EVALUATION OF NONPOINT-SOURCE CONTAMINATION, WISCONSIN: LAND-USE AND BEST-MANAGEMENT-PRACTICES INVENTORY, SELECTED STREAMWATER-QUALITY DATA, URBAN-WATERSHED QUALITY ASSURANCE AND QUALITY CONTROL, CONSTITUENT LOADS IN RURAL STREAMS, AND SNOWMELT-RUNOFF ANALYSIS, WATER YEAR 1994

By J.F. Walker, D.J. Graczyk, S.R. Corsi, D.W. Owens, and J.A. Wierl

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CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To Obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
acre	0.4048	hectare
square mile (mi^2)	2.590	square kilometer
million cubic feet (Mft^3)	0.02832	million cubic meters
pound (lb)	453.6	gram
pounds per square mile (lb/mi^2)	0.17573	kilograms per square kilometer (kg/km^2)
ton (short)	0.9072	megagram (mg)
ton per square mile (ton/mi^2)	0.303	megagram per square kilometer (mg/km^2)

Abbreviated water-quality units used in this report: Chemical concentrations and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million. Other units of measurement used in this report are microsiemens per centimeter at 25° Celsius (µS/cm).

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Abstract

The objective of the watershed-management evaluation monitoring program in Wisconsin is to evaluate the effectiveness of best-management practices (BMP) for controlling nonpoint-source contamination in rural and urban watersheds. This report is an annual summary of the data collected for the program by the U.S Geological Survey and a report of the results of several different detailed analyses of the data.

A land-use and BMP inventory is ongoing for 12 evaluation monitoring projects to track the sources of nonpoint-source pollution in each watershed and to document implementation of BMP's that may cause changes in the water quality of streams. Updated information is gathered each year, mapped, and stored in a geographic-information-system data base. Summaries of data collected during water years 1989-94 are presented. A water year is the period beginning October 1 and ending September 30; the water year is designated by the calendar year in which it ends.

Suspended-sediment and total-phosphorus data (storm loads and annual loads) are summarized for eight rural sites. For all sites, the annual suspended-sediment or suspended-solids load for water year 1993 exceeded the average for the period of data collection; the minimum annual loads were transported in water year 1991 or 1992.

Continuous dissolved-oxygen data were collected at seven rural sites during water year 1994. Data for water years 1990-93 are summarized and plotted in terms of percentage of time that a particular concentration is equaled or exceeded. Dissolved-oxygen concentrations in four streams were less than 9 mg/L at least 50 percent of the time, a condition that fails to meet suggested criterion for coldwater streams. The dissolved-oxygen probability curve for one of the coldwater streams is markedly different than the curves for the other streams, perhaps because of differences in aquatic biomass.

Blank quality-assurance samples were collected at two of the urban evaluation monitoring sites to isolate contamination in the sample bottle, the automatic sampler and splitter, and the filtration system. Significant contamination caused excessive concentrations of dissolved chloride, alkalinity, and biochemical oxygen demand. The level of contamination may be large enough to affect data for water samples in which these analytes are present at low concentration. Further investigation

is being done to determine the source of contamination and take measures to minimize its effect on the sampling.

A preliminary regression analysis was done for the rural sites using data collected during water years 1989-93. Loads of suspended solids and total phosphorus in stormflow were regressed against various precipitation-related measures. The results indicate that, for most sites, changes in constituent load on the order of 40 to 50 percent could be detected with a statistical test. For two sites, the change would have to be 60 to 70 percent to be detected.

A detailed comparison of snowmelt runoff and rainfall stormflow in urban and rural areas was done using data collected during water years 1985-93. For the rural sites where statistically significant differences were found between constituent loads in snowmelt and storm runoff, the loads of suspended solids and total phosphorus in snowmelt runoff were greater than those in storm runoff. For the urban sites where statistically significant differences were found between snowmelt and storm runoff, the loads of suspended solids and total phosphorus in storm runoff were greater than those in snowmelt runoff. The importance of including snowmelt runoff in designing and analyzing the effects of BMP's on streamwater quality, particularly in rural areas, is emphasized by these results.

INTRODUCTION

In October 1989, the U.S. Geological Survey (USGS) began a watershed-management evaluation-monitoring program in cooperation with the Wisconsin Department of Natural Resources (WDNR). The overall objective of the 12 individual projects in the program is to determine whether the water quality of a receiving stream has improved as a result of the implementation of land-management practices in a watershed. This determination is made through monitoring of water chemistry and ancillary variables before best-management practices (BMP's) are implemented, during implementation, and after BMP's have been completely implemented. The period before BMP implementation is termed "pre-BMP," the period during active implementation is termed "transitional," and the period after complete implementation is termed "post-BMP."

The county Land Conservation Departments (LCD's) and the WDNR have identified sources of nonpoint pollution in the eight rural watersheds. This information was used to select sites that are eligible for partial funding of BMP implementation. The LCD's are in the process of contacting landowners to request that they implement the appropriate BMP's for streamwater-quality improvement. This BMP implementation is a voluntary program and, therefore, may result in varied success, depending largely upon the amount of land treated.

For the four urban watersheds, the WDNR and each city have identified sources of nonpoint pollution. Goals for reduction of nonpoint-source pollution have been set, but specific plans identifying the types and locations of BMP's needed to achieve these goals have not been defined.

Eight rural and four urban sites were selected jointly by WDNR and USGS for detailed evaluation monitoring. Among the criteria for site selection were likelihood for extensive BMP implementation, relatively small watershed size (less than 50 mi^2), and feasibility of accurate stream gaging. An additional stream was selected for a detailed analysis of dissolved oxygen along a river reach. Locations of the sites are shown in figure 1, and a brief summary of site characteristics is given in table 1.

This report, the third in a series of annual progress reports, is divided into five sections. The following topics are addressed: (1) land-use and best-management-practices inventory, including a discussion of data-collection efforts and the status of BMP implementation; (2) streamwater-quality data, including a discussion of data-collection efforts during water year 1994, a comparison of annual loads for the rural sites, and a discussion of dissolved-oxygen data collection; (3) urban quality assurance and quality control, including an analysis of blank samples collected to examine for contamination of inorganic constituents; (4) rural load regression analysis, including a brief discussion of the statistical approach for trend detection and pre-

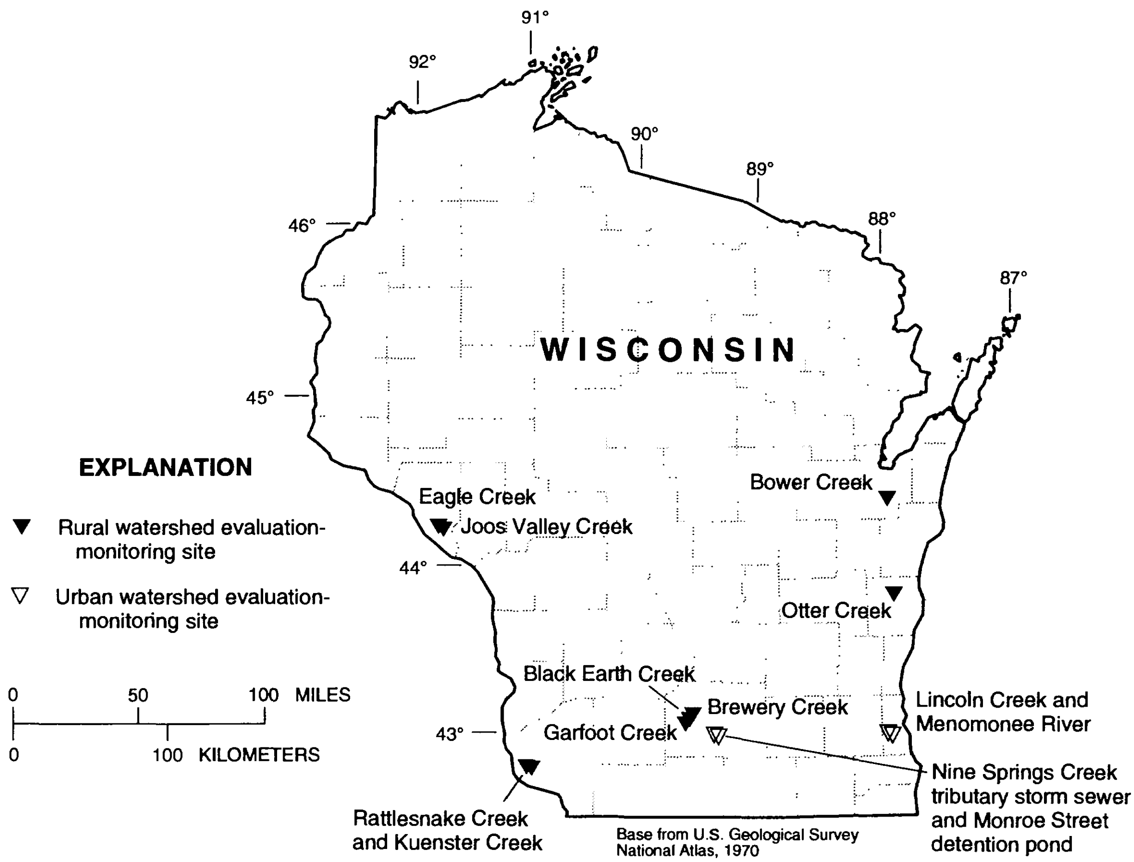

Figure 1. Locations of rural and urban sites in the Wisconsin watershed-management evaluation monitoring program, water year 1994.

sentation and discussion of preliminary pre-BMP regressions for the rural sites; and (5) snowmelt runoff analysis, including a comparison of loads and event-mean concentrations for snowmelt and storm runoff for rural and urban watersheds. For sections presenting ongoing data-collection efforts, data collected during water year 1994 (October 1993 through September 1994) are summarized and, if appropriate, implications for future data-collection efforts are discussed.

LAND-USE AND BEST-MANAGEMENT-PRACTICES INVENTORY

The Land-Use Program was started in 1992 to provide information on the effects of land-use changes on water quality. A detailed description of the program is given in Corsi and others (1994). The geographic information system (GIS) data base used for the land-use and BMP inventory was developed by the USGS in cooperation with the WDNR using ARC/INFO[1] software.

The evaluation-monitoring program started tracking BMP's using GIS in 1992. Basin outlines, hydrography, roads, stream and rain gages, BMP's, and forests were digitized at the scale of 1:24,000 from topographic maps. Field coverages were digitized from aerial photos. Field coverages have been completed for Waumadee, Otter, and Rattlesnake watersheds at approximate scales of 1:600. The amount of sediment and phosphorus reaching the streams will be estimated using a land-use management model. The model will incorporate information from the field, elevation,

[1]Use of trade names in the report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Table 1. Site name, data collection period, site type, and data collected for sites in the Wisconsin evaluation-monitoring program
[years are water years; -- indicates management implementation has not begun]

Site name	Pre-BMP period	Transitional period	Site type	Data collected
Black Earth Creek at County Trunk P	1985-86	1990-94	Rural	Dissolved oxygen and water temperature
Black Earth Creek at Mills Street	1985-86	1990-94	Rural	Dissolved oxygen and water temperature
Black Earth Creek at South Valley Road	1985-86	1990-94	Rural	Dissolved oxygen and water temperature
Bower Creek	1991-92	1993-94	Rural	Water chemistry[1]
Brewery Creek	1985-86	1990-94	Rural	Water chemistry[2]
Eagle Creek	1990-91	1992-94	Rural	Water chemistry[1]
Garfoot Creek	1985-86	1990-94	Rural	Water chemistry[2] and dissolved oxygen
Joos Valley Creek	1990-91	1992-94	Rural	Water chemistry[1]
Kuenster Creek	1993-94	--	Rural	Water chemistry[1] and dissolved oxygen
Lincoln Creek	1993-94	--	Urban	Water chemistry[1]
Menomonee River	1991-94	--	Urban	Water chemistry[1]
Monroe Street detention pond inlet	1991-94	--	Urban	Water chemistry[1]
Nine Springs Creek tributary storm sewer	1991-94	--	Urban	Water chemistry[1]
Otter Creek	1991-92	1993-94	Rural	Water chemistry[1] and dissolved oxygen
Rattlesnake Creek	1992-94	--	Rural	Water chemistry[1] and dissolved oxygen

[1]Samples analyzed for suspended solids, total phosphorus, and ammonia nitrogen.
[2]Samples analyzed for suspended sediment, total phosphorus, and ammonia nitrogen.

and hydrologic-unit coverages. The model results will be used to verify the need for BMP's within the monitored watersheds. The comparison between the BMP's being installed and those needed will help in the evaluation of water quality.

Data Collection

ARC/INFO coverages of BMP's are updated annually if BMP's are either contracted or installed. The information is obtained from the local Land Conservation Department. Streambanks were inventoried in the summer of 1994. The height and length of the streambank and the recession rate were used to estimate sediment loading from a particular streambank. The sediment loads and location of the eroded sites are currently being added to the data base.

Best-Management-Practice Status

Eligible, contracted, and installed BMP's for the evaluation-monitoring watersheds are summarized in table 2. Animal-waste management prac-

Table 2. Summary of eligible, contracted, and implemented rural best-management practices in evaluation-monitoring watersheds
[N/A, information not available; ft, feet]

Practice	Watershed: Brewery	Garfoot	Eagle and Joos Valley	Bower	Otter	Rattlesnake and Kuenster
Animal-waste management						
Eligible manure storage	0	0	6	6	2	[a]60
Contracted manure storage	0	0	[b]3	6	2	1
Implemented manure storage	0	0	1	6 12 others from previous farm programs	1	1
Eligible barnyard control systems	21	7	[c]9	25	6	103
Contracted barnyard control systems	14	6	8	12	6	11
Implemented barnyard control systems	7 4 barns without livestock	4 2 barns without livestock	1	6	4	5
Streambank protection						
Eligible streambank protection[d]	[e]22,000 ft	[e]16,800 ft	[e]28,100 ft	[e]2,320 ft	[e]7,000 ft	[a,e]255,000 ft
Contracted streambank protection	[e]22,000 ft	[e]16,800 ft	[e]4,990 ft	0	[e]9,400 ft	[e]1,720 ft
Implemented streambank protection	[e]19,100 ft	[e]16,700 ft	[e]240 ft	0	[e]1,300 ft	[e]1,120 ft
Contracted fencing	1,200 ft	5,000 ft	23,700 ft	625 ft	0	0
Implemented fencing	Site no longer with livestock	4,900 ft	0	625 ft	0	0
Contracted stream crossing	2	8	11	1	3	3
Implemented stream crossing	Sites no longer with livestock	5	0	1	3	3
Contracted grade stabilization	2	4	8	0	1	0
Implemented grade stabilization	1 1 no longer with livestock	4	0	0	1	0
Upland management						
Eligible nutrient management	2,440 acres	592 acres	990 acres	4,020 acres	1,130 acres	[a]2,980 acres
Contracted nutrient management	2,440 acres	592 acres	554 acres	1,230 acres	1,130 acres	[a]1,140 acres
Implemented nutrient management	1,100 acres	288 acres	0	644 acres	1,130 acres	[a]691 acres
Eligible upland BMP's[f]	[a]5,170 acres	[a]1,520 acres	[a]2,140 acres	4,480 acres	553 acres or [a]303 tons	[a]17,400 acres
Contracted upland BMP's	1,560 acres	212 acres	0	92 acres	[a]136 tons	346 acres
Implemented upland BMP's	1,290 acres	212 acres	0	92 acres	[a]136 tons	346 acres

[a]Estimates from the land-county conservations offices or from priority watershed. [b]Does not include one storage just below eligible area. [c]Does not include one eligible yard that was sold. [d]The contracts for length of streambank protection reflects the total length of each practice. One eroded site can include several practices such as rip rap, shoreline and streambank stabilization, and shoreline buffers. [e]Both banks may have been eroded, contracted, or installed BMP's. [f]Includes an individual practice or series of practices, other than nutrient management, which result in a reduced pollutant source, such as, contour farming, contour strip cropping, field strip cropping, grassed waterways, and reduced tillage.

tices are installed to control phosphorus loads in runoff. These improvements restructure the barnyard and (or) contain manure to reduce the amount of organic matter reaching the stream. Streambank-protection practices are designed to control erosion from the banks. These practices usually limit the access of animals to the streambank. Upland sediment-control practices are designed to control the amount of manure and sediment transported from steeply sloping lands. All planning is done by local Land Conservation Department staff; the practices must be installed within 5 years of the signup date.

Monitoring Activities in Water Year 1995

The following land-use and BMP-monitoring activities are planned for water year 1995:

1. Update all pertinent land-use data in the GIS data base. The data base will provide the information necessary to create land-use maps and to generate sediment and phosphorus loads from the land-use management model.
2. Publish a summary of (a) land-use changes in the watersheds, incorporating the original evaluation-monitoring watershed inventories, and (b) progress of each Land Conservation Department in implementing BMP's. A U.S. Geological Survey Open-File Report is the expected outlet.
3. Produce a manual on updating and maintaining the land-use inventory.
4. Complete an inventory of crops and gully erosion in each watershed.

SELECTED STREAMWATER-QUALITY DATA

Streamwater-quality data that have been collected are summarized in four parts. The first part discusses the availability of water-quality data. Second, constituent loads in stormflow are summarized for the period of record at each rural evaluation-monitoring site (table 1). This summary includes the number of constituent loads computed at all rural evaluation-monitoring sites. The third part summarizes constituent loads and yields calculated at the rural evaluation-monitoring sites for their specific period of record. The fourth part summarizes dissolved-oxygen data.

Availability of Water-Quality Data

Daily water-quality loads for selected constituents and discrete concentration data for the samples used to calculate these loads are published in "Water Resources Data–Wisconsin" for water years 1985-86, 1989-90, 1991-93 (Holmstrom and others, 1986-87; Holmstrom and Erickson, 1989; Holmstrom and others 1990-91, 1992-93). Maximum, minimum, and means of dissolved-oxygen concentrations and water temperatures also are published in "Water Resources Data–Wisconsin." The data for water year 1994 are to be published in "Water Resource Data–Wisconsin, 1994." Constituent loads for stormflow periods for water year 1994 are to be published in the 1995 annual progress report on the evaluation monitoring program. Data are available by request from the USGS office in Madison, Wis.

Constituent Loads in Stormflow

Water-quality monitoring continued in water year 1994 with sampling during the base-flow and stormflow periods at the eight rural evaluation monitoring sites (fig. 1). The instantaneous water-quality data were used in conjunction with continuous streamflow data to estimate total constituent loads for stormflow periods. Suspended-sediment or suspended-solids, total-phosphorus, and ammonia-nitrogen loads were computed at the eight rural evaluation monitoring sites. For Brewery and Garfoot Creeks, suspended sediment is used to be consistent with pre-BMP data collected in a previous study; for all other sites, suspended solids is used. Ammonia-nitrogen loads were not computed for sites on Otter and Bower Creeks. The storm-load data will be used to evaluate the effect of BMP's on streamwater quality. Previous research (Walker, 1994) has shown that minimum detectable change reaches a minimum at roughly 40 total storms; this corresponds to 20 pre-BMP and 20 post-BMP storms for a balanced data collection. The number of storms for the period of record for which loads were calculated at rural evaluation monitoring sites is shown in figure 2.

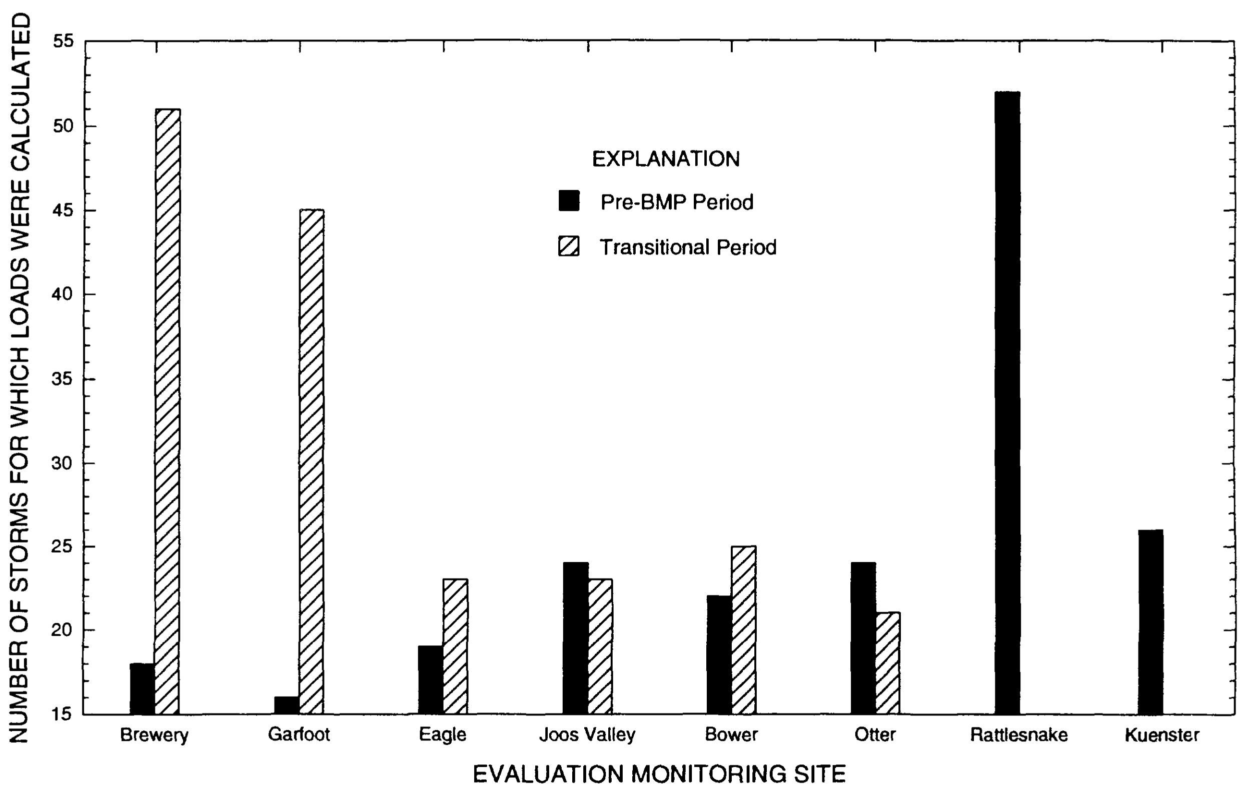

Figure 2. Number of storms for which loads were calculated at the evaluation monitoring sites before implementation of best-management-practices (BMP's) and during transitional periods.

Loads for a sufficient number of storms are probably available for the pre-BMP implementation period at five of the sites; at the other three sites, BMP implementation has begun, hence collection of additional pre-BMP data is not possible.

Annual Constituent Loads

Annual loads of suspended sediment or suspended solids and total phosphorus and corresponding yields of these constituents were determined at each of the eight rural evaluation monitoring sites (fig. 1) for the entire period of data collection (table 3).

Streamflow for water year 1993 was greater than the 5-year mean at Brewery and Garfoot Creeks; total streamflow at Brewery Creek was about 200 percent above the 5-year mean, and total streamflow at Garfoot Creek was about 165 percent above the 5-year mean.

Statewide precipitation in water year 1993 was about 120 percent above the 1961-90 average (Holmstrom and others, 1993). Streamflow statewide was also above normal and ranged from 99 percent of normal in north-central Wisconsin to about 270 percent above normal in southwestern Wisconsin (Holmstrom and others, 1993). Streamflow where the evaluation monitoring sites are located ranged from 160 to 240 percent above normal (Holmstrom and others, 1993).

At the evaluation monitoring sites, the highest loads and yields of suspended sediment or suspended solids were transported in water year 1993. The suspended-sediment load at Brewery

Table 3. Suspended-sediment or suspended-solids, total-phosphorus loads and yields, and total streamflow at evaluation-monitoring sites for water years 1985, 1986, and 1990-93

[mi^2, square miles; ton/mi^2, tons per square mile; lb/mi^2, pounds per square mile]

Water year	Suspended-sediment or suspended-solids load (tons)	Suspended-sediment or suspended-solids yield (ton/mi^2)	Total-phosphorus load (pounds)	Total-phosphorus yield (lb/mi^2)	Total streamflow (million cubic feet)
			Brewery Creek		
1985	894	116	4,840	628	86
1986	[1]279	[1]36.2	[1]1,590	[1]206	[1]75
1990	521	67.7	3,850	500	36
1991	45.3	5.88	700	91	18
1992	180	23.4	1,960	254	28
1993	2,640	342	10,700	1,392	135
Mean[2]	[2]855	[2]111	[2]4,410	[2]573	[2]61
			Garfoot Creek		
1985	462	85.7	3,060	568	166
1986	[1]441	[1]81.8	[1]2,450	[1]454	[1]156
1990	337	62.5	2,850	528	100
1991	290	53.8	2,100	390	103
1992	200	37.1	2,230	413	127
1993	1,160	216	7,080	1,310	243
Mean[2]	[2]490	[2]91	[2]3,460	[2]643	[2]148
			Eagle Creek		
1990	[1]4,340	[1]304	[1]9,460	[1]661	[1]84.5
1991	6,580	460	11,600	815	244
1992	3,920	274	8,900	623	287
1993	7,960	556	17,900	1,250	425
Mean[2]	[2]6,150	[2]430	[2]12,800	[2]896	[2]318

Table 3. Suspended-sediment or suspended-solids, total-phosphorus loads and yields, and total streamflow at evaluation-monitoring sites for water years 1985, 1986, and 1990-93--Continued

Water year	Suspended-sediment or suspended-solids load (tons)	Suspended-sediment or suspended-solids yield (ton/mi^2)	Total-phosphorus load (pounds)	Total-phosphorus yield (lb/mi^2)	Total streamflow (million cubic feet)
			Joos Valley Creek		
1990	[1]1,150	[1]195	[1]3,080	[1]523	[1]28.3
1991	1,470	250	3,160	537	95.6
1992	1,390	237	3,880	658	127
1993	2,900	493	6,440	1,090	183
[2]Mean	[2]1,920	[2]327	[2]4,490	[2]763	[2]135
			Bower Creek		
1991	718	48.5	9480	640	217
1992	1,450	97.8	10,800	730	200
1993	11,100	751	26,600	1,800	584
Mean	4,430	299	15,600	1,060	334
			Otter Creek		
1991	308	32.4	2,490	262	181
1992	285	30.0	2,180	230	202
1993	867	91.2	5,580	588	343
Mean	487	51.2	3,420	360	242
			Rattlesnake Creek		
1992	5,870	139	30,600	722	675
1993	35,500	837	156,000	3,670	1,690
Mean	20,700	488	93,100	2,200	1,180
			Kuenster Creek		
1993	9,690	1,010	38,000	3,960	152

[1]Partial year of data collected October through June or July through September.
[2]Mean does not include partial years.

Creek in water year 1993 was about 300 percent above the 5-year mean of 855 tons (table 3). At Garfoot Creek, suspended-sediment loads in water year 1993 were about 200 percent above the 5-year mean of 490 tons. At all the remaining sites, suspended-solids loads for the 1993 water year were greater than the means for their data-collection periods, ranging from 130 to 250 percent above mean loads (table 3). The minimum loads for suspended sediment and (or) suspended solids were transported in either water year 1991 or 1992. At Brewery Creek, the suspended-sediment load for water year 1991 was 45.3 tons, about 5 percent of the 5-year mean of 855 tons. In water year 1991, the suspended-solids load at Bower Creek was 718 tons, about 16 percent of the 3-year mean of 4,430 tons.

Total-phosphorus loads and yields also were highest in water year 1993 at the eight rural evaluation-monitoring sites (table 3). The maximum load of 156,000 lb was at Rattlesnake Creek during water year 1993; the corresponding yield was 3,670 lb/mi^2. The total-phosphorus loads and yields vary with suspended-sediment and suspended-solids loads because phosphorus sorbs to sediment particles. Total-phosphorus load at Brewery Creek in water year 1993 was about 250 percent greater (10,700 lb) than the 5-year mean of 4,410 lb (table 3). Total-phosphorus load at Garfoot Creek (7,080 lb) was 200 percent greater than the 5-year mean of 3,460 lb (table 3). Similar trends were noted for the other sites; total-phosphorus load at Joos Valley Creek was 140 percent greater than the mean load, and total-phosphorus load at Bower Creek was about 170 percent greater than the mean load for the years monitored.

Dissolved Oxygen

Dissolved oxygen is an essential element for aquatic life. Dissolved-oxygen concentrations may be depleted by processes that consume dissolved, suspended, or precipitative organic matter (Hem, 1985). Aquatic macrophytes consume oxygen by respiration at night and produce oxygen by photosynthesis during the day. Dissolved-oxygen requirements differ from species to species, life stages, and life processes. The State of Wisconsin water-quality standard for warmwater streams (maximum water temperature greater than 24°C) is 5 mg/L; the standard for coldwater streams (maximum water temperature less than 24°C) is 6 mg/L. Another approach to setting standards is to specify a concentration that is equaled or exceeded for specified durations during the year. For warmwater streams, reasonable criteria are 5 mg/L for 50 percent of the time and 2 mg/L for 5 percent of the time. For coldwater streams, reasonable criteria are 9 mg/L for 50 percent of the time and 5 mg/L for 5 percent of the time (Alabaster and Lloyd, 1982).

Continuous dissolved-oxygen (DO) concentration data were collected at seven monitoring sites: Garfoot Creek, Black Earth Creek at County Trunk P, Black Earth Creek at Mills Street, Black Earth Creek at South Valley Road, Otter Creek, Rattlesnake Creek, and Kuenster Creek. Dissolved-oxygen concentration data was collected from May 1 through September 30.

Maximum, minimum, and mean dissolved-oxygen concentrations for each of the monitoring sites for water years 1990, 1991, 1992 and 1993 were published previously (Graczyk and others, 1993; Corsi and others, 1994). The maximum dissolved-oxygen concentration at the evaluation monitoring sites was 19.9 mg/L at Kuenster Creek during water year 1992 (Graczyk and others, 1993). The minimum dissolved-oxygen was 0 mg/L at Rattlesnake Creek during water year 1992 (Graczyk and others, 1993).

Streamwater at the sites had dissolved-oxygen concentrations below the State standards at some time during 1990-93 (Corsi and others, 1994). Dissolved-oxygen concentration remained above the lower limit of the alternative standards (5 mg/L more than 5 percent of the time) at the 4 coldwater streams from 1990-93 (fig. 3). The dissolved-oxygen concentration was 5 mg/L or less for about 2 percent of the days monitored. However, concentrations were frequently less than the upper limit of 9 mg/L for 50 percent of the time. The dissolved-oxygen concentrations for 50 percent of the time ranged from 7.7 mg/L at Black Earth Creek at County Trunk P to 8.1 mg/L at Garfoot Creek at Garfoot Road (fig. 3).

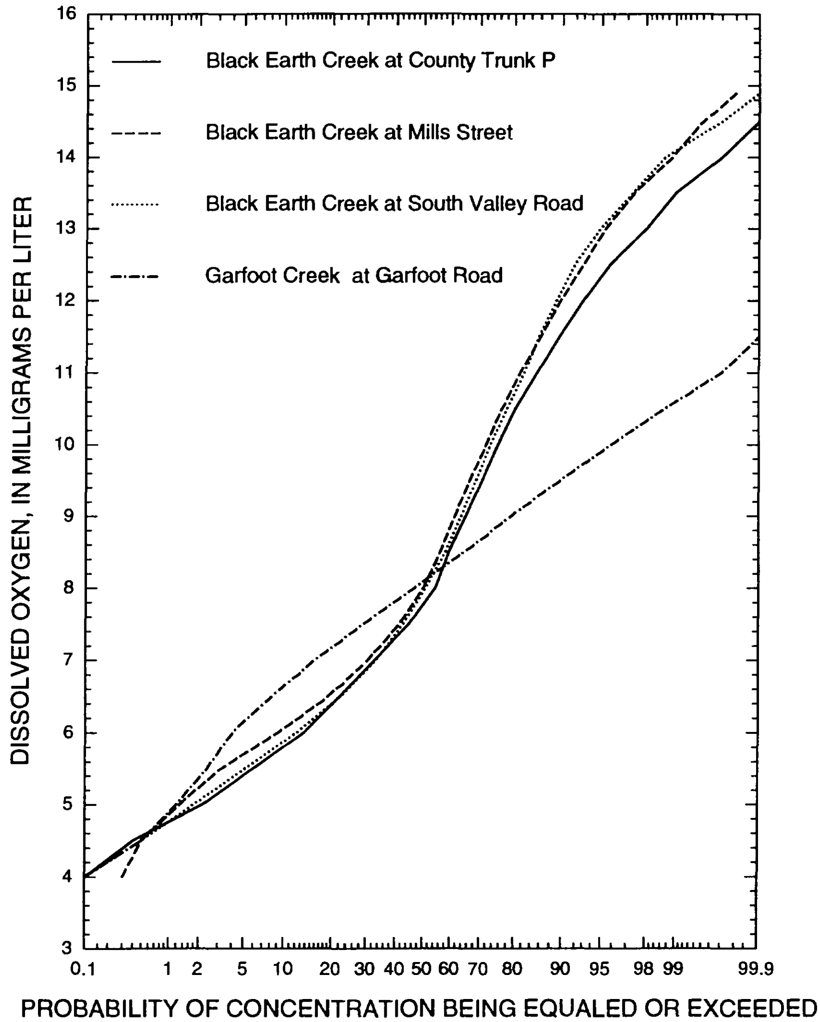

Figure 3. Distribution of percentage of time that dissolved-oxygen concentrations were equaled or exceeded at coldwater streams, water years 1990-93.

Dissolved-oxygen duration curves for the three Black Earth Creek stations had the same shape, but the curve for Garfoot Creek was considerably different. All four sites are considered to be representative of coldwater streams. The difference in shape may result from a difference in biological productivity. Black Earth Creek is capable of supporting more plant biomass than Garfoot Creek (Madsen, 1986); thus, fluctuations in dissolved-oxygen concentration because of respiration and photosynthesis would be more extreme in Black Earth Creek (fig. 3). This may account for the difference in the shape of the dissolved-oxygen duration curves.

Monitoring Activities in Water Year 1995

The following water-quality-monitoring activities are planned for water year 1995:

1. Continue collection of stormflow samples for determination of suspended-solids or suspended-sediment and total phosphorus loads and yields. Data collection may be scaled back at some sites if installation of BMP's in the watersheds has not begun. Intensive data collection can begin again once a sufficient number of BMP's have been installed.

2. Continue dissolved-oxygen monitoring at the seven sites and analyze data for the coldwater sites. The coldwater sites are in the watersheds where most of the BMP's have been installed. Available data may be sufficient at the end of water year 1995 to determine whether dissolved-oxygen concentrations have changed as a result of the BMP implementation.

URBAN-WATERSHED QUALITY ASSURANCE AND QUALITY CONTROL

The quality-assurance/quality-control (QA/QC) plan for the urban watershed-management evaluation monitoring sites was defined previously by Corsi and others (1994). The field procedures, sample processing, and equipment-cleaning procedures during water year 1994 also were outlined by Corsi and others (1994).

Blank Samples for Inorganic Constituents

The QA/QC plan for the urban watershed-management evaluation monitoring program during water year 1994 consisted of a series of blank samples collected from Milli-Q (analyte-free) water, which were passed through the automatic sampling system used in sample collection and processing of streamwater samples from urban sites. In water year 1994, data from blank samples indicated contamination from two parts of the sample-processing system: the automatic sampler and splitter and the filtration system. Two types of samples were used for this purpose: the "cumulative splitter blank" and the "cumulative filter blank." The cumulative splitter blanks consist of reagent water that has been through the automatic sampling system and the churn splitter. The cumulative filter blanks consist of reagent water that has been run through the automatic sampling system, poured into the churn splitter, and filtered. A detailed description of the protocol for blank samples is outlined in Corsi and others (1994). Blank samples are analyzed for the same constituents as streamwater samples.

Blank samples were collected on six different days during April 1994 through October 1994 at Monroe Street Detention Pond and Lincoln Creek. All six samples at both sites included a cumulative splitter blank and a cumulative filter blank.

Sample Contamination

Most constituents in most of the blank samples were not found at concentrations above detectable limits; however, a few constituents were detected. Dissolved chloride was detected in all six samples at Lincoln Creek, ranging from 0.4 to 1.9 mg/L. Dissolved chloride was detected in three of the six samples at Monroe Street Detention Pond, ranging from 0.8 to 9.8 mg/L. Concentrations of chloride contamination are significant with respect to some of the water samples from Monroe Street Detention Pond and Lincoln Creek, which ranged from 1.9 to 4,330 mg/L.

Alkalinity was detected between 1 and 3 mg/L for all blank samples at Lincoln Creek and Monroe Street Detention Pond. Concentrations of alkalinity in water samples from Monroe Street Detention Pond ranged from 20 to 68 mg/L during 1994, whereas concentrations in water samples from Lincoln Creek ranged from 53 to 207 mg/L. The levels of contamination are relatively low in comparison to concentrations found in water samples from Monroe Street Detention Pond and Lincoln Creek but still are probably unacceptable.

Biochemical oxygen demand (BOD) was detected in three of the six blank samples at Monroe Street Detention Pond and five of the six blank samples at Lincoln Creek. Concentrations ranged from 0.5 to 1.7 mg/L. Concentrations of BOD in water samples from Monroe Street Detention Pond and Lincoln Creek ranged from 1.5 to 110 mg/L during water year 1994. Concentration of BOD in the blank water is quite high in comparison to concentrations in some of the water samples.

Dissolved chloride, alkalinity, and BOD were clearly being introduced from a systematic source(s) of contamination. By comparing the concentrations found in blank samples to the concentrations found in water samples, one can conclude that lower concentrations of dissolved chloride, alkalinity, and BOD in water samples from Monroe Street Detention Pond and Lincoln Creek may be unreliable, whereas higher concentrations of these constituents in water samples are probably not adversely affected by contamination.

A few incidents of random contamination also were noted in the blank samples. Specific conductance was generally below 10 µS/cm in the blank samples, but two of six samples at the Monroe Street Detention Pond had specific conductances of 44 and 27 µS/cm, and one of six samples at Lincoln Creek had a specific conductance of 25 µS/cm. Total recoverable zinc was near or below the limit of detection (10 µg/L) in the blank samples except for one of six samples at Lincoln Creek, which contained 130 µg/L. Dissolved calcium, dissolved magnesium, and dissolved hardness were found to be below the limits of detections of 1.0 and 6.0 mg/L, respectively, except for one of six samples at the Monroe Street Detention Pond. In this sample, dissolved calcium was detected at 50 mg/L, dissolved magnesium at 31 mg/L, and dissolved hardness at 250 mg/L. The levels of specific conductance and elevated concentrations of total recoverable zinc, dissolved calcium, dissolved magnesium, and dissolved hardness in blank samples appear to be random and not attributable to any given site or time period. Water-sample data for these constituents and properties at Monroe Street Detention Pond and Lincoln Creek during water year 1994 are probably not adversely affected by contamination.

Monitoring Activities in Water Year 1995

The following urban QA/QC activities are planned for water year 1995:

1. Attempt to determine the source or sources of dissolved chloride, alkalinity, and BOD in blank samples. If the source or sources are found, appropriate measures can be taken to ensure that future contamination is minimized.

2. Continue to collect blank samples monthly during the sampling season (March through November). The protocols for collecting blank samples will remain the same as outlined previously (Corsi and others, 1994) unless it is determined that changing these protocols will reduce contamination in future blank samples and ambient water samples. Bottle washing, sampling, sample splitting, and filtration will also continue in accordance with protocols outlined previously (Corsi and others, 1994) unless it is determined that changing these protocols will reduce contamination in future samples.

ANALYSIS OF CONSTITUENT LOADS IN RURAL STREAMS BEFORE INSTALLATION OF BEST-MANAGEMENT-PRACTICES

The goal of the evaluation monitoring program is to determine if the implementation of BMP's has resulted in an improvement in the water quality of streams receiving agricultural runoff. Previous research has identified an appropriate statistical approach that can be used to determine if statistically significant changes have occurred (Walker, 1994). The general approach is to compare constituent loads in storm runoff for pre-BMP conditions to constituent loads in storm runoff for post-BMP conditions. Because of the substantial variability in constituent loads, regression analyses are used to account for some of the natural variability of the constituent loads and to improve the chances of detecting a statistically significant difference between pre- and post-BMP conditions.

The purpose of this section of the report is to explore preliminary regressions for pre-BMP conditions for the rural streams and to assess the likelihood of detecting changes in the individual watersheds. Data for two of the rural streams, Brewery and Garfoot Creeks, were not used in the analysis because those watersheds are in the transitional period; preliminary results for these streams are presented in Walker and Graczyk (1993). A third rural stream, Kuenster Creek, was not used because sufficient constituent-load data were not available. Constituent-load data collected through water year 1993 for the remaining five rural streams were included in the regression analysis, which was limited to suspended-solids and total-phosphorus loads in storm runoff.

Regression analyses require specification of a dependent variable and a set of independent variables thought to control the variability of the dependent variable. For this report, separate analyses were done with loads of suspended solids and total phosphorus chosen as dependent variables. Measures related to precipitation and time were chosen as independent variables because these were felt to be free from any changes that may be induced through the installation of BMP's. Several primary precipitation measures were computed for individual storms: total rainfall, 15- and 30-minute maximum rainfall intensities, and the Universal Soil Loss Equation (USLE) erosivity index (Wischmeier and Smith, 1978). Antecedent precipitation measures were computed as the total rainfall occurring 1, 3, 5 and 7 days before the beginning of each individual stormflow period.

Two periodic terms were computed to allow for the possibility of cyclical processes; the two terms were cos(2π T/365.25) and sin(2π T/365.25), where T is the beginning date of the storm, expressed as the number of years since 1904, and cos() and sin() are the trigonometric cosine and sine functions, respectively. In some instances, the data were divided into three seasonal groups (spring, summer, fall/winter). In other instances, the data were divided into two groups on the basis of U.S. Soil Conservation Service (SCS) definition of antecedent moisture conditions (AMC), summarized in table 4. For all the streams, the growing season was defined as June 1 through September 30.

For Eagle Creek, two groups of data were defined on the basis of SCS AMC criteria. Group 1 corresponds to SCS AMC I, and group 2 corresponds to SCS AMC II (table 4). For Joos Valley Creek, the SCS AMC criteria were used to define two preliminary groups of data. Group 1 (SCS AMC I) was further subdivided into three subgroups: (1a), spring stormflow periods; (1b), summer stormflow periods when the 3-day antecedent precipitation was less than 0.3 in.; and (1c), summer stormflow periods when the 3-day antecedent precipitation was greater than 0.3 in. Group 2 represents SCS AMC II. For Bower Creek and Otter Creek, three seasonal groups were defined on the basis of starting date of each stormflow period. For Rattlesnake Creek, the SCS AMC criteria were used as with Eagle and Joos Valley Creeks and to define two preliminary groups of data. The first group (SCS AMC I) was further subdivided into two subgroups: (1a), stormflow periods when the 7-day antecedent precipitation was less than 0.6 in.; and (1b), stormflow periods when the 7-day antecedent precipitation was greater than 0.6 in. Group 2 represents SCS AMC II.

Table 4. Definition of Soil Conservation Service antecedent moisture conditions

[Modified from U.S. Soil Conservation Service 1972: AP_5 = total precipitation for previous 5 days; <, less than; >, greater than; in., inch]

Antecedent moisture condition	Growing season[1]	
	Dormant	Active
I	$AP_5 < 0.5$ in.	$AP_5 < 1.4$ in.
II	$AP_5 > 0.5$ in.	$AP_5 > 1.4$ in.

[1]Active growing season is June 1 through September 30.

Stepwise regression equations for suspended solids and total phosphorus were computed for each of the five rural streams. Separate regression equations were determined for each subgroup of data identified previously. In many cases, a few anomalously large constituent loads were removed from the data set to allow for a reasonable fit of the regression equation to the data. (These loads were so large that they could not be explained by any of the independent variables.) One possible explanation for the anomalous loads is a storage component to the sediment delivery process; during some high streamflows, the velocity of the streamwater may exceed a critical threshold and begin to scour the channel. Additional research is needed to define appropriate independent variables to bring the large loads back into the regressions.

The resulting regressions are summarized for loads of suspended solids and total phosphorus in tables 5 and 6. For most regressions, one independent variable explained most of the variability in the loads; in other cases, a second independent variable was used to increase the precision of the regression equation. In some regressions, an independent variable equal to the sum of total precipitation and one of the antecedent precipitation measures was used. This variable proved to be the most effective single variable for explaining the variability in constituent loads for some streams.

Two measures are used to indicate the ability of the regression equation to explain the variability of the constituent loads: R^2, the portion of the total variability in the dependent variable that is explained by the independent variables in the equation, and the standard error of the regression, reported as a percentage of the mean value of the dependent variable. (The standard error is basically a measure of the variability of the regression residuals, which indicates the variability remaining in the dependent variable.) Previous work by Walker (1994) has indicated that the standard error, expressed as percent of the mean, can be used as a proxy for the minimum change in condi-

Table 5. Summary of regression results for loads of suspended solids in storm runoff
[P_t, total precipitation; EI, Universal Soil Loss Equation Erosivity Index; AP_n, total precipitation for previous n days; T, starting date of stormflow period, in years since 1904; sin(), trigonometric sine function; R^2, ratio of total variance to variance explained by the regression]

Stream	Group[a]	Sample size	Independent variables	Adjusted R^2	Standard error[b]
Eagle	1	17	P_t+AP_3, AP_1	0.88	48
	2	8	P_t	.77	43
Joos Valley	1a	5	P_t^2	.93	20
	1b	7	EI	.58	55
	1c	6	P_t+AP_1	.82	42
	2	9	P_t^2	.82	52
Bower	1	7	EI	.77	60
	2	8	AP_7, AP_3	.86	62
	3	12	P_t, EI	.82	68
Otter	1	8	P_t	.94	16
	2	9	EI, sin(2πT/365.25)	.56	83
	3	11	P_t	.27	67
Rattlesnake	1a	7	EI	.85	49
	1b	7	AP_1	.87	32
	2	7	EI	.9	51

[a]For Eagle, Joos Valley, and Rattlesnake, group 1 represents U.S. Soil Conservation Service (SCS) antecedent moisture condition (AMC) I; group 2 represents SCS AMC II. For Bower and Otter, groups 1-3 are defined on the basis of season. Letters after group numbers represent further subdivision on the basis of season.

[b]Expressed as a percentage of the average suspended-solids storm runoff load.

Table 6. Summary of regression results for loads of total phosphorus in storm runoff
[P_t = total precipitation; EI = USLE Erosivity Index; AP_n = total precipitation for previous n-days; I15 = 15-minute maximum precipitation intensity; T = starting date of stormflow period, in years since 1904; cos() = trigonometric cosine function; R^2, ratio of total variance to variance explained by the regression]

Stream	Group[a]	Sample size	Independent variables	Adjusted R^2	Standard error[b]
Eagle	1	17	P_t+AP_3, AP_1	0.84	52
	2	8	P_t+AP_3	.74	47
Joos Valley	1a	5	P_t^2	.90	19
	1b	7	AP_1, AP_5	.98	26
	1c	6	P_t+AP_1	.93	26
	2	9	P_t^2, cos(2πT/365.25)	.94	28
Bower	1	7	P_t	.86	37
	2	7	AP_7, AP_3	.68	76
	3	12	P_t, EI	.81	60
Otter	1	8	P_t	.85	26
	2	9	EI, I_{15}	.72	62
	3	11	P_t, AP_7	.33	52
Rattlesnake	1a	7	EI, I_{15}	.89	47
	1b	7	AP_1	.73	40
	2	7	EI	.90	45

[a]For Eagle, Joos Valley, and Rattlesnake, group 1 represents U.S. Soil Conservation Service (SCS) antecedent moisture condition (AMC) I; group 2 represents SCS AMC II. For Bower and Otter, groups 1-3 are defined on the basis of season. Letters after group numbers represent further subdivision on the basis of season.

[b]Expressed as a percentage of the average suspended-solids storm runoff load.

tions before and after BMP installation that would be statistically significant. Experience from the preliminary results from the Black Earth Creek priority watershed (Walker and Graczyk, 1993) indicates that the minimum detectable change could be somewhat less than the pre-BMP standard error of regression.

The results for Eagle Creek indicate that a change of 40 to 50 percent in suspended-solids and total-phosphorus stormflow load could be detected with a statistical test. For Joos Valley Creek, a change in suspended-solids stormflow load would have to be 20 to 50 percent to be detected; the results for total phosphorus are somewhat less restrictive (20 to 30 percent). For Bower Creek, a change in suspended-solids and total-phosphorus load of 40 to 70 percent would be needed to be statistically significant. For Otter Creek, a change in suspended-solids stormflow load would have to be 20 to 80 percent to be statistically significant; the results for total phosphorus are less restrictive (30 to 60 percent). Finally, for Rattlesnake Creek, a change in suspended-solids and total-phosphorus stormflow load of 30 to 50 percent would probably be detected with a statistical test. For each site, the reported figures for potential minimum detectable change should be considered in the context of the potential for BMP implementation in the corresponding watershed to achieve the minimum levels of change.

For all the sites, the figures reported for minimum detectable change could potentially decrease as the regression relations are further refined. More sophisticated statistical techniques could be used to divide the data into groups that behave similarly, and additional research may reveal better ways to incorporate the antecedent precipitation measures into the regressions. On the other hand, the reported figures for minimum detectable change could potentially increase as the few anomalously large loads are brought back into the data sets.

ANALYSIS OF SNOWMELT RUNOFF

Snowmelt runoff periods are frequent in Wisconsin during the winter and early spring months. As a result, a significant portion of the annual load can occur during these months. A determination of whether the concentration and load are different for snowmelt runoff than for storm runoff would greatly enhance the ability of planners to design and develop BMP's because BMP's could then be targeted toward the types of runoff that contribute significant proportions of the annual load.

The purpose of this section of the report is to determine whether the event mean concentrations (EMC's) and runoff loads of suspended solids and total phosphorus are different for snowmelt and storm runoff periods in rural and urban areas. Rural snowmelt runoff data are compared to rural storm runoff data, and urban snowmelt runoff data are compared to urban storm runoff data.

For the purpose of this analysis, snowmelt runoff periods are defined as periods where snow is still present on the ground. This definition includes not only "pure" snowmelt but also rain-on-snow runoff. An attempt was made to separate the snowmelt runoff types, but the resulting sample size was too small for reliable statistical analyses. The analysis was limited to sites where more than five snowmelt runoff periods were sampled. Data for all evaluation monitoring sites except Joos Valley Creek, Eagle Creek, and Lincoln Creek were used.

Runoff loads for rural and urban evaluation monitoring sites have been computed for runoff periods from 1984-93. To determine if a runoff period was rainfall induced or snowmelt induced, field notes were consulted and a rainfall-runoff analysis was done. Field notes were considered to be the more reliable of the two indicators because they were made during or just after the runoff occurred. The rainfall-runoff analysis was used if field notes were not conclusive as to the type of runoff. If the hydrograph increased without an associated rainfall, then the runoff was "pure" snowmelt. If the rainfall produced higher runoff volumes than expected and climatological data indicated snow cover, then the runoff was classified as rain on snow.

Event-mean concentrations (EMC's) and constituent loads for suspended solids and total phosphorus are plotted in figures 4 and 5. The Mann-Whitney U test was used to determine whether a statistically significant difference between constituent concentration and loads in snowmelt and storm runoff could be detected. If statistically significant differences at the 5 percent level were found between either the rainfall or snowmelt runoff EMC's or loads, the type of runoff with the greater EMC or load is shown in bold type (R or SM) in figures 4 and 5.

Three general observations could be made regarding the rural data. First, median loads of suspended solids and total phosphorus tend to be higher for snowmelt runoff than loads for rainfall storm runoff. Second, at sites where a statistically significant difference was found between snowmelt and rainfall storm load, the snowmelt load is greater than the rainfall load. Third, snowmelt data are visually less variable than rainfall data.

Four general observations could be made regarding the urban data. First, median loads of suspended solids and total phosphorus for snowmelt runoff tend to be lower than loads for rainfall storm runoff. Second, median snowmelt concentrations of suspended solids and total phosphorus tend to be lower than median rainfall concentrations. Third, at sites where a statistically significant difference was found between snowmelt and rainfall load, the rainfall load is greater than the snowmelt load. Fourth, snowmelt data are visually less variable than rainfall data.

The large median loads for snowmelt in rural areas indicate that (1) snowmelt runoff periods could be of importance in the design of BMP's and (2) models that are designed to estimate annual loads would be most representative if they incorporate snowmelt functions. The lower urban snowmelt loads, however, can still be a problem. As suggested by Battaglia (1976), detrimental effects to the receiving water can be increased because of the low flows of the receiving waters during the winter months.

SUMMARY AND CONCLUSIONS

This report is an annual summary of the data collected for the Wisconsin watershed-management evaluation monitoring program and a presentation of the results from several different detailed analyses conducted within this program.

A land use and best-management-practice inventory is ongoing for each evaluation monitoring project to track the sources of nonpoint pollution in each watershed. Information is being gathered from the county Land Conservation Districts, the county highway commissions, the Wisconsin Department of Transportation, and the U.S. Soil Conservation Service. This information is mapped and stored in a geographic-information-system data base. Each year, the information for each watershed is reviewed and updated.

Water-quality data collection efforts from eight rural sites and four urban sites are summarized. Annual loads and yields for suspended sediment and total phosphorus were computed for the rural sites. For all sites, the annual suspended-sediment or suspended-solids load for water year 1993 exceeded the average for the period of data collection (see table 1 for data collection periods); the minimum annual loads were transported in either water year 1991 or 1992.

Continuous dissolved-oxygen data were collected at seven rural sites during water year 1994. Data for water years 1990-93 are summarized and plotted in terms of percentage of time that a particular concentration is equaled or exceeded. Concentrations in all the coldwater streams were less than 9 mg/L at least 50 percent of the time, a condition that fails to meet a suggested criterion for coldwater streams. The dissolved-oxygen probability distribution curve for one of the coldwater streams has a markedly different shape than the curves for the other streams, perhaps because of differences in aquatic biomass among the four coldwater streams.

Blank quality-assurance samples were collected at two of the urban evaluation monitoring sites. The sampling protocol was designed to isolate contamination from the sample bottle, the automatic sampler and splitter, and the filtration system. Contamination was found for dissolved chloride, alkalinity, and biochemical oxygen demand. The level of contamination may be large enough to adversely affect data for water samples in which these analytes are at low concentration. Further investigation is being done to determine the source of contamination and to attempt to correct the problem.

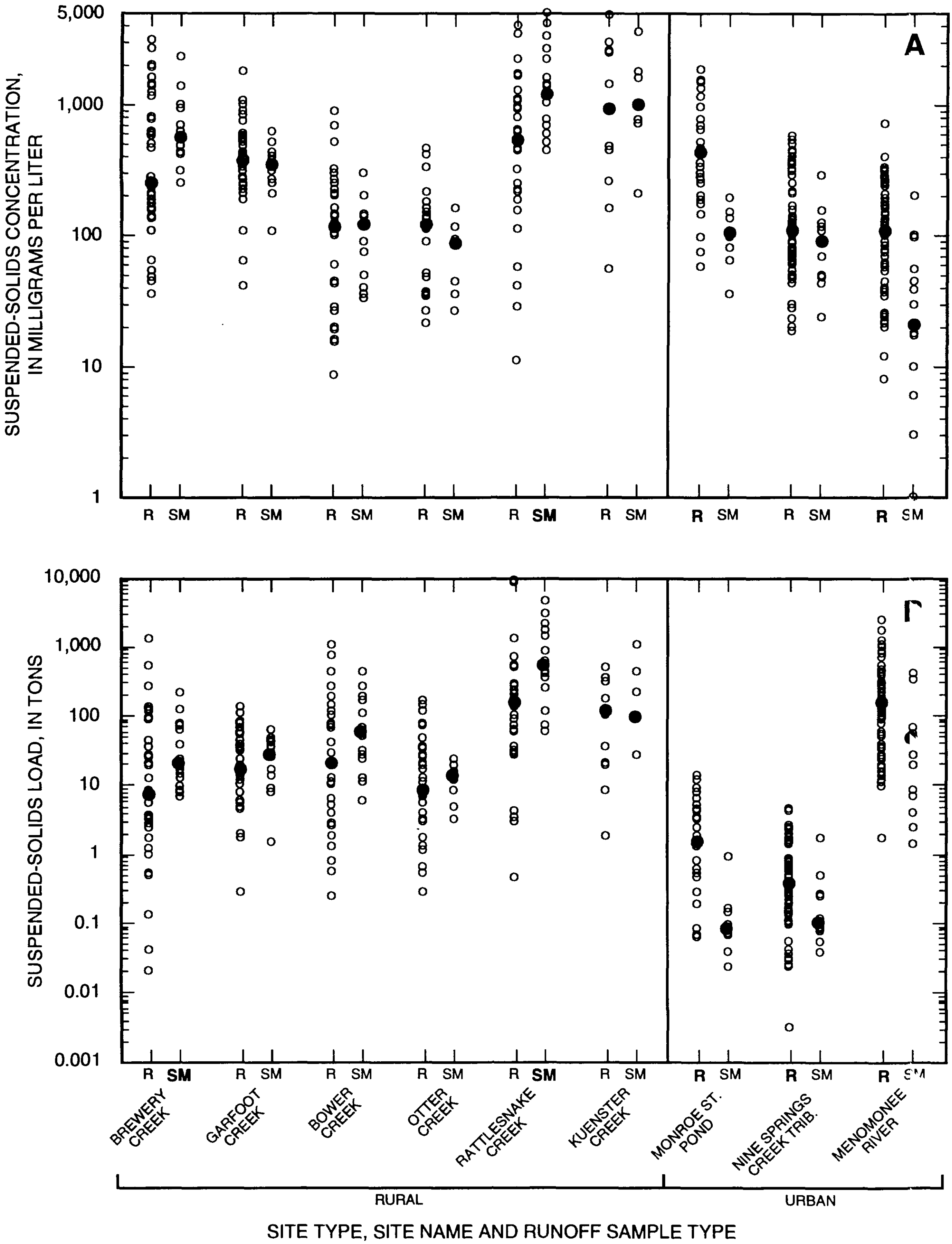

Figure 4. Suspended-solids concentration (panel A) and load (panel B) for rain (R) and snowmelt (SM) runoff samples from rural and urban evaluation monitoring sites, water years 1985-93. Sample values are shown with open circles, and medians are shown with filled circles. Bold runoff sample-type codes indicate sites where statistically significant differences were found between the two types of runoff samples.

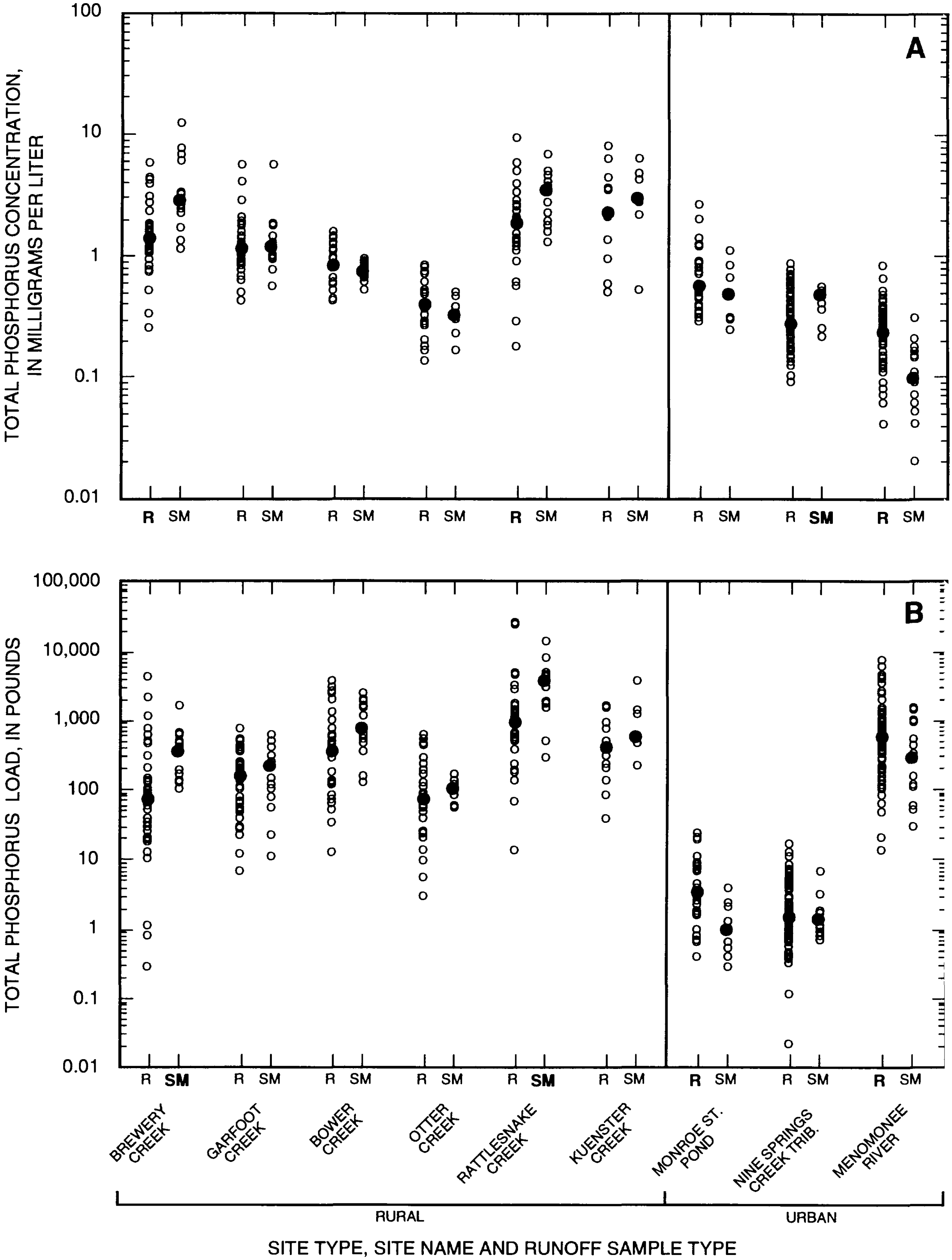

Figure 5. Total-phosphorus concentration (panel A) and load (panel B) for rain (R) and snowmelt (SM) runoff samples from rural and urban evaluation monitoring sites, water years 1985-93. Sample values are shown with open circles, and medians are shown with filled circles. Bold runoff sample-type codes indicate sites where statistically significant differences were found between the two types of runoff samples.

A preliminary regression analysis was done for the rural sites using data collected from water years 1989-93 to estimate what level of water-quality change before and after BMP installation could be statistically detected. Suspended-solids and total-phosphorus loads were used as dependent variables, and various precipitation-related measures were used as independent variables. Dividing the data sets into groups based on time of year and antecedent precipitation greatly improved the regressions. The results indicate that, for most sites, changes in constituent load on the order of 40 to 50 percent would be detected with a statistical test. For two sites, the change would have to be 60 to 70 percent to be detected.

A detailed comparison of snowmelt and storm runoff periods in urban and rural areas was done using data from water years 1985-93. For the rural sites where statistically significant differences were found between snowmelt and rainfall, the snowmelt load is greater than the rainfall load for suspended solids and total phosphorus. In addition, the snowmelt loads for rural areas tended to be less variable than the rainfall loads. For the urban sites where statistically significant differences were found between snowmelt and rainfall loads, the rainfall load is greater than the snowmelt load for both constituents considered. The importance of including snowmelt runoff in designing and analyzing the effects of BMP's on streamwater quality, particularly in rural areas, is further emphasized by these results.

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