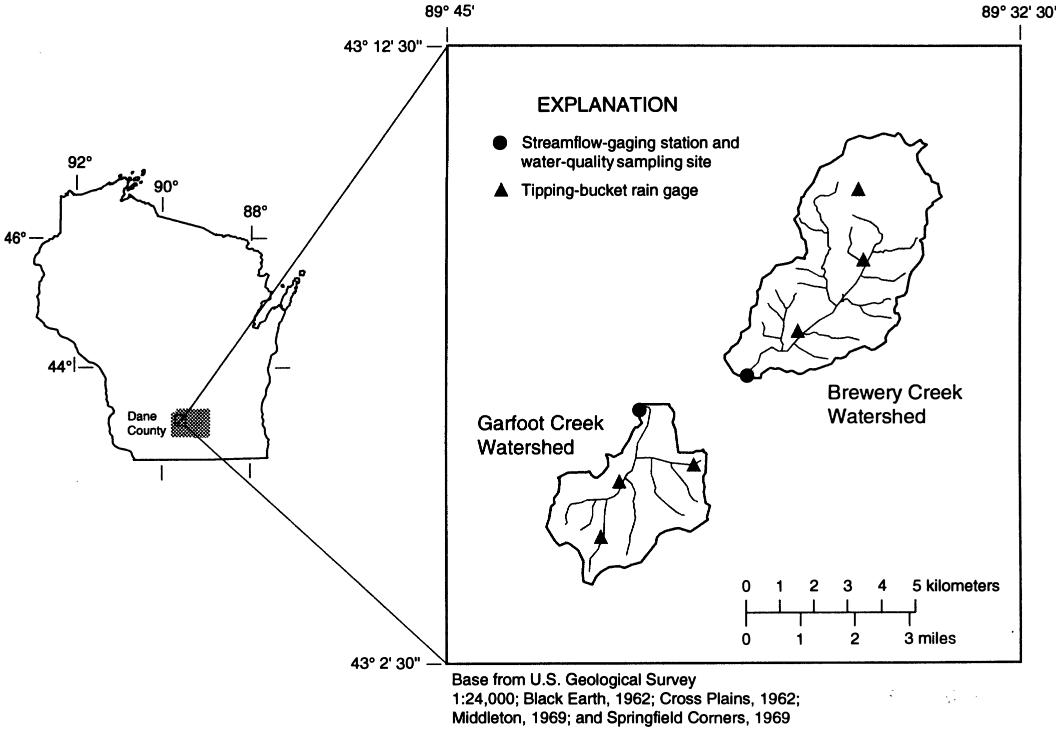


Fig. 1. Location of study area and data-collection sites in the Brewery and Garfoot Creek watersheds

Brewery Creek drains 27.2 km^2 (10.5 mi^2) upstream from the streamflow-gaging station near Cross Plains, which includes a 7.30 km^2 (2.82 mi^2) non-contributing area. The stream channel is 9.8 km (6.1 mi) long from the station to the stream headwaters, and has been channelized in some parts. The main channel slope is 7.6 m/km (40 ft/mi) and the channel slope between the 10- and 85-percent points of the main channel is 6.6 m/km (35 ft/mi). The bed material of the stream channel is mostly soft silt and clay. Brewery Creek flows through outwash and alluvium composed of sandstone with some shale; most of the bedrock in the watershed is dolomite. The soils of the Brewery Creek watershed are silt loams that are poorly drained in valley bottoms and highly erodible in the uplands (Glocker and Patzer, 1978). The land use is characterized by more agriculture (63% of the area) and less woodland (24% of the area) than in the Garfoot Creek watershed (Wisconsin Department of Natural Resources, 1989).

A variety of BMPs were recommended for the Black Earth Creek Priority Watershed (Wisconsin Department of Natural Resources, 1989). Because the program is voluntary, a period of several years is allowed for landowners to express interest and enter into contracts with the county conservation office and the Nonpoint Program. Practice implementation began in 1989, and is expected to continue until 1994. Currently (1992) implemented cropland practices are summarized in table 1, and locations of planned and implemented barnyard- and streambank-protection practices are shown in figures 2 and 3, respectively.

In the Brewery Creek watershed, 6 of the 15 barnyards thought to produce significant nonpoint-source runoff had implemented practices as of 1992, and 5 more implementations were planned for the future (Fig. 2). Prior to 1989, 27% of the cropland area was involved in conservation measures; during 1989-92, an additional 39% of the cropland area had BMP s implemented (table 1). A small portion of the eligible streambanks were protected, and protection for most of the remaining eligible streambanks is planned in future years (Fig. 3).

Table 1. Cropland area erosion control practices implemented in the Brewery and Garfoot Creek watersheds, 1989-1992

	Cropland area, km^2	
Practice type	Brewery Creek	Garfoot Creek
Conservation reserve program	1.5	0.99
Contour stripcropping	0.56	0.10
Minimum tillage	4.6	1.4
Rotation change	0	0.30
Total	6.7	2.8

In the Garfoot Creek watershed, four of the six barnyards thought to produce significant nonpoint-source runoff had implemented practices as of 1992, and practices were planned for the remaining two barnyards (Fig. 2). Prior to 1989, 39% of the cropland area was involved in conservation measures; during 1989-92, an additional 42% of the cropland area had BMP s implemented (table 1). More than half of the eligible streambanks were protected, and protection for the the remaining portion is planned in future years (Fig. 3).

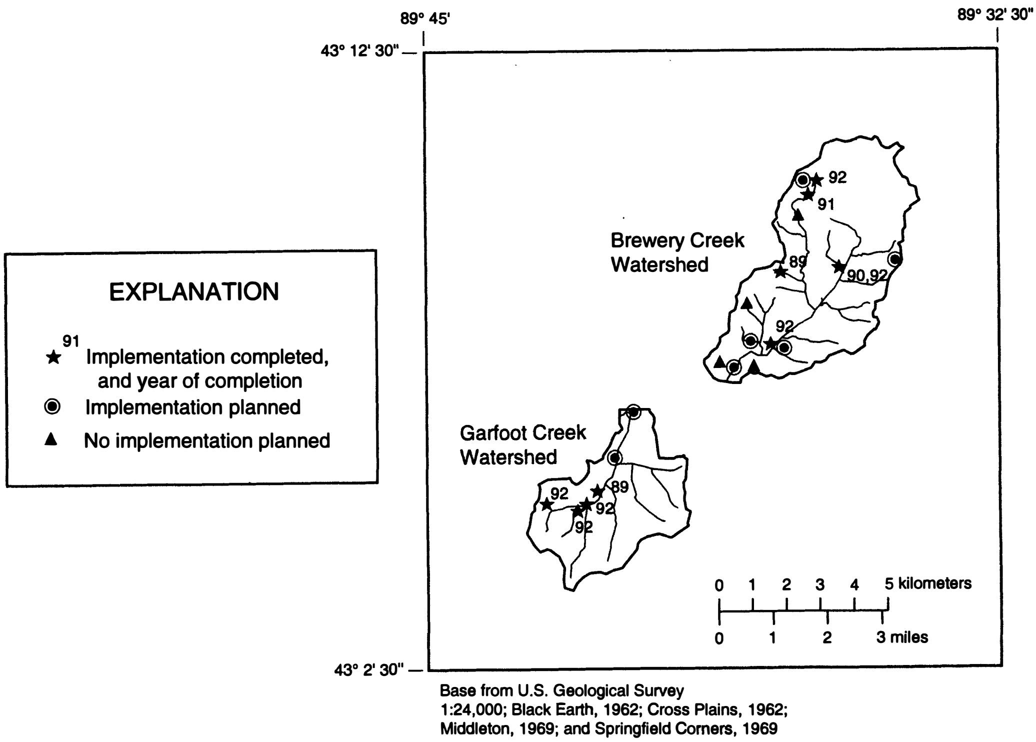


Fig. 2. Location of barnyards believed to produce significant nonpoint-source runoff in the Brewery and Garfoot Creek watersheds

DATA COLLECTION

Streamflow-gaging stations equipped for continuous recording of data were installed in October 1989 at Garfoot and Brewery Creeks at the same locations as the gaging stations from the previous study (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 representing medium to high flows. A datalogger was programmed to collect a sample with each 0.061 m (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 0.122 m (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 the constituents of interest would be changing the most. The samples, which were chilled to 4 C after collection, were analyzed for suspended sediment, total phosphorus, and ammonia nitrogen. Samples collected were selected for analysis to represent variation in water quality over the stream hydrograph.

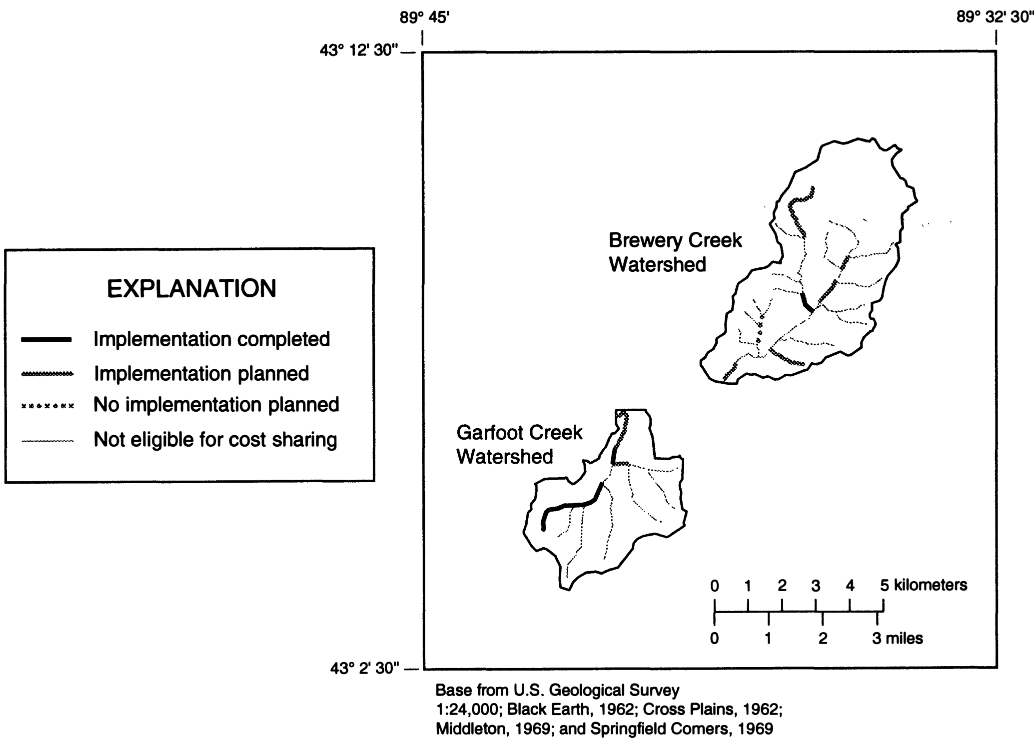


Fig. 3. Location of stream segments believed to have streambank erosion problems in the Brewery and Garfoot Creek watersheds

Water samples were collected every 2 weeks in the spring, summer, and fall and once a month in the winter during base-flow periods (periods of no or very little overland flow). Samples were integrated over the depth and width of the stream by use of a hand-held sampler (Edwards and Glysson, 1988). The base-flow samples were analyzed for suspended sediment, total phosphorus, and ammonia nitrogen.

The suspended-sediment samples were analyzed by a USGS laboratory according to USGS methods (Guy, 1973). The other constituents were analyzed by the Wisconsin Laboratory of Hygiene according to standard methods (American Public Health Association, 1989; Wisconsin Laboratory of Hygiene, 1992).

Precipitation during the previous study was measured at one location at the approximate centroid of each watershed. Precipitation was collected in a 20.3-cm (8-in) collector, which drained into a 7.6-cm (3-in) inside-diameter standpipe. Precipitation measurements were made every 15 minutes. Precipitation was collected during non-freezing periods only (March 1 - November 30) at the two sites.

In October 1989, three rain gages were installed in each basin (Fig. 1). One rain gage was at the site of the rain gage from the previous study. The other two rain gages were sited 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 is then computed as a weighted average using the Thiessen polygon areas as the weighting factor (Viessman *et al.*, 1977). Thus, because the Thiessen polygon areas are approximately equal, the average precipitation for a given basin is simply the arithmetic average of the precipitation at the three rain gages. Precipitation was collected in a 20.3-cm (8-in) collector that drained into a tipping bucket rain gage. Each tip represented 0.0254 cm (0.01 in) of rain; all rainfall data were recorded every 5 minutes.

EVALUATION OF BEST MANAGEMENT PRACTICES

Data collected in the previous study and during the present study were used to determine if the BMP s implemented to date (1992) have had an appreciable effect on the water quality of Brewery and Garfoot Creeks. Data collected during the 1985-86 water years were considered to represent pre-BMP conditions, whereas data collected during the 1991-92 water years were considered representative of transitional-period conditions. (A limited number of practices had been implemented by the summer of 1990; hence, data collected in the 1990 water year were omitted from the analysis.)

Because a great deal of the annual constituent transport occurs during storms, fixed-interval sampling, particularly with a monthly frequency, may not show changes resulting from BMP implementation (Walker, 1992). Consequently, mass transport resulting from individual storms was analyzed. Mass transport of the constituent of interest is determined by multiplying the water discharge by the concentration of the constituent and a units conversion factor (Porterfield, 1972), as follows:

$$Q_s = Q_w \bullet C_s \bullet K \qquad (1)$$

Q_s = mass transport.
Q_w = water discharge.
C_s = concentration of the constituent of interest.
K = conversion factor to maintain consistent units.

The integration method was used to determine the mass transport of each storm (Porterfield, 1972). Concentration at the beginning of a storm was estimated from samples collected during previous low-flow periods between storms. Concentration at the end of a storm was estimated from samples collected immediately after the end of the storm. Some samples for individual storms were estimated by the relation of concentration and discharge. Estimated samples within a storm period were kept to a minimum; storms with more than approximately 25% of samples estimated were not used in the analysis.

Regressions of storm mass transport and precipitation characteristics were used to compensate for natural variability among storms. Variables related to precipitation characteristics were used as exogenous variables, because these variables drive the hydrologic processes governing the response of the watershed to storms. The variables used were total storm precipitation (P_{tot}); maximum 15- and 30-minute precipitation intensities (P_{15} and P_{30}); the Universal Soil Loss Equation (Wischmeier and Smith, 1978) erosivity index (EI); the number of days preceding the storm without significant precipitation (D_{dry}); and two seasonal terms ($\sin(2\pi T)$ and $\cos(2\pi T)$, where T is the serial date for the beginning of the storm, in years; T = 1980.5 for June 30, 1985). Three constituents were considered for the dependent variable; suspended sediment (SS), total phosphorus (TP), and ammonia nitrogen (NH_4). All possible combinations of independent variables were computed for each constituent (SS, TP and NH_4) by use of as many as three independent variables. The best regression was selected on the basis of the value of Mallow s C_p (Hocking, 1972) and an examination of diagnostic residual plots. The final regression equations are summarized in table 2. Runoff from snowmelt and early spring storms were omitted from the analysis because the mass-transport characteristics were strikingly different than the other storms monitored. Continued research will address techniques needed to include these mass transports in the overall analysis.

Table 2. Final regression summary for Brewery and Garfoot Creeks, 1985-86 and 1991-92

Dependent variable[1]	Independent variables[2]	Sample size	Adjusted R^2	Standard error	Standard error (%)[3]
		Brewery Creek			
SS	EI, $\cos(2\pi T)$, $\sin(2\pi T)$	23	0.955	21.9	68
TP	EI, $\sin(2\pi T)$	24	0.930	110	69
NH_4	P_{tot}, $\cos(2\pi T)$, $\sin(2\pi T)$	20	0.857	15.1	40
		Garfoot Creek			
SS	P_{tot}, $\sin(2\pi T)$	15	0.550	14.0	61
TP	P_{tot}, $\cos(2\pi T)$, $\sin(2\pi T)$	15	0.715	107	64
NH_4	D_{dry}, $\cos(2\pi T)$, $\sin(2\pi T)$	13	0.193	28.5	80

[1] SS, suspended sediment; TP, total phosphorus; NH_4, ammonia nitrogen.
[2] EI, erosivity index; cos(x), cosine of x; sin(x), sine of x; T, serial date in years; P_{tot}, total precipitation; D_{dry}, number of dry days between storms.
[3] Expressed as a percent of the mean dependent variable

Table 3. Probability levels for statistical tests applied to storm mass transports and regression residuals for Brewery and Garfoot Creeks, 1985-86 and 1991-92 (numbers in bold type are significant at the 5% level for a two-tailed test)

	Sample size		t-test		Mann-Whitney U-test	
Constituent[1]	Pre-BMP	Transition	Raw data	Residuals	Raw data	Residuals
			Brewery Creek			
SS	14	10	0.454	**0.012**	0.907	**0.010**
TP	12	13	0.446	0.459	0.586	0.480
NH_4	9	12	0.173	**0.006**	0.177	**0.007**
			Garfoot Creek			
SS	14	2	0.539	0.923	0.427	1.000
TP	12	4	0.281	0.293	0.225	0.544
NH_4	10	4	0.260	0.080	0.203	0.048

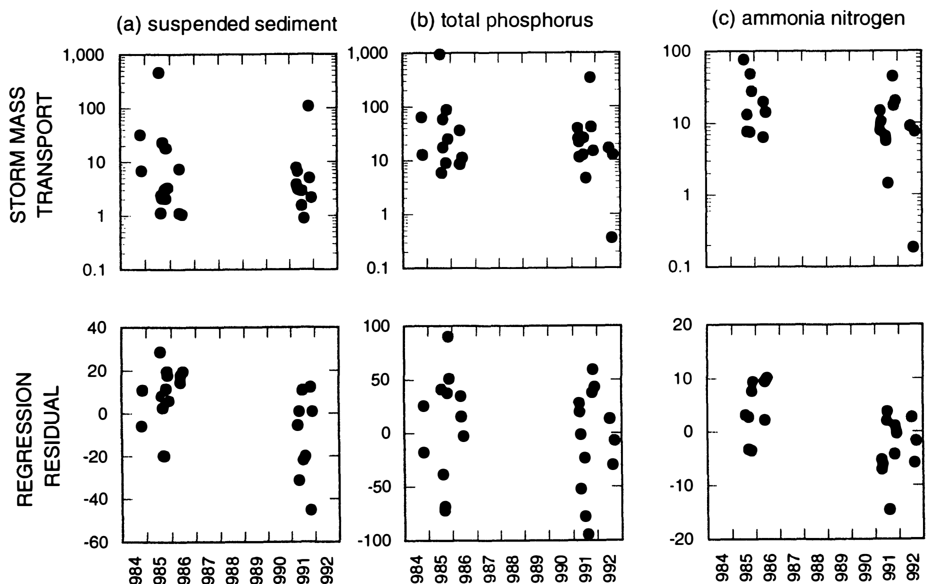
[1] SS, suspended sediment; TP, total phosphorus; NH_4, ammonia nitrogen.

Two statistical tests were used to determine if the pre-BMP data differed from the transitional-period data: the t-test (Benjamin and Cornell, 1970) and the Mann-Whitney U-test (Conover, 1980). The two statistical tests were applied to the storm mass transports and the regression residuals (table 3). For each site and dependent variable, a single regression equation was computed for the entire period of analysis (1985-86 and 1991-92); hence, if the BMPs have had an impact in improving the stream water quality, the pre-BMP residuals should be mostly positive, and the transitional residuals should be mostly negative. Statistically significant differences were detected at the 5% level for suspended sediment and ammonia nitrogen in the Brewery Creek watershed.

No significant differences were detected in the storm mass-transport data for Garfoot Creek, primarily because of a lack of transitional-period storm data (table 3). Continued data collection through the 1995 water year is expected to result in enough storms to balance the pre-BMP and post-BMP sample sizes and may result in significant differences in storm mass transports for the Garfoot Creek watershed.

Results of the mass-transport data and regression residuals for Brewery and Garfoot Creeks are presented graphically in figures 4 and 5, respectively. In all cases, the variability of the residuals is less than the variability for the corresponding mass-transport data, indicating that statistical tests applied to the residuals will be able to detect smaller differences than the tests applied to storm mass transports. For Brewery Creek, the subtle differences in suspended-sediment and ammonia-nitrogen residuals are statistically significant, primarily as a result of reduced variability. The central tendency of the residuals has decreased with the implementation of BMP s (Fig. 4a and 4c). The average decrease in the suspended-sediment residuals is 45% of the average pre-BMP suspended-sediment mass transport; for ammonia nitrogen, the average decrease in residuals is 30% of the average pre-BMP ammonia-nitrogen mass transport. Assuming the change represents a shift in the intercept of the underlying regression relation, then the percent change in the residuals represents the average percent change in the mass transports. The residuals represent the variability of data after natural variability has been removed; hence, the improvement in water quality in the Brewery Creek watershed is likely a result of BMP implementation. For Garfoot Creek there seems to be the beginning of a downward trend in total-phosphorus and ammonia-nitrogen mass transports and residuals; additional data may reveal statistically significant differences.

Fig. 4. Storm mass transports and regression residuals for (a) suspended sediment, in megagrams, (b) total phosphorous, in kilograms, and (c) ammonia nitrogen, in kilograms, for the Brewery Creek watershed, 1985-86 (pre-BMP) and 1991-1992 (transition)



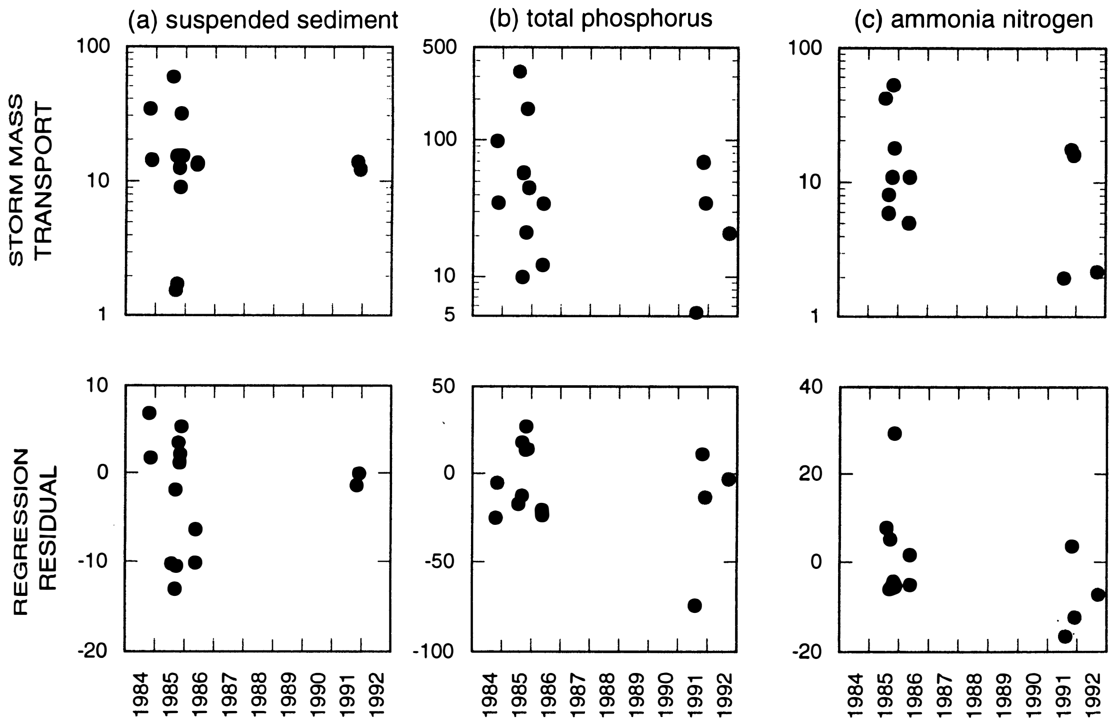


Fig. 5. Storm mass transports and regression residuals for (a) suspended sediment, in megagrams, (b) total phosphorous, in kilograms, and (c) ammonia nitrogen, in kilograms, for the Garfoot Creek watershed, 1985-86 (pre-BMP) and 1991-1992 (transition)

CONCLUSIONS

Substantial nonpoint-source contamination management in the Brewery and Garfoot Creek watersheds has been ongoing since 1989. Progress has been made toward controlling a substantial part of the barnyard-runoff problems in the two watersheds; nearly half of the Brewery Creek barnyards have controls, and two-thirds of the Garfoot Creek barnyards have implemented BMPs. Progress also has been made in controlling cropland erosion in both basins, and protecting the streambanks in the Garfoot Creek basin. Data collected during the 1985-86 water years (pre-BMP conditions) and 1991-92 water years (transition conditions) were used to test for significant differences after BMP implementation began.

Statistically significant differences in storm mass transport of suspended sediment and ammonia nitrogen were detected for the Brewery Creek watershed. The central tendency of the residuals decreased with the implementation of BMPs (Fig. 4a and 4c); hence, the improvement in water quality in the Brewery Creek watershed is likely a result of BMP implementation. Changes in storm mass transport were not detected for the Garfoot Creek watershed, primarily because of a lack of transitional-period storms. Continued data collection through water year 1995 will provide additional data for further analysis. It is postulated that the additional data can be used in an incremental fashion to help determine the level of watershed management needed to produce statistically significant differences in streamwater quality. Future research will address techniques for including snowmelt runoff and early spring storms.

REFERENCES

American Public Health Association. (1989). *Standard methods for the examination of water and wastewater* (*16th ed.*). American Public Health Association, Washington, DC.

Benjamin, J. R. and Cornell, C. A. (1970). *Probability, statistics, and decision for civil engineers.* McGraw-Hill Book Company, New York.

Cline, D. V. (1963). Hydrology of upper Black Earth Creek basin, Wisconsin. *U.S. Geological Survey Water-Supply Paper 1669-C.*

Conover, W. J. (1980). *Practical nonparametric statistics* (*2d ed.*). John Wiley & Sons, New York.

Edwards, T. K. and Glysson, G. D. (1988). Field methods for measurement of fluvial sediment. *U.S. Geological Survey Open-file Report 86-531.*

Field, S. J. and Graczyk, D. J. (1990). Hydrology, aquatic macrophytes, and water quality of Black Earth Creek and its tributaries, Dane County, Wisconsin, 1985-86. *U.S. Geological Survey Water-Resources Investigations Report 89-4089.*

Glocker, C. L. and Patzer, R. A. (1978). Soil survey of Dane County. *U.S. Department of Agriculture Soil Conservation Service* .

Guy, H. P. (1973). Laboratory theory and methods for sediment analysis. *U.S. Geological Survey Techniques of Water-Resources Investigations Chapter C1.*

Hocking, R. R. (1972). Criteria for selection of a subset regression: which one should be used? *Technometrics, 14*, 967-970.

Porterfield, G. (1972). Computation of fluvial-sediment discharge. *U.S. Geological Survey Techniques of Water-Resources Investigations Book 3, Chapter C2.*

Rantz, S. E. and others. (1982). Measurement and computation of streamflow: Volume 2. computation of discharge. *U.S. Geological Survey Water-Supply Paper 2175.*

Viessman, W. J., Knapp, J. W., Lewis, G. L. and Harbaugh, T. E. (1977). *Introduction to Hydrology* (*2d ed.*). Harper & Row, Publishers Inc., New York.

Walker, J. F. (1992). Techniques for detecting effects of best-management practices on stream-water chemistry. *U.S. Geological Survey Open-File Report, in press.*

Wischmeier, W. H. and Smith, D. D. (1978). Predicting rainfall erosion losses-a guide to conservation planning. *U.S. Department of Agriculture Handbook No. 537.*

Wisconsin Department of Natural Resources. (1989). A plan for the control of nonpoint sources and related resource management in the Black Earth Creek priority watershed. *Wisconsin Department of Natural Resources Publication WR-218-89.*

Wisconsin Laboratory of Hygiene. (1992). *Manual of analytical methods and quality assurance.* University of Wisconsin, Madison, Wis.