In cooperation with the University of Wisconsin-Green Bay

Hydrology, Phosphorus, and Suspended Solids in Five Agricultural Streams in the Lower Fox River and Green Bay Watersheds, Wisconsin, Water Years 2004–06

Scientific Investigations Report 2011–5111

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

Cover photo. Runoff from a field in the Ashwaubenon Creek watershed.

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U.S. Geological Survey
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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	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	metric ton per year
ton per year (ton/yr)	907.2	kilogram per year (kg/yr)
ton per year (ton/yr)	0.9072	metric ton per year
	Yield rate	
cubic foot per second per square mile ($ft^3/s/mi^2$)	0.010953	cubic meter per second per square kilometer ($m^3/s/km^2$)
pound per square mile (lb/mi^2)	0.017514	kilogram per square kilometer (kg/km^2)
ton per square mile (ton/mi^2)	350.27	kilogram per square kilometer (kg/km^2)
	Slope	
feet 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×°C)+32

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

Abbreviations

ADCP	Acoustic Doppler current profiler
BMP	Best-management practices
DEM	Digital Elevation Model
DP	Dissolved phosphorus
GCLAS	Graphical Constituent Loading Analysis System
GBMSD	Green Bay Metropolitan Sewerage District
LFR	Lower Fox River
LFRWMP	Lower Fox River Watershed Monitoring Program
NOAA	National Oceanographic and Atmospheric Administration
NRCS	National Resources Conservation Service
RAP	Remedial Action Plan
SSURGO	Soil Survey Geographic
SWAT	Soil and Water Assessment Tool
SWTP	Southeastern Wisconsin Till Plains
TMDL	Total Maximum Daily Load
TP	Total phosphorus
TSS	Total suspended solids
USGS	U.S. Geological Survey
UWGB	University of Wisconsin-Green Bay
UWM	University of Wisconsin-Milwaukee
VWC	Volumetrically weighted concentration
WDNR	Wisconsin Department of Natural Resources
WY	Water year

Hydrology, Phosphorus, and Suspended Solids in Five Agricultural Streams in the Lower Fox River and Green Bay Watersheds, Wisconsin, Water Years 2004–06

By David J. Graczyk[1], Dale M. Robertson[1], Paul D. Baumgart[2], and Kevin J. Fermanich[2]

Abstract

A 3-year study was conducted by the U.S. Geological Survey and the University of Wisconsin-Green Bay to characterize water quality in agricultural streams in the Fox/Wolf watershed in northeastern Wisconsin and provide information to assist in the calibration of a watershed model for the area. Streamflow, phosphorus, and suspended solids data were collected between October 1, 2003 and September 30, 2006 in five streams, including Apple Creek, Ashwaubenon Creek, Baird Creek, Duck Creek, and the East River. During this study, total annual precipitation was close to the 30-year normal of 29.12 inches. The 3-year mean streamflow was highest in the East River (113 ft^3/s), followed by Duck Creek (58.2 ft^3/s), Apple Creek (26.9 ft^3/s), Baird Creek (12.8 ft^3/s), and Ashwaubenon Creek (9.11 ft^3/s). On a yield basis, during these three years, the East River had the highest flow (0.78 $ft^3/s/mi^2$), followed by Baird Creek (0.61 $ft^3/s/mi^2$), Apple Creek (0.59 $ft^3/s/mi^2$), Duck Creek (0.54 $ft^3/s/mi^2$), and Ashwaubenon Creek (0.46 $ft^3/s/mi^2$).

The overall median total suspended solids (TSS) concentration was highest in Baird Creek (73.5 mg/L), followed by Apple and Ashwaubenon Creeks (65 mg/L), East River (40 mg/L), and Duck Creek (30 mg/L). The median total phosphorus (TP) concentration was highest in Ashwaubenon Creek (0.60 mg/L), followed by Baird Creek (0.47 mg/L), Apple Creek (0.37 mg/L), East River (0.26 mg/L), and Duck Creek (0.22 mg/L).

The average annual TSS yields ranged from 111 tons/mi^2 in Apple Creek to 45 tons/mi^2 in Duck Creek. All five watersheds yielded more TSS than the median value (32.4 tons/mi^2) from previous studies in the Southeastern Wisconsin Till Plains (SWTP) ecoregion. The average annual TP yields ranged from 663 lbs/mi^2 in Baird Creek to 382 lbs/mi^2 in Duck Creek. All five watersheds yielded more TP than the median value from previous studies in the SWTP ecoregion, and the Baird Creek watershed yielded more TP than the statewide median of 650 lbs/mi^2 from previous studies.

Overall, Duck Creek had the lowest median and volumetric weighted concentrations and mean yield of TSS and TP. The same pattern was true for dissolved phosphorus (DP), except the volumetrically weighted concentration was lowest in the East River. In contrast, Ashwaubenon, Baird, and Apple Creeks had greater median and volumetrically weighted concentrations and mean yields of TSS, TP, DP than Duck Creek and the East River. Water quality in Duck Creek and East River were distinctly different from Ashwaubenon, Baird, and Apple Creeks.

Loads from individual runoff events for all of these streams were important to the total annual mass transport of the constituents. On average, about 20 percent of the annual TSS loads and about 17 percent of the TP loads were transported in 1-day events in each stream.

Introduction

Phosphorus and sediment are the primary stressors to the Green Bay ecosystem in northeastern Wisconsin, and they impair more beneficial uses than any other stressors (Harris and others, 1994). In addition to impairing the Green Bay ecosystem, phosphorus is exported from Green Bay to Lake Michigan and increases its productivity. Excessive algae and suspended sediment (often measured as suspended solids) in lower Green Bay and Lake Winnebago, upstream of Green Bay (fig.1), reduce their water clarity and impair major water uses (Millard and Sager, 1994; Wisconsin Department of Natural Resources, 1993). To reach the goals for water clarity and water chemistry, total phosphorus (TP) and total suspended solids (TSS), in lower Green Bay, the Science and Technical Advisory Committee recommended that external loads of TP and TSS be reduced by 50 percent (Green Bay Remedial Action Plan, 2000).

Approximately 70 percent of the annual TP load to Green Bay and 25 percent of the annual TP load to Lake Michigan is from the Fox River (approximately 558,000 kg, Robertson, 1997; Klump and others, 1997; Pauer and others, 2005). About half of this load originates in watersheds that are within the 610-mi^2 Lower Fox River (LFR) watershed (fig. 1; Wisconsin

[1] U.S. Geological Survey

[2] University of Wisconsin-Green Bay.

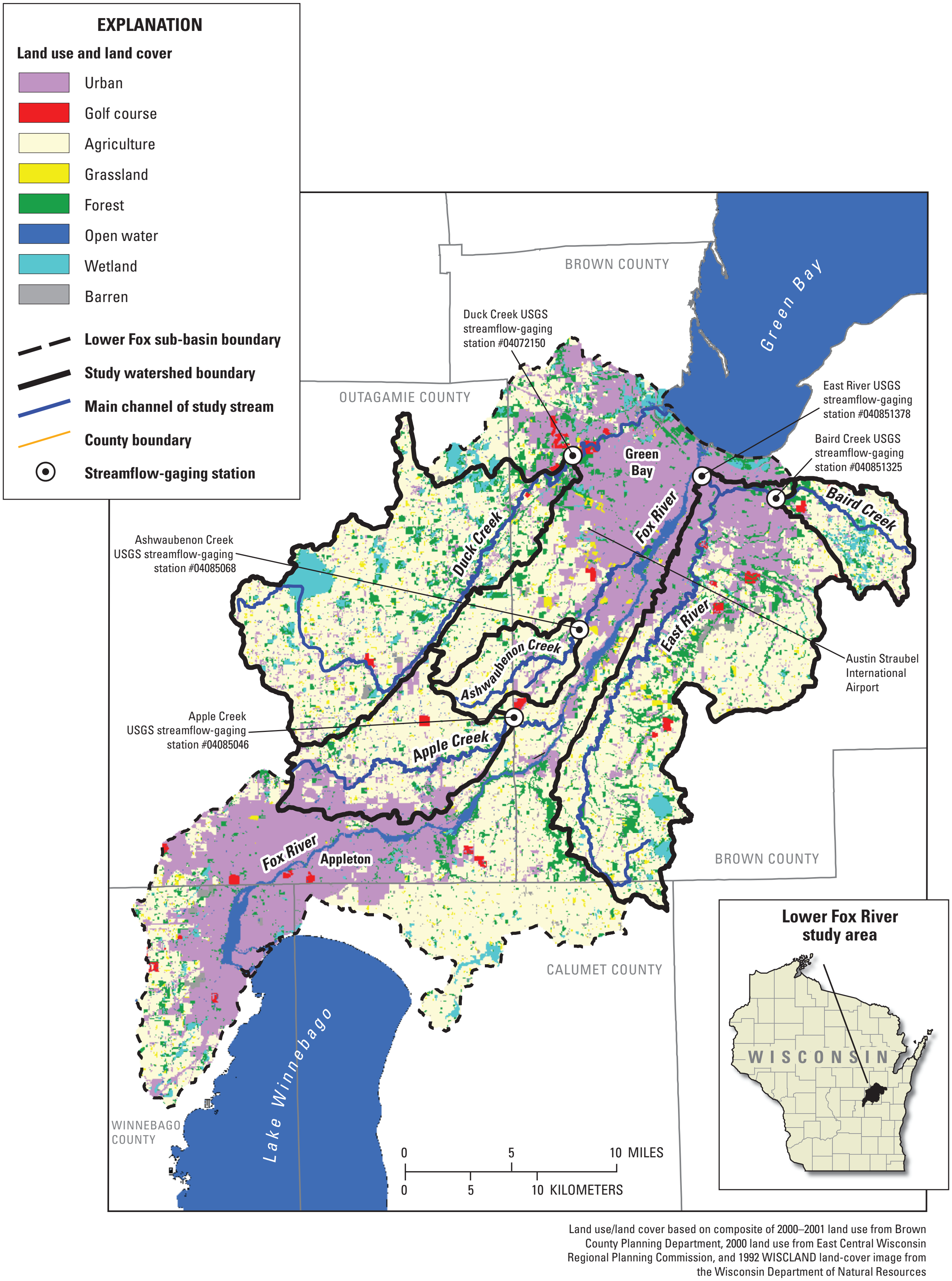

Figure 1. Location of study sites in the Lower Fox River Watershed, in northeastern Wisconsin.

Department of Natural Resources, 1993), which is within the Southeastern Wisconsin Till Plains (SWTP) ecoregion. The LFR watershed is the most downstream watershed of the 6,330-mi^2 Fox-Wolf Basin, which drains a large part of Northeastern Wisconsin and represents about 15 percent of the Lake Michigan drainage basin. The LFR watershed is dominated by agricultural land use, which primarily consists of dairy farm operations, but there are relatively large urban centers near the outlet of Lake Winnebago and along the Fox River. Because of impairment from nonpoint-source pollution, nearly all of the subwatersheds and streams in the LFR watershed have been classified as priority watersheds or listed as impaired waters under Section 303(d) of the Clean Water Act (U.S. Environmental Protection Agency, 2009) by the Wisconsin Department of Natural Resources (WDNR). Therefore, substantial reductions in the export of TP and TSS from the LFR watersheds are needed to achieve the desired water-quality goals.

In reviews of historical water-quality and biological monitoring of streams within the LFR watershed by the University of Wisconsin-Green Bay (UWGB) and in the Green Bay Remedial Action Plan (RAP), it was concluded that more data were needed to provide adequate baseline data to: 1) better characterize TP and TSS export from this area; 2) support the establishment of Total Maximum Daily Loads (TMDLs) to reduce TP and TSS export; 3) support water-quality modeling that will be used as a tool in assessing alternative pollutant-reduction schemes to achieve water-quality targets; and 4) track water-quality and habitat trends. As a result, UWGB obtained a grant from Arjo Wiggins Appleton, Inc., with additional funding from the U.S. Geological Survey (USGS), the Oneida Nation, and the Green Bay Metropolitan Sewerage District (GBMSD), to establish a habitat and water-quality monitoring network. The network consisted of five key agricultural watersheds in the LFR watershed that were identified as significant contributors of nutrients and TSS to the LFR and Green Bay, which represent the range in land use and environmental conditions in the area. The Lower Fox River Watershed Monitoring Program (LFRWMP) was established to support these monitoring efforts. The LFRWMP is a multiyear education, monitoring, and assessment program in and around the LFR watershed. The program was administered by UWGB, with major cooperators that include the USGS, University of Wisconsin-Milwaukee (UWM), GBMSD, Oneida Nation, and six local high schools. The overall goal of the LFRWMP program was to establish a long-term monitoring network that engages watershed stakeholders in the collection of high quality data. These data can be used to: educate the community on how agricultural watersheds affect water quality, aid in water-quality modeling, and predict impacts of management decisions on the ecosystem. The long-term goal of this project was to develop cost-effective approaches to reduce the delivery of TP and TSS to the Lower Green Bay of Lake Michigan by using water-quality models to scale up the methodology and results from LFRWMP studies to encompass the entire Fox-Wolf River drainage basin.

Purpose and Scope

The purpose of this report is to describe the watersheds of the five LFR streams and summarize streamflow, precipitation, and water-quality data that were collected by the USGS and UWGB for these streams for three water years, from October 1, 2003 to September 30, 2006. A water year (WY) is defined as the 12-month period from October 1 for any given year through September 30 of the following year, and is designated by the year in which the period ends. Additional data, collected as part of the LFRWMP but not discussed in this report, include: 1) habitat, macroinvertebrate, and fish-survey data, and real-time sonde data collected by UWM; 2) water-quality, habitat, macroinvertebrate, amphibian and bird surveys data collected by local high schools; 3) additional monitoring at Baird and Duck Creeks by USGS and UWGB after 2006; and 4) studies conducted by students from UWGB, including those examining the effects of urbanization in the Baird Creek watershed (Fink, 2005), the forms of phosphorus at different spatial scales in the LFR watershed (Reckinger, 2007), and the changes in land management, water quality and biotic conditions in Duck Creek over a 20-year period (Cibulka, 2009).

Study Sites

As part of this project, five sites were examined in the LFR watershed (fig. 1). Monitoring stations at four of these sites were installed as part of this study. Streamflow-gaging stations equipped with continuous data recorders were installed in October 2003 on Apple Creek at Sniderville (USGS station number–04085046; 45.8 mi^2 drainage area), Ashwaubenon Creek near Little Rapids (04085068; 19.9 mi^2), and Baird Creek at Green Bay (040851325; 20.8 mi^2); and one station was installed in December 2003, on the East River at Green Bay (040851378; 145 mi^2). A streamflow-gaging station had previously been installed in May 1988 at the fifth site on Duck Creek near Howard (04072150; 108 mi^2).

Land Use

The land use/land cover in the watersheds of the five study sites is summarized in table 1 and displayed in figure 1. Agriculture is the dominant land use and ranges from 58 percent in the East River watershed to 78 percent in the Ashwaubenon Creek watershed. The proportion of wetlands ranges from less than 1 percent in the Ashwaubenon Creek watershed to 10 percent in Baird Creek watershed. Forested areas range from 6 percent in the Apple Creek watershed to 14 percent in the East River watershed. Urban areas range from 7 percent in the Baird Creek watershed to 27 percent in the Apple Creek watershed.

Table 1. Land use and land cover in the watersheds of the five sites in the study.

[Drainage area in square miles, land use and land cover in percent of watershed]

Watershed	Drainage area	Land use/land cover							
		Urban	Recreation	Cropland	Grassland	Forest	Water	Wetland	Barren
Apple Creek	45.8	27	1	62	1	6	1	1	1
Ashwaubenon Creek	19.9	11	0	78	2	9	0	0	0
Baird Creek	20.8	7	1	66	3	13	0	10	0
Duck Creek	108	8	0	67	2	12	1	8	1
East River	145	20	1	58	2	14	0	4	1

Watershed and Channel Lengths and Slopes

Mean overland slopes, derived from the WDNR 30-m Digital Elevation Model (DEM), are summarized in table 2 by major land use/land cover classes for each watershed. Slopes in urban and cropland areas are relatively gentle. Cropland and urban slopes range from 1 percent in the Ashwaubenon Creek watershed to about 2 percent in the East River watershed. Forested areas have slopes that are often 2–3 times those of cropland and urban areas.

Table 2. Mean overland slopes by major land use and land-cover class in the watersheds of the five sites in the study.

[Drainage area in square miles, land use and land cover in percent of watershed]

Watershed	Urban	Cropland	Forest	All
Apple Creek	1.2	1.3	3.0	1.4
Ashwaubenon Creek	1.0	1.0	1.7	1.0
Baird Creek	1.1	1.1	2.8	1.1
Duck Creek	1.8	1.6	2.3	1.7
East River	1.7	2.0	5.7	2.2

The main channel lengths and mean stream slopes of each of the monitored streams are summarized in table 3. The Wisconsin Department of Natural Resources 24k Version 6 hydrography shapefile was used to determine the spatial extent of the designated named main channel for each stream; however, the south branch of Ashwaubenon Creek was merged with the main channel of Ashwaubenon Creek for purposes of calculating the combined channel length and slope. Stream slopes range from 6.5 ft/mi in Duck Creek to 18.3 ft/mi in Baird Creek.

Table 3. Main stream channel length, mean stream slope, and mean slope of the watersheds of the five sites in the study.

[Length in miles, and slopes in feet per mile]

Watershed	Length	Overall mean stream slope	Mean slope of watersheds
Apple Creek	19.9	9.3	8.8
Ashwaubenon Creek	11.8	14.3	10.6
Baird Creek	9.6	18.3	22.4
Duck Creek	35.9	6.5	11.1
East River	42.3	7.3	25.8

Soil Characterization

Soil characteristics for each watershed (table 4) were estimated from the Soil Survey Geographic (SSURGO) Database (U.S. Department of Agriculture, National Resources Conservation Service, 2007a). Only the surface soils, from the surface to a depth of 5 ft, were quantified. Soils in the LFR area are relatively impermeable silt and clay loams, and result in high relative runoff rates and low base flow. Soil types are mostly silt loam to silty clay loam. Silt loam soils represent about 50 percent of soils in each of the five watersheds. The percent clay in surface soils ranged from 15 percent in the Duck Creek watershed to 26 percent in the Ashwaubenon and Apple Creek watersheds. The Duck Creek watershed has the highest proportion of sand in the surface soil (35 percent), and generally has the most permeable soils. Therefore, its flow is expected to have the lowest proportion of surface runoff and highest proportion of base flow.

Table 4. Soil characteristics and hydrological groups in the watersheds of the five sites in the study, based on data in the Natural Resources Conservation Service's (NRCSs) Soil Survey Database.

[All values are in percent]

	Apple Creek	Ashwaubenon Creek	Baird Creek	Duck Creek	East River
Soil texture components					
Sand	26	25	27	35	30
Silt	48	49	52	50	50
Clay	26	26	21	15	20
NRCS hydrologic group*					
A	4	4	1	5	2
A/D	1	0	7	5	2
B	7	5	2	9	12
B/D	1	1	0	6	1
C	84	87	75	72	77
D	5	5	14	3	6

*When thoroughly wet, runoff potential is A: low, B: moderately low, C: moderately high, and D: high.

The proportions of soils of specific hydrologic groups are summarized in table 4 for each watershed. The U.S. Department of Agriculture, National Resources Conservation Service (NRCS) National Soil Survey Handbook (2007b) defines a hydrologic group as a group of soils having similar runoff potential under similar storm and cover conditions. When thoroughly wet, runoff potential is defined as either A: low, B: moderately low, C: moderately high, and D: high. In addition, soils designated as dual soil hydrologic groups (A/D and B/D) are wetland soils and exhibit properties of a D soil when undrained. The combined proportion of soils in hydrologic groups C and D soils ranged from 75 percent at Duck Creek to 92 percent at Ashwaubenon Creek. These groups have a layer that impedes the downward movement of water, which results in slow to very slow infiltration rates and moderately high to high runoff potential. Therefore, most of the soils in the five LFRWMP watersheds are expected to have high runoff potential under saturated conditions.

Methods of Data Collection and Analysis

Precipitation Monitoring

To describe precipitation throughout the LFR watershed, precipitation gages were installed near the stream gages on Apple, Ashwaubenon, Baird, and Duck Creeks in October 2003. Precipitation was collected in 8-in. diameter tipping bucket rain gages. Rainfall was summed and recorded every 5 minutes during non-freezing periods. During winter months (November through March), daily precipitation was obtained from the long-term National Oceanographic and Atmospheric Administration (NOAA) precipitation station at the Green Bay Airport (Austin Straubel Airport; fig. 1).

Streamflow and Water-Quality Data Collection

Streamflow-gaging stations equipped with data recorders were installed at each site (fig. 1). At all stations except the one at the East River site, stages were measured with a gas-purge-pressure system and recorded in a Campbell Scientific data logger. Discharge measurements were made according to standard USGS methods every 4 to 6 weeks and more frequently during high flow to define a stage-discharge relation for each site (Rantz and others, 1982). An acoustic Doppler current profiler (ADCP) was installed at the East River site to measure water velocities because this site is affected by backwater and seiche effects from Green Bay. Water velocities and the cross-sectional areas were then used to determine the discharge at this site (Laenen, 1985; Oberg and others, 2005; Ruhl and Simpson, 2005). Streamflow data were published each year in “Water Resources Data, Wisconsin” for water years 2004 through 2006 (Waschbusch and others, 2005–07).

Each station was equipped with a stage-activated, refrigerated sampler for automated collection of water samples that are representative of different flow conditions (increasing and decreasing flow). A data logger was programmed to collect a sample with each 0.2-ft increase in stage once the stage reached an initial sampling threshold. The initial sampling threshold was variable and changed seasonally. After the stage peaked, samples were collected with each 0.4-ft decrease in stage. This sampling strategy was designed to collect most samples during increasing stage, when constituent concentrations were expected to be changing most rapidly. Samples were only collected at the East River during positive flows to Green Bay. To minimize the possibility of collecting water from Green Bay, the data logger would send a signal to the sampler to collect a sample after a set volume of water passed the gage in a positive direction. During events, a daily sample was analyzed which was a composite of positive flow subsamples. After the samples were collected, they were chilled to 4°C and then analyzed for TSS and TP. A subset of the samples was selected and vacuum filtered through 0.45 µm mixed cellulose ester membranes, and then analyzed for dissolved phosphorus (DP).

In addition to the automated samples, manual samples were collected at each station at a fixed interval − approximately every two weeks in spring, summer, and fall, and once a month in winter. These samples were integrated over the depth and width of the stream by use of a hand-held sampler (Edwards and Glysson, 1999). The fixed-interval samples were analyzed for TSS, TP, and DP. Paired manual-automated samples were collected to test for any potential bias in the autosampler; corrections were applied if needed.

All water samples were analyzed by the GBMSD according to standard methods. TSS was analyzed using Standard Method 2540 D (Clesceri and others, 1998). TP and DP were analyzed using colorimetric methods using Automated Block Digester Method 365.4 from the U.S. EPA Methods for Chemical Analysis of Water and Wastes (U.S. Environmental Protection Agency, 1983). In this study, DP samples were fully digested, so they represent the total dissolved P in the water samples.

Flow Separation

Daily mean flows were separated into either base flow or overland runoff by use of the Base Flow Index (BFI) automated hydrograph separation program (Institute of Hydrology, 1980 a,b), and the results were used to classify samples into either base-flow samples or runoff samples. The BFI program divides the water year into N-day increments and the minimum flow for each N-day period is identified, where N is a user-specified duration in days. The application was run using standard Institute of Hydrology methods with a 5-day interval. Overland runoff—the difference between the daily mean discharge and base flow—is water that flows over the land surface and enters the stream. Base flow primarily represents groundwater discharge to the stream. Each day was classified as either dominated by overland runoff or base flow. If less than 80 percent of the daily mean flow was classified as base flow, then that day was considered a runoff event and the samples collected on that day were classified as runoff samples. In addition, samples collected within a few days following runoff events were also classified as being runoff samples. The number of affected days were computed from the drainage area of the watersheds (in square miles) raised to the 0.20 power and rounded up to the next whole value (Viessman and others, 1977). The number of extra days affected by runoff was 2 days for Apple, Ashwaubenon, and Baird Creeks, and 3 days for Duck Creek and the East River.

Load Computation

TSS and TP loads were computed for the entire monitoring period using the Graphical Constituent Loading Analysis System (GCLAS; Koltun and others, 2006). GCLAS is a program developed by the USGS to estimate loads of water-quality constituents from instantaneous measurements of streamflow and constituent concentration, which collectively can be used to compute instantaneous loads. Generally, concentrations are linearly extrapolated between measurements except at the beginning and end of each event. Prior to the extrapolations, additional concentrations are often added to the time series to better describe concentrations just prior to an event and just following an event, or to describe events with no measured concentrations. Concentrations at the beginning of an event were estimated from concentrations measured during previous base-flow periods. Concentrations at the end of the events were estimated from concentrations measured shortly after the end of an event. For the East River site, the monthly and annual loads were adjusted for reverse flows and negative daily loads. Data collection at the East River was started in December of 2003; therefore, for WY 2004, loads were only estimated from December 16 to September 30.

Samples were analyzed for DP to describe general changes during different flow conditions and different seasons. Loads for DP were not calculated directly from GCLAS because too few samples were analyzed to adequately characterize the variability during runoff events required for accurate daily load estimation. Therefore, to estimate loads, a ratio of DP to TP concentrations (DP/TP) was first computed based on all available coinciding samples. Time series plots of the DP/TP ratio were constructed for each site to determine if there was seasonality in this ratio; however, no seasonality was found. Scatterplots between DP/TP ratios and daily mean discharge demonstrated a nonlinear response (fig. 2). Therefore, breakpoints were computed such that streamflow partitioned the ratios into two groups that minimized the intra-group variance and maximized the intergroup variance. The breakpoints were determined by use of regression-tree analysis in the statistical package SPLUS (Lam, 2001). The flow breakpoint was different for each stream (table 5). The median DP/TP ratios below and above the flow breakpoints are also listed in table 5. The DP/TP ratio below the breakpoint (low flows) ranged from 0.50 for the East River to about 0.7–0.8 for the other four sites. The DP/TP ratios above the breakpoint (high flows) were all about 0.4–0.5. Each day was assigned a DP/TP ratio based on daily mean discharge, and then daily DP loads were computed by multiplying the TP load by the DP/TP ratio.

Statistical Analyses

To determine if median concentrations for each constituent for a specified flow condition were statistically different among sites, a nonparametric Kruskal-Wallis test was first performed to determine if there were differences among the groups. If the Kruskal-Wallis test indicated there were differences, then the data were ranked, and a Tukey multiple-comparison procedure was used to determine which groups were statistically different from one another (SAS Institute, Inc., 2004). All statistical differences were significant at $p < 0.05$, unless otherwise stated.

Table 5. Discharge breakpoints in the dissolved phosphorus to total phosphorus (DP/TP) ratio relation and median values of the ratio less than and greater than the breakpoints for the at the five sites in the study.

[ft^3/s, cubic feet per second]

Stream	Breakpoint, in ft^3/s	Median ratio - dissolved phosphorus/total phosphorus	
		Ratio less than breakpoint	Ratio greater than breakpoint
Apple Creek	106	0.71	0.37
Ashwaubenon Creek	33.6	0.78	0.45
Baird Creek	16.8	0.67	0.47
Duck Creek	533	0.74	0.38
East River	755	0.50	0.40

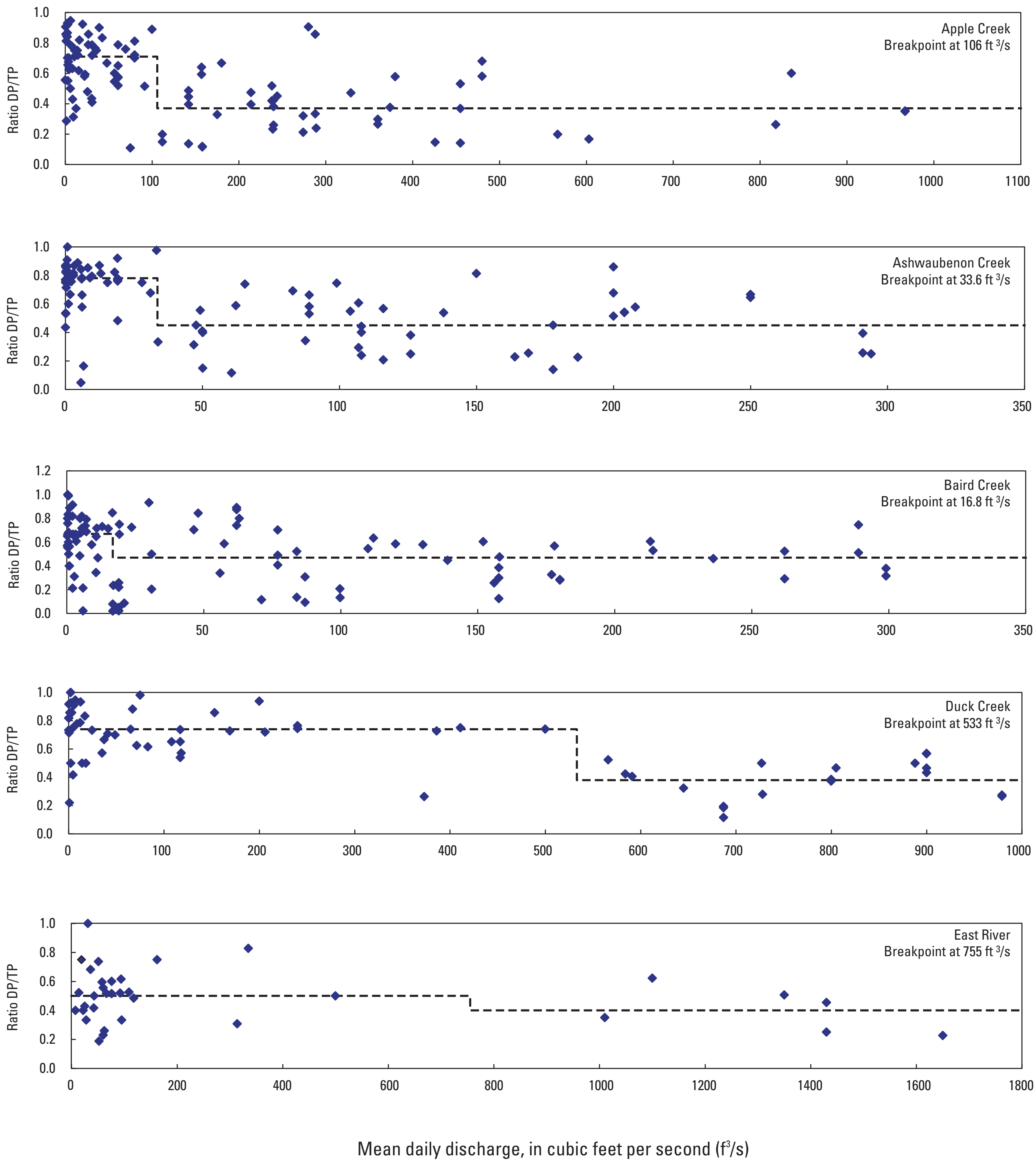

Figure 2. Ratio of dissolved phosphorus to total phosphorus (DP/TP), with breakpoints in daily mean discharge for the five sites in the study.

Hydrology and Water Quality

Hydrologic Conditions

Precipitation, stream discharge, and runoff data were collected at the five monitoring stations during WYs 2004–06, and are described in the following sections.

Precipitation

The 30-year normal (1971–2000) total annual precipitation for the study area was 29.12 in., based on data collected at the weather station at the Green Bay Airport (fig. 1; National Oceanic and Atmospheric Administration, 2006). Total annual precipitation for each of the three monitoring years was close to the long-term normal precipitation.

In WY 2004, total annual precipitation was slightly above normal at all sites, ranging from 30.13 in. (0.94 in. above normal, 3 percent) at Apple Creek to 32.40 in. (3.21 in. above normal, 11 percent) at Ashwaubenon Creek (table 6 and fig. 3). The highest monthly precipitation was 9.12 in. at Baird Creek in May 2004, which was 6.37 in. (232 percent) above normal. Minimum monthly precipitation was 0.24 in. at Ashwaubenon Creek in October 2003, which was 1.93 in. below normal (-89 percent).

In WY 2005, total annual precipitation was slightly below normal at Duck Creek (29.05 in, -0.14 in., -1 percent), Apple Creek (28.45 in., -0.74 in., -3 percent), and Baird Creek (28.76 in, -0.43 in., -1 percent; table 6 and fig. 3), but above normal at Ashwaubenon Creek (31.48 in., 2.29 in., 8 percent). The highest monthly precipitation was 5.57 in. in August at Ashwaubenon Creek, which was 2.00 in. above normal (53 percent). Minimum monthly precipitation was 1.33 in. in February and March 2005, estimated from the Green Bay airport when most precipitation occurred as snow.

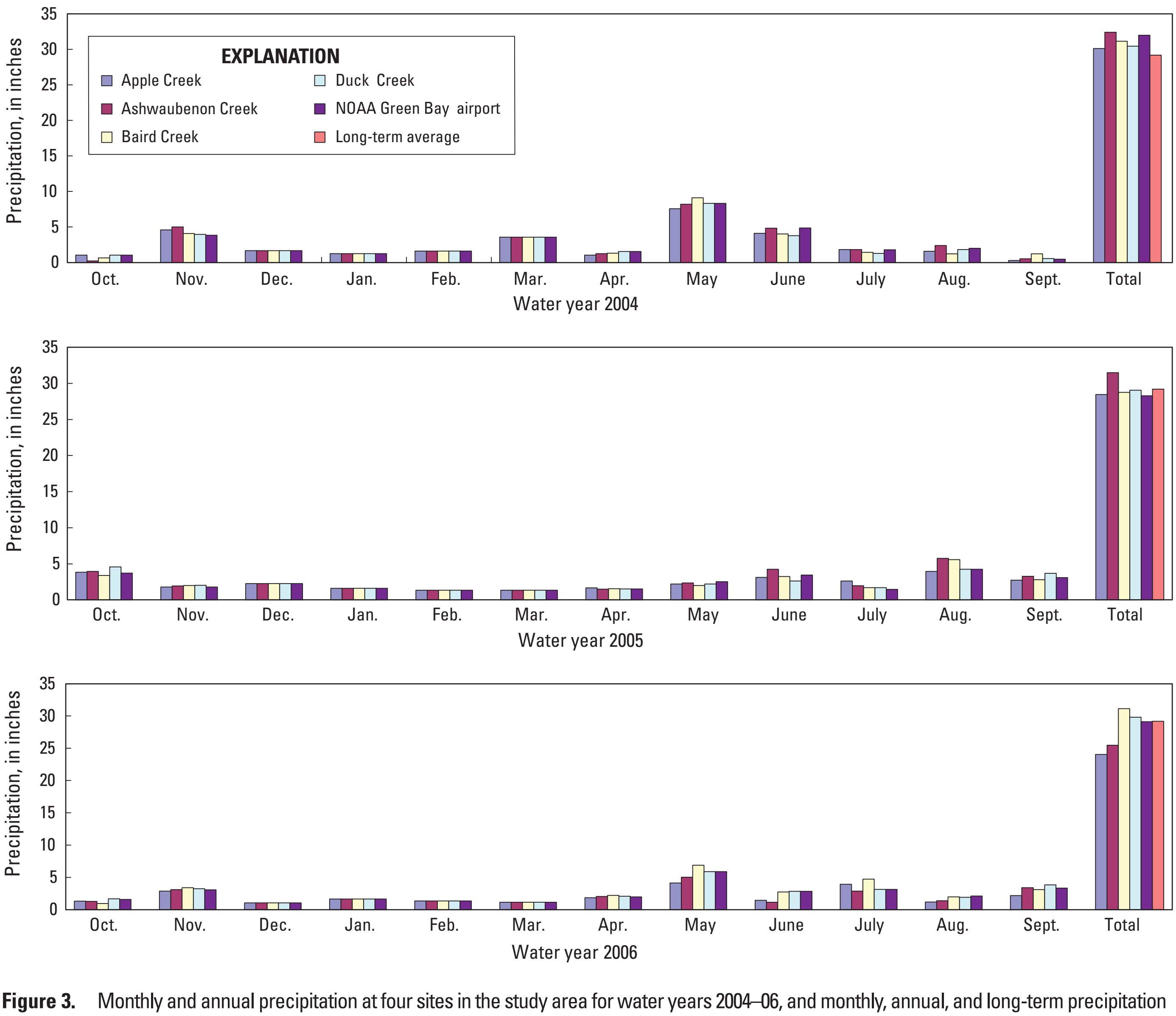

Figure 3. Monthly and annual precipitation at four sites in the study area for water years 2004–06, and monthly, annual, and long-term precipitation at the National Oceanographic and Atmospheric Administration (NOAA) weather station at Austin Straubel Airport, Green Bay, Wisconsin.

Table 6. Monthly and annual precipitation at rain gages in the study area and the National Oceanographic and Atmospheric Administration (NOAA) rain gage, for water years 2004–06.

[all values are in inches]

Month	Watershed				NOAA
	Apple Creek	Ashwaubenon Creek	Baird Creek	Duck Creek	Green Bay airport
Water year 2004					
October	1.05[1]	0.24	0.65	1.05[1]	1.05
November	4.58	5.02	4.07	3.96	3.83
December	1.68[1]	1.68[1]	1.68[1]	1.68[1]	1.68
January	1.24[1]	1.24[1]	1.24[1]	1.24[1]	1.24
February	1.62[1]	1.62[1]	1.62[1]	1.62[1]	1.62
March	3.58[1]	3.58[1]	3.58[1]	3.58[1]	3.58
April	1.04	1.26	1.31	1.56	1.56
May	7.57	8.21	9.12	8.33	8.31
June	4.10	4.84	4.03	3.79	4.87
July	1.82	1.81	1.42	1.28	1.78
August	1.57	2.38	1.21	1.81	2.00
September	0.28	0.52	1.23	0.56	0.47
Total	30.13	32.40	31.16	30.46	31.99
Water year 2005					
October	3.84	3.95	3.40	4.56	3.70
November	1.80[1]	1.93	1.98	2.01	1.80
December	2.26[1]	2.26[1]	2.26[1]	2.26[1]	2.26
January	1.60[1]	1.60[1]	1.60[1]	1.60[1]	1.60
February	1.33[1]	1.33[1]	1.33[1]	1.33[1]	1.33
March	1.33[1]	1.33[1]	1.33[1]	1.33[1]	1.33
April	1.67	1.49	1.55	1.53[1]	1.53
May	2.20	2.34	2.00	2.20	2.52
June	3.13	4.23	3.24	2.62	3.44
July	2.61	1.97	1.70	1.70	1.46
August	3.94	5.77	5.57	4.23[1]	4.23
September	2.74	3.28	2.80	3.68	3.08
Total	28.45	31.48	28.76	29.05	28.28
Water year 2006					
October	1.31	1.27	0.95	1.67	1.59
November	2.86	3.09	3.41	3.25	3.07
December	1.04[1]	1.04[1]	1.04[1]	1.04[1]	1.04
January	1.64[1]	1.64[1]	1.64[1]	1.64[1]	1.64
February	1.34[1]	1.34[1]	1.34[1]	1.34[1]	1.34
March	1.16[1]	1.16[1]	1.16[1]	1.16[1]	1.16
April	1.86	2.06	2.20	2.07	1.97
May	4.12	5.04	6.88	5.90	5.90
June	1.44	1.15	2.74	2.84	2.83
July	3.92	2.86	4.72	3.14[1]	3.14
August	1.17	1.40	1.98	1.93	2.11
September	2.19	3.41	3.09	3.82	3.33
Total	24.05	25.46	31.15	29.80	29.12

[1] Monthly total from NOAA Green Bay airport precipitation station.

In WY 2006, total annual precipitation was slightly above normal at Duck Creek (29.80 in., 0.61 in., 2 percent) and Baird Creek (31.15 in., 1.96 in., 7 percent), but below normal at Apple Creek (24.05 in., -5.14 in., -18 percent) and Ashwaubenon Creek (25.46 in., -3.73 in., -13 percent; table 6 and fig. 3). The highest monthly precipitation was 6.88 in. in May at Baird Creek, which was 4.13 in. (150 percent) above normal. Minimum monthly precipitation was 0.95 in. in October at Baird Creek, which was 56 percent below normal.

Streamflow

Annual mean streamflow was the highest in WY 2004 at all sites. In WY2004, the highest mean flow of 178 ft^3/s occurred in the East River and lowest mean flow of 14.6 ft^3/s occurred in Ashwaubenon Creek (table 7 and fig. 4). In WY 2005, the highest mean flow was 72.6 ft^3/s in the East River and the lowest mean flow was 6.4 ft^3/s in Baird Creek. In WY2006, the highest mean flow was 87.4 ft^3/s in the East River and the lowest mean flow was 5.4 ft^3/s in Ashwaubenon Creek.

The average of the three annual mean streamflows was the highest in the East River (113 ft^3/s), followed by Duck Creek (58.2 ft^3/s), Apple Creek (26.9 ft^3/s), Baird Creek (12.8 ft^3s), and Ashwaubenon Creek (9.1 ft^3/s) (table 7 and fig. 4). On a yield basis, the East River had the highest average streamflow (0.78 $ft^3/s/mi^2$), followed by Baird (0.61 $ft^3/s/mi^2$), Apple (0.59 $ft^3/s/mi^2$), Duck (0.54 $ft^3/s/mi^2$), and Ashwaubenon (0.46 $ft^3/s/mi^2$) Creeks.

The annual yield of water was the highest in the East River in WY 2004 (1.23 $ft^3/s/mi^2$) and WY 2006 (0.60 $ft^3/s/mi^2$), and in WY 2005 the highest was in Apple Creek (0.55 $ft^3/s/mi^2$) (table 7 and fig. 4). The annual yield of water was lowest in all years in Ashwaubenon Creek and ranged from 0.27 to 0.73 $ft^3/s/mi^2$.

The majority of flow (83–91 percent of total flow over the 3 years) at all sites came from overland runoff: 91 percent for Ashwaubenon Creek and about 85 percent for the other sites. Estimates of base flow were not made at the East River site because the flows often reverse and the daily mean discharge was occasionally negative. Base flow represented 16 to 22 percent of the total annual flow. For Baird Creek, base flow represented 21 percent of the total flow in WY 2004, 12 percent in WY 2005, 16 percent in WY 2006, and 17 percent for the 3 years. In comparison, on average, base flow accounted for 14 percent of the flow in Apple Creek, 15 percent in Duck Creek, and 9 percent in Ashwaubenon Creek.

Lowest daily flows occurred in the East River because of negative flows associated with flow reversals caused by seiches in Green Bay. Duck Creek had the next lowest daily mean flows, and had no flow for seven consecutive days. The highest of the minimum daily flows occurred in Baird Creek (0.23 ft^3/s), followed by Ashwaubenon and Apple Creeks, both with 0.02 ft^3/s.

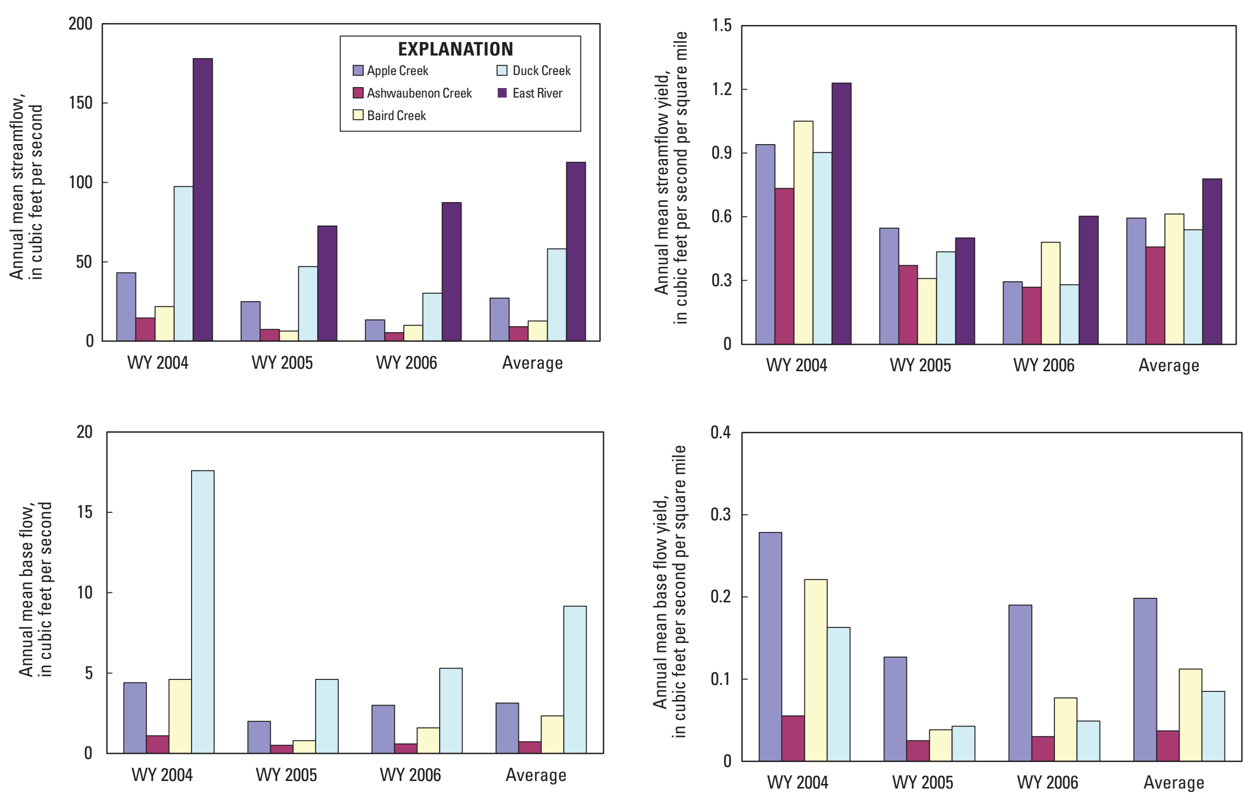

Figure 4. Streamflow characteristics for Apple, Ashwaubenon, Baird, and Duck Creeks and the East River, for water years 2004–06.

Table 7. Summary of streamflow characteristics for the five sites in the study, for water years 2004–06.

[ft^3/s, cubic feet per second; $ft^3/s/mi^2$, cubic feet per second per square mile; NA, not available; NC, not computed]

Streamflow characteristics	WY 2004	WY 2005	WY 2006	3-year average
Apple Creek				
Annual mean streamflow, ft^3/s	42.1	25.0	13.5	26.9
Annual mean runoff , inches	12.5	7.4	4.0	8.0
Annual streamflow yield, $ft^3/s/mi^2$	0.92	0.55	0.29	0.59
Annual mean base flow, ft^3/s	4.4	2.0	3.0	3.1
Annual mean base flow yield, $ft^3/s/mi^2$	0.28	0.13	0.19	0.20
Percent base flow	10%	8%	22%	14%
Lowest daily mean, ft^3/s	0.05	0.02	0.08	NA
Annual 7-day-minimum	0.09	0.04	0.34	NA
Ashwaubenon Creek				
Annual mean streamflow, ft^3/s	14.6	7.4	5.4	9.1
Annual mean runoff , inches	10.0	5.0	3.7	6.2
Annual streamflow yield, $ft^3/s/mi^2$	0.73	0.37	0.27	0.46
Annual mean base flow, ft^3/s	1.1	0.5	0.6	0.7
Annual mean base flow yield, $ft^3/s/mi^2$	0.06	0.03	0.03	0.04
Percent base flow	8%	7%	11%	9%
Lowest daily mean, ft^3/s	0.04	0.02	0.03	NA
Annual 7-day-minimum	0.06	0.02	0.04	NA
Baird Creek				
Annual mean streamflow, ft^3/s	21.9	6.4	9.9	12.8
Annual mean runoff , inches	14.3	4.2	6.5	8.3
Annual streamflow yield, $ft^3/s/mi^2$	1.05	0.31	0.48	0.61
Annual mean base flow, ft^3/s	4.6	0.8	1.6	2.3
Annual mean base flow yield, $ft^3/s/mi^2$	0.22	0.04	0.08	0.11
Percent base flow	21%	12%	16%	17%
Lowest daily mean, ft^3/s	0.23	0.23	0.26	NA
Annual 7-day-minimum	0.26	0.26	0.36	NA
Duck Creek				
Annual mean streamflow, ft^3/s	97.5	47.0	30.2	58.2
Annual mean runoff , inches	12.3	5.9	3.8	7.3
Annual streamflow yield, $ft^3/s/mi^2$	0.90	0.44	0.28	0.54
Annual mean base flow, ft^3/s	17.6	4.6	5.3	9.2
Annual mean base flow yield, $ft^3/s/mi^2$	0.16	0.04	0.05	0.08
Percent base flow	18%	10%	18%	15%
Lowest daily mean, ft^3/s	0.00	0.00	0.00	NA
Annual 7-day-minimum	0.02	0.00	0.00	NA
East River				
Annual mean streamflow, ft^3/s	178	72.6	87.4	113
Annual mean runoff , inches	13.3	6.8	8.2	9.4
Annual streamflow yield, $ft^3/s/mi^2$	1.23	0.50	0.60	0.78
Annual mean base flow, ft^3/s	NC	NC	NC	NC
Annual mean base flow yield, $ft^3/s/mi^2$	NC	NC	NC	NC
Percent base flow	NC	NC	NC	NC
Lowest daily mean, ft^3/s	-40[1]	-55[1]	-43[1]	NA
Annual 7-day-minimum	7.50	2.0	1.7	NA

[1] Negative daily mean flow result of reverse flow

Water Quality

Water quality in the five monitored streams varied as a function of flow. Therefore, in addition to describing overall water quality, water quality is described during periods classified as base-flow or overland-runoff dominated.

The overall median TSS concentration was highest in Baird Creek (73.5 mg/L; table 8 and fig. 5), slightly lower in Apple and Ashwaubenon Creeks (about 65 mg/L), moderate in the East River (40 mg/L), and lowest in Duck Creek (30 mg/L). Median TSS concentrations in Baird, Ashwaubenon, and Apple Creeks were not statistically different from each other, and median TSS concentrations of Duck Creek and East River were not statistically different from each other; the TSS concentrations were significantly different between the two groups (table 8). The highest maximum TSS concentration was measured in Ashwaubenon Creek (6,180 mg/L), followed by Baird Creek (2,810 mg/L), Apple Creek (2,460 mg/L), East River (1,040 mg/L), and Duck Creek (956 mg/L).

The overall median TP concentration was highest in Ashwaubenon Creek (0.60 mg/L; table 9 and fig. 6), followed by Baird Creek (0.47 mg/L), Apple Creek (0.37 mg/L), East River (0.26 mg/L), and Duck Creek (0.22 mg/L). The median TP concentrations in Ashwaubenon Creek, Baird Creek and Apple Creek were statistically different from each other. TP concentrations in Duck Creek and East River were not statistically different from each other, but were different from the other three sites. The highest maximum TP concentration was measured in Ashwaubenon Creek (9.46 mg/L), followed by the East River (5.64 mg/L), Apple Creek (4.96 mg/L), Baird Creek (3.22 mg/L), and Duck Creek (2.79 mg/L). Median total phosphorus concentrations at the five study sites were above both the reference or background concentration of 0.03-0.04 mg/L determined for streams in this area of Wisconsin (Robertson and others, 2006a) and the 0.075-mg/L phosphorus criteria for wadeable streams in Wisconsin (J. Baumann, Wisconsin Department of Natural Resources, written commun., 2010).

The overall median DP concentration was highest in Ashwaubenon Creek (0.33 mg/L; table 10 and fig. 7), followed by Baird Creek (0.20 mg/L), Apple Creek (0.18 mg/L), East River (0.15 mg/L), and Duck Creek (0.13 mg/L). Median DP concentration for Ashwaubenon Creek was statistically different from those at the other four sites. Median DP concentrations for Baird and Apple Creeks were not statistically different from each other, but different from the other three sites. Median DP concentrations for East River and Duck Creek were not statistically different, but different from the other three sites. The highest maximum DP concentration was measured in the East River (3.25 mg/L), followed by Ashwaubenon (1.23 mg/L), Apple (1.00 mg/L), Baird (0.69 mg/L), and Duck (0.44 mg/L) Creeks.

Water Quality During Base Flow and Runoff Events

Median TSS concentrations during base flow ranged from 34 mg/L in the East River to 4 mg/L in Duck Creek (table 8 and fig. 5). The median TSS concentration during base flow in East River was much higher (statistically different) than the other sites. The high concentrations in the East River may be due to greater algal productivity in this large stream. Concentrations in Ashwaubenon Creek were second highest and statistically different from all other sites. The median TSS base-flow concentrations in Apple and Baird Creeks were next highest and not statistically different from each other. Apple and Baird Creeks were statistically different from all other sites except Duck Creek. The median base-flow concentration in Duck Creek was lowest and statistically different from all sites except Apple Creek.

Median TSS concentrations during runoff events ranged from 119 mg/L in Baird Creek to 43 mg/L in the East River (table 8 and fig. 5). The median TSS concentrations during runoff events were not statistically different in Baird, Ashwaubenon, and Apple Creeks. Median TSS concentrations during runoff events were also not statistically different in Duck Creek and the East River, but these sites were statistically different from the other three sites. Median TSS concentrations during base flow and runoff events in the East River were fairly similar (34 and 43 mg/L, respectively). For all of the other sites, concentrations of TSS were much higher during runoff events than during base flow. Higher concentrations during runoff events than during base flow indicate that overland flow may be suspending sediments from the land surface, stream banks, and from the bottom of channels.

Median TP concentrations during base flow ranged from 0.26 mg/L in Ashwaubenon Creek to 0.12 mg/L in Baird and Duck Creeks (table 9 and fig. 6). The median TP concentration in Ashwaubenon Creek and the East River during base flow were not statistically different from one another. Median concentrations in Apple and Baird Creeks were slightly lower (statistically significant) than these two but not statistically different from one another. Median TP concentration in Duck Creek was the lowest, but not statistically different from Baird Creek. The highest median TP concentration during runoff events was highest in Ashwaubenon Creek (0.64 mg/L), followed by Baird Creek (0.57 mg/L), Apple Creek (0.44 mg/L), East River (0.27 mg/L), and Duck Creek (0.26 mg/L). Only the median concentrations in the East River and Duck Creek were not statistically different from each other. These runoff concentrations were higher than during base flow by a factor of about 2–3. All median TP concentrations were above both the reference concentration of 0.03–0.04 mg/L determined for streams in this area of Wisconsin (Robertson and others, 2006a), and the 0.075-mg/L phosphorus criteria for wadeable streams in Wisconsin (J. Baumann, Wisconsin Department of Natural Resources, written commun., 2010).

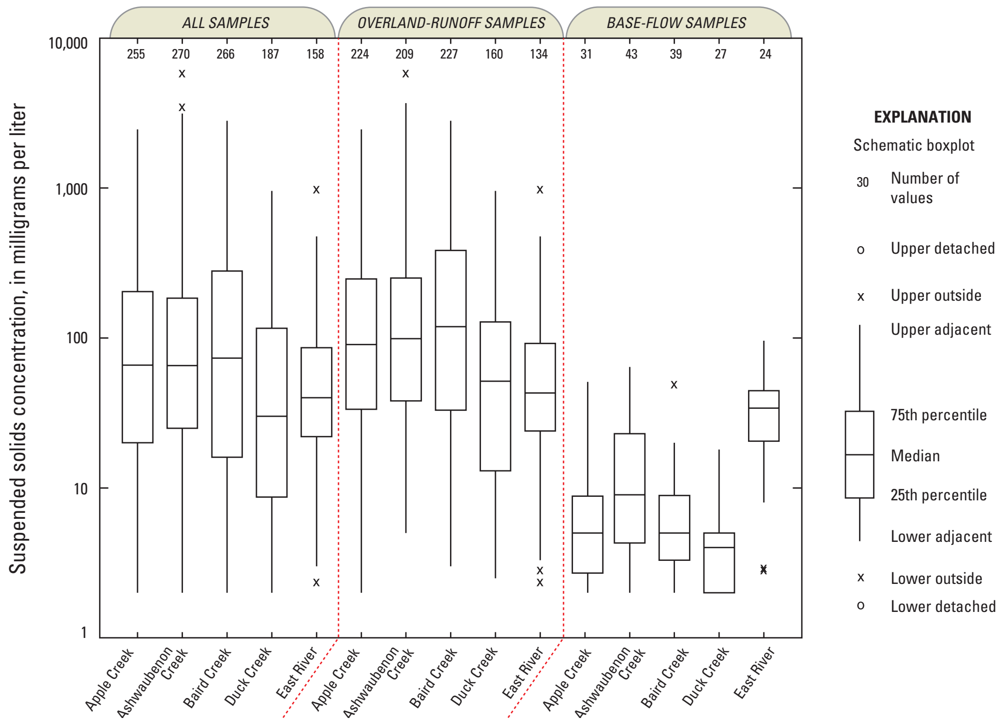

Figure 5. Total suspended solids concentrations in Apple, Ashwaubenon, Baird, and Duck Creeks and the East River, during different flow conditions, for water years 2004–06.

Table 8. Summary of total suspended solids data collected at five sites in in the study, for water years 2004–06.

[Median values with the same letters are not statistically different from one another at $p<0.05$; median values with two letters are similar with either letter. Concentrations are in milligrams per liter]

	Apple Creek	Ashwaubenon Creek	Baird Creek	Duck Creek	East River
All data (both base-flow and overland-runoff samples)					
Minimum	2.00	2.00	2.00	2.00	2.50
25th percentile	20.0	25.2	16.0	8.85	22.0
Mean	184	236	305	92.6	71.6
Median	65[a]	65.5[a]	73.5[a]	30[b]	40[b]
75th percentile	202	184	279	112	85.5
Maximum	2,460	6,180	2,810	956	1,040
Number of samples	255	252	266	187	158
Base-flow samples					
Minimum	2.00	2.00	2.00	2.00	3.00
25th percentile	3.05	4.65	3.55	2.10	20.8
Mean	8.50	15.9	7.31	5.08	36.7
Median	5[cd]	9[b]	5[c]	4[d]	34[a]
75th percentile	8.00	23.0	8.85	5.00	43.8
Maximum	51.0	64.0	52.0	18.0	96.0
Number of samples	31	43	39	27	24
Runoff samples					
Minimum	2.00	5.00	3.00	2.50	2.50
25th percentile	33.8	38.0	33.5	13.0	24.0
Mean	209	286	356	107	77.8
Median	90.5[a]	99[a]	119[a]	51.5[b]	43[b]
75th percentile	245	251	377	128	91.5
Maximum	2,460	6,180	2,810	956	1,040
Number of samples	224	209	227	160	134

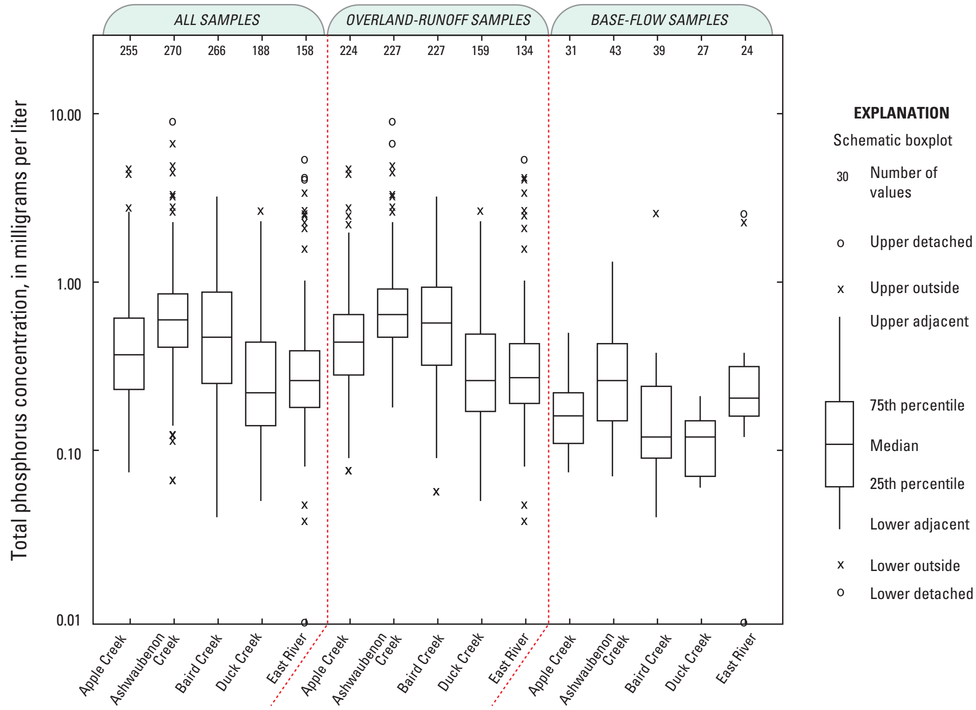

Figure 6. Total phosphorus concentrations in Apple, Ashwaubenon, Baird, and Duck Creeks and the East River, during different flow conditions, for water years 2004–06.

Table 9. Summary of total phosphorus data collected at five sites in in the study, for water years 2004–06.

[Median values with the same letters are not statistically different from one another at $p<0.05$; median values with two letters are similar with either letter. Concentrations are in milligrams per liter]

	Apple Creek	Ashwaubenon Creek	Baird Creek	Duck Creek	East River
All data (both base-flow and overland-runoff samples)					
Minimum	0.074	0.070	0.040	0.050	0.010
25th percentile	0.230	0.410	0.250	0.140	0.180
Mean	0.520	0.770	0.670	0.350	0.480
Median	0.37[c]	0.60[a]	0.47[b]	0.22[d]	0.26[d]
75th percentile	0.610	0.840	0.860	0.440	0.390
Maximum	4.96	9.46	3.22	2.79	5.64
Number of samples	257	270	266	186	158
Base-flow samples					
Minimum	0.070	0.070	0.040	0.060	0.010
25th percentile	0.110	0.150	0.090	0.070	0.160
Mean	0.190	0.329	0.225	0.118	0.410
Median	0.16[b]	0.26[a]	0.12b[c]	0.12[c]	0.205[a]
75th percentile	0.215	0.420	0.230	0.145	0.308
Maximum	0.500	1.32	2.700	0.210	2.68
Number of samples	31	43	39	27	24
Runoff samples					
Minimum	0.080	0.180	0.060	0.050	0.040
25th percentile	0.280	0.470	0.325	0.170	0.190
Mean	0.560	0.859	0.747	0.396	0.502
Median	0.44[c]	0.64[a]	0.57[b]	0.26[d]	0.27[d]
75th percentile	0.640	0.905	0.925	0.490	0.428
Maximum	4.96	9.46	3.22	2.79	5.64
Number of samples	224	227	227	159	134

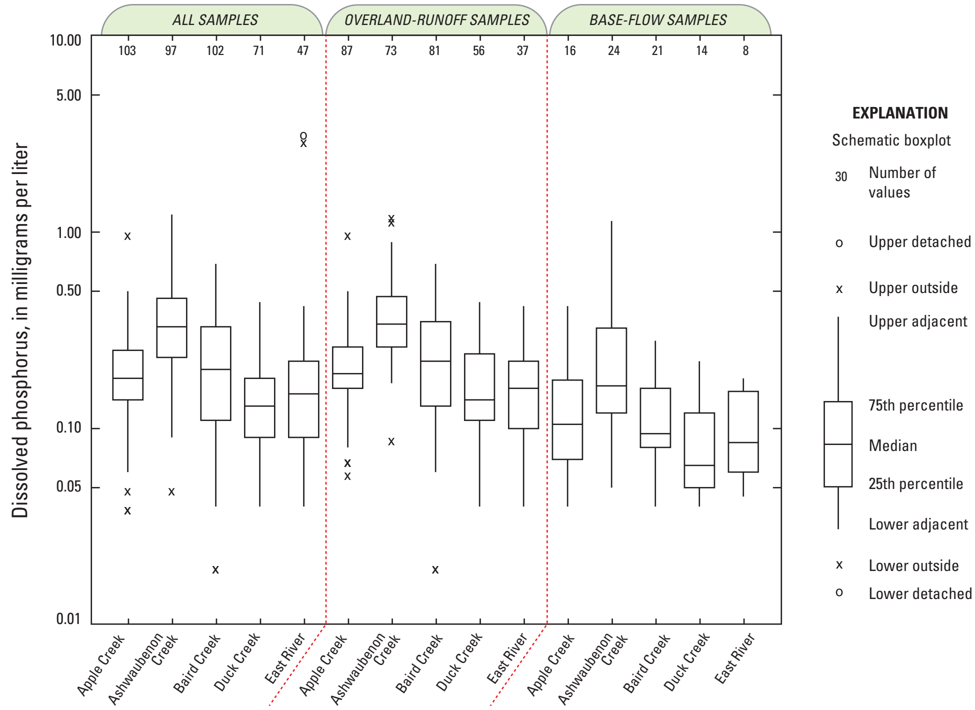

Figure 7. Dissolved phosphorus concentrations in Apple, Ashwaubenon, Baird, and Duck Creeks and the East River during different flow conditions, for water years 2004–06.

Table 10. Summary of dissolved phosphorus data collected at five sites in in the study, for water years 2004–06.

[Median values with the same letters are not statistically different from one another at p<0.05; median values with two letters are similar with either letter. Concentrations are in milligrams per liter]

	Apple Creek	Ashwaubenon Creek	Baird Creek	Duck Creek	East River
All data (both base-flow and overland-runoff samples)					
Minimum	0.040	0.050	0.020	0.040	0.040
25th percentile	0.140	0.230	0.110	0.090	0.090
Mean	0.210	0.368	0.228	0.150	0.289
Median	0.18[b]	0.33[a]	0.20[b]	0.13[c]	0.15[c]
75th percentile	0.250	0.460	0.330	0.180	0.210
Maximum	1.00	1.23	0.690	0.440	3.25
Number of samples	103	97	102	70	45
Base-flow samples					
Minimum	0.040	0.050	0.040	0.040	0.045
25th percentile	0.070	0.120	0.080	0.050	0.060
Mean	0.127	0.286	0.122	0.089	0.103
Median	0.105[b]	0.165[a]	0.094[b]	0.065[b]	0.085[b]
75th percentile	0.175	0.318	0.160	0.118	0.148
Maximum	0.420	1.14	0.280	0.220	0.180
Number of samples	16	24	21	14	8
Runoff samples					
Minimum	0.060	0.090	0.020	0.040	0.040
25th percentile	0.160	0.260	0.130	0.110	0.100
Mean	0.228	0.396	0.255	0.166	0.170
Median	0.19[bc]	0.34[a]	0.22[b]	0.14[d]	0.16[cd]
75th percentile	0.260	0.470	0.350	0.235	0.220
Maximum	1.00	1.23	0.690	0.440	0.420
Number of samples	87	73	81	56	37

Median DP concentrations during base flow ranged from 0.165 mg/L in Ashwaubenon Creek to 0.065 mg/L in Duck Creek (table 10 and fig. 7). The median DP concentration during base flow in Ashwaubenon Creek was statistically different than those at the other four sites, which were not statistically different from one another. Median DP concentrations during runoff events ranged from 0.34 mg/L in Ashwaubenon Creek to 0.14 mg/L in Duck Creek. The median DP concentration in Ashwaubenon Creek was again the highest and statistically different from the other four sites. Median concentrations in Baird and Apple Creeks were next highest and not statistically different from one another. Median concentrations in Duck Creek and East River were the lowest and not statistically different from one another, but statistically different from the other sites. DP concentrations were about twice as high during runoff events than during base flow.

Suspended Solids and Phosphorus Loads

TSS, TP, and DP concentration data alone may not reflect the true impact of nutrients because the amount of sediment and phosphorus transported downstream (load) to receiving waters, such as Green Bay, can impair the waters' beneficial uses. Therefore, daily, monthly, and annual loads and yields were computed for TSS, TP, and DP.

Annual Loads and Yields

Average annual TSS loads ranged from 10,300 tons in the East River to 1,720 tons in Ashwaubenon Creek (table 11 and fig. 8). Loads in the East River were highest because it has the largest drainage area and highest flows. To better enable comparisons among the river and creeks, annual yields (loads per unit area of the watershed) were examined. The average annual TSS yield was highest in the Apple Creek watershed (111 tons/mi^2), followed by Baird Creek (95 tons/mi^2), Ashwaubenon Creek (87 tons/mi^2), East River (71 tons/mi^2), and Duck Creek (45 tons/mi^2) watersheds (table 11 and fig. 9). The yields varied by a factor of about 2.5. All five streams had higher yields than the median value of 32.4 tons/mi^2 based on previously monitored streams in the SWTP ecoregion, but the yields were similar to or a little less than the statewide median value of 111 tons/mi^2 based on previously monitored streams (Corsi and others, 1997).

Annual TSS loads and yields were highest in each stream in WY 2004 (table 11, and figs. 8 and 9). TSS loads in WY 2004 were highest in the East River (22,700 tons, even though this value only represented a partial year: December 16 to September 30), followed by Apple (12,000 tons), Duck (10,200 tons), Baird (4,350 tons), and Ashwaubenon (3,680 tons) Creeks. The lowest annual loads were transported in WY 2006, with the exception of Baird Creek and the East River, which had their lowest loads in WY 2005.

Average annual TP loads ranged from 77,400 lbs in the East River to 12,400 lbs in Ashwaubenon Creek (table 11 and fig. 8). The greatest amount of TP was transported in WY 2004, similar to TSS. The East River transported the most TP (138,000 lbs, even though this value only represents a partial year), followed by Duck (68,100 lbs), Apple (48,900 lbs), Baird (27,800 lbs), and Ashwaubenon (21,100 lbs) Creeks. The lowest amount of TP was transported in WY 2006 for all of the sites except Baird Creek and the East River, which had their lowest loads in 2005. The average annual TP yields were highest from Baird Creek (648 lbs/mi^2), followed by Ashwaubenon Creek (625 lbs/mi^2), Apple Creek (576 lbs/mi^2), East River (533 lbs/mi^2), and Duck Creek (382 lbs/mi^2). The yields varied by a factor of about 1.7. All five watersheds had higher yields than the median value of 283 lbs/mi^2, based on previously monitored streams in the SWTP ecoregion (283 lbs/mi^2; Corsi and others, 1997). Only Baird Creek yielded more TP than the median value in previously monitored watersheds throughout the state of 650 lbs/mi^2 (fig. 9).

Average annual DP loads ranged from 35,200 lbs in the East River to 6,470 lbs in Ashwaubenon Creek (table 11 and fig. 8). The average annual DP yields were highest from Ashwaubenon Creek (325 lbs/mi^2), followed by Baird Creek (322 lbs/mi^2), Apple Creek (252 lbs/mi^2), East River (243 lbs/mi^2), and Duck Creek (200 lbs/mi^2). The yields varied by a factor of about 1.6. Over 50 percent of the phosphorus in Ashwaubenon and Duck Creeks was transported in the dissolved form. The greatest amount of DP was transported in WY 2004. East River transported the most DP (59,900 lbs), followed by Duck (34,200 lbs), Apple (20,300 lbs), Baird (13,300 lbs), and Ashwaubenon (10,600 lbs) Creeks. The lowest amount of DP was transported in WY 2006 in all of the streams except for Baird Creek and the East River, which had the lowest transport in WY 2005. The percentage of phosphorus transported in the dissolved form was highest in Ashwaubenon and Duck Creeks (52 percent), followed by Baird Creek (49 percent), East River (45 percent), and Apple Creek (44 percent).

Table 11. Suspended solids, total phosphorus, and dissolved phosphorus loads and yields for five sites in the study, water years 2004–06.

[NC, not computed; tons/mi², tons per square mile; lbs/mi², pounds per square mile]

Water year	Suspended solids		Total phosphorus		Dissolved phosphorus	
	Load (tons)	Annual yield (tons/mi²)	Load (pounds)	Annual yield (lbs/mi²)	Load (pounds)	Annual yield (lbs/mi²)
			Apple Creek			
2004	12,000	262	48,900	1,070	20,300	443
2005	1,850	40	20,800	454	9,600	210
2006	1,420	31	9,270	202	4,760	104
Total	15,300	NC	79,000	NC	34,600	NC
Average	5,100	111	26,300	576	11,500	252
			Ashwaubenon Creek			
2004	3,680	185	21,100	1,060	10,600	533
2005	1,150	58	10,700	538	5,660	284
2006	340	17	5,500	276	3,120	157
Total	5,170	NC	37,300	NC	19,400	NC
Average	1,720	87	12,400	625	6,470	325
			Baird Creek			
2004	4,350	209	27,800	1,340	13,300	639
2005	565	27	4,350	209	2,690	129
2006	1,040	50	8,240	396	4,100	197
Total	5,960	NC	41,400	NC	20,100	NC
Average	2,000	95	13,800	648	6,700	322
			Duck Creek			
2004	10,200	94	68,100	631	34,200	317
2005	3,500	32	39,200	363	18,800	174
2006	845	8	16,600	154	11,800	109
Total	14,500	NC	124,000	NC	64,800	NC
Average	4,840	45	41,300	382	21,600	200
			East River			
2004[a]	22,700	157	138,000	952	59,900	413
2005	2,670	18	38,100	263	19,400	134
2006	5,550	38	56,000	386	26,200	181
Total[a]	30,900	NC	232,000	NC	105,000	NC
Average[a]	10,300	71	77,400	533	35,200	243

[a] Partial year for 2004: December 16-September 30.

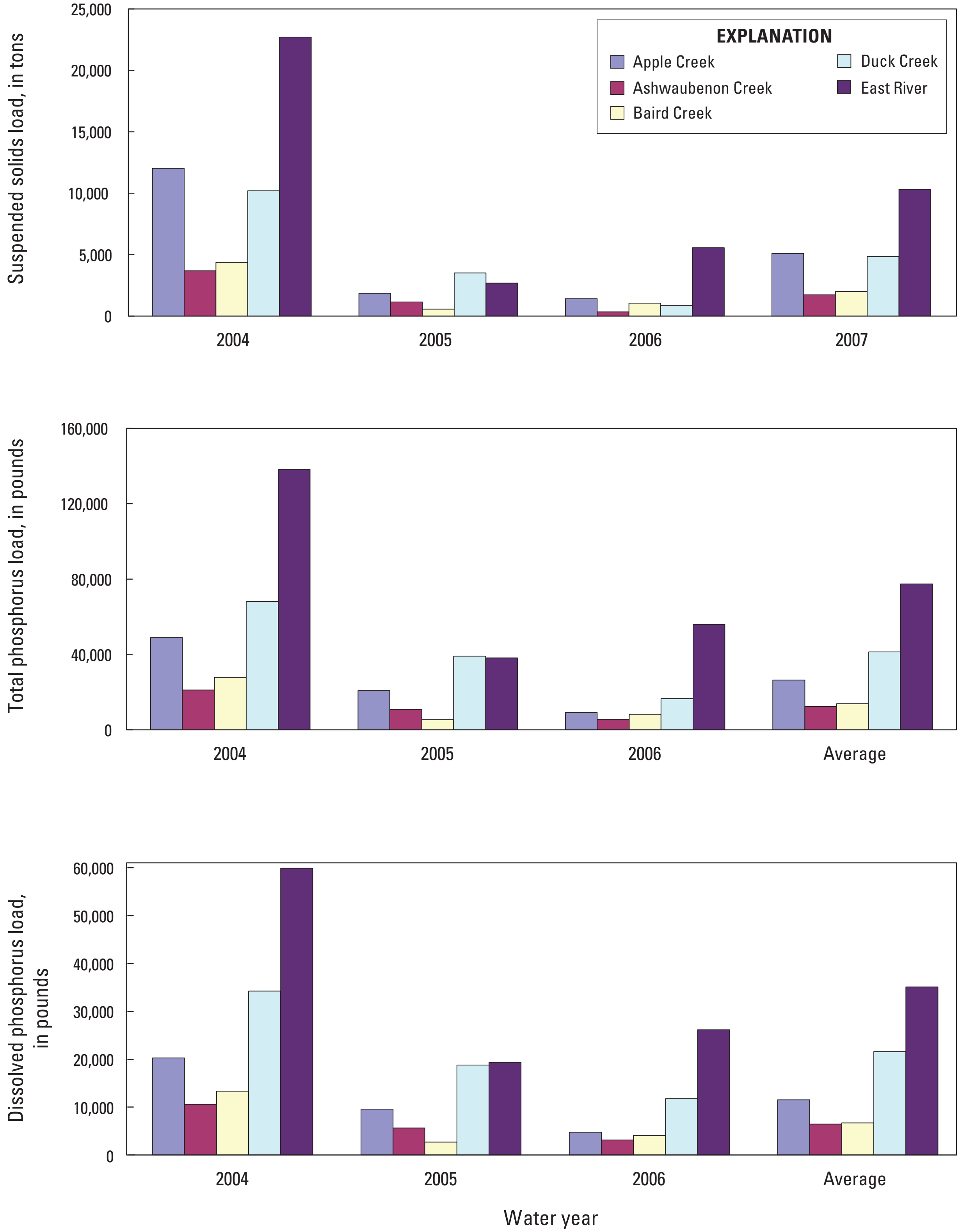

Figure 8. Suspended solids, total phosphorus, and dissolved phosphorus loads in Apple, Ashwaubenon, Baird, and Duck Creeks and the East River, for water years 2004–06.

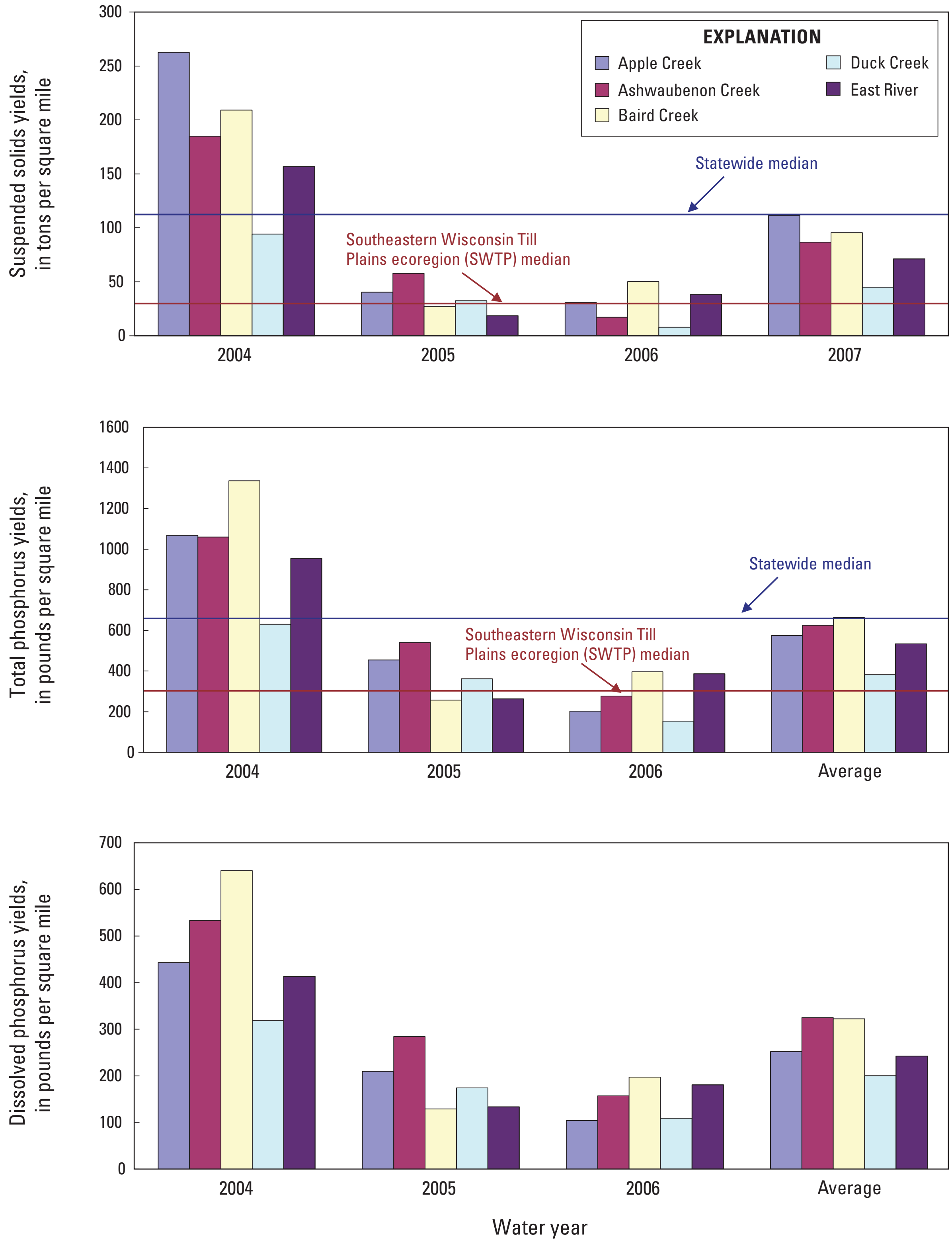

Figure 9. Suspended solids, total phosphorus, and dissolved phosphorus yields for Apple, Ashwaubenon, Baird, and Duck Creeks and the East River, for water years 2004–06.

Seasonality in Loads

To determine the seasonality in the loads in these streams, daily loads were summed by month and the percentages of the total annual loads were computed for each month; the average monthly loads from WY 2005 and WY2006 were used for October and November in WY 2004 for the East River (table 12). Highest TSS loads occurred between March and June at each site: highest TSS loads were in March in Apple and Baird Creeks, whereas highest loads were in June in Ashwaubenon Creek, Duck Creek and the East River (fig. 10). Most of the TSS load occurred during the four months with the highest flows (March, November, May, and June): Ashwaubenon Creek (97 percent), Baird and Duck Creeks (96 percent), Apple Creek (95 percent) and the East River (87 percent). In Apple, Ashwaubenon, Baird, and Duck Creeks, the lowest transport occurred in September and October. These months typically had the lowest flows and contributed less than 1 percent of the TSS load. In the East River, the minimum loads were transported in January and February, although loads in September and October were also very low.

The seasonality in TP loads was similar to that for TSS loads and discharge. Highest TP loads were delivered in March (table 12 and fig. 10), followed by May, and June or November. Most of the TP loads occurred during these four months: Baird Creek (88 percent), Ashwaubenon Creek (82 percent), Apple Creek (84 percent), Duck Creek (86 percent), and East River (80 percent). These four months had the highest discharge and the highest TP concentrations. Lowest transport typically occurred in September and October, similar to TSS, at all five sites. During September and October, less than 1 percent of the TP load was transported.

Distribution of Daily Flows and Loads

The distribution of flows and constituent loads was highly nonlinear. Most of the flow and load of various constituents occurred over a small number of days. On average, about 50 percent of the annual streamflow occurred in 14 days at all sites except for the larger East River, for which 50 percent of the flow occurred in about 30 days (table 13 and fig. 11). For these five sites, about 17–27 percent of the total annual flow occurred in 4 days.

Individual runoff events can be very important to the total mass transport of most constituents. TSS and TP concentrations were found to be higher during runoff events than during base-flow and average conditions; therefore, more TSS and TP would be expected to be transported in a shorter period of time than the water itself. About 20 percent of the annual TSS load was transported in the most extreme 1-day event at each site (table 13 and fig. 11). About 48–55 percent of the TSS load was transported in 4 days, and 73–85 percent was transported in 14 days. A similar pattern was found for TP loads, for which about 12–23 percent was transported in 1 day, 40–60 percent in 7 days, and 68–85 percent in 30 days.

The high percentage of annual load being transported in just a few days indicates that only a few storms each year can dominate the total annual loading for both TSS and TP (table 13). This nonlinearity has implications to the installation and types of best-management practices (BMPs) that need to be installed in a watershed to reduce nutrient and sediment export. To reduce mass transport to the streams, BMPs must be sized appropriately to handle the very high single-day runoff events. If BMP's are sized too small, they may be overwhelmed and may not be effective in reducing loads to the stream. Constituents transported with sediment are most affected by runoff events. About one-half of the annual TSS load is transported in 4 days, and 90 percent is transported in 30 days. Constituents that are transported with sediment, such as TP, are also strongly affected by rainfall and runoff. Excluding the East River watershed, about one-half of the annual TP load was transported in 7 days, as compared to 4 days for TSS; and about 90 percent of the annual TP load was transported in 60 days, as compared to 30 days for TSS (table 13). Annual TSS and TP loads were separated into that transported during baseflow and that transported during runoff events. Over 80 percent of the TSS, TP, and DP loads were transported during runoff events in streams except Baird Creek. In Baird Creek, a higher percentage of streamflow occurred during base flow and a subsequent smaller part of the annual load (60 to 66 percent, 3-year average) occurred during overland runoff periods.

Volumetrically Weighted Concentration

Volumetrically weighted concentrations (VWC) for each constituent were calculated for each stream and each year (table 14) by dividing the total annual load by the total annual flow (with the appropriate conversion factor for unit transformation). Highest VWCs of TSS for the entire 3-year period were in Apple Creek (193 mg/L), followed by Ashwaubenon Creek (192 mg/L), Baird Creek (158 mg/L), East River (104 mg/L), and Duck Creek (84 mg/L). The VWCs of TSS were highest in WY 2004 at each site: highest in Apple Creek (289 mg/L), followed by Ashwaubenon (256 mg/L), Baird Creek (202 mg/L), East River (163 mg/L), and Duck Creek (106 mg/L). The lowest annual VWCs for TSS were in WY 2005 for Apple Creek, Baird Creek, and East River; the lowest VWCs in Ashwaubenon and Duck Creeks were in WY 2006. These values agree with estimated median annual VWC of TSS in this area found by Robertson and others (2006b; 87 to 161 mg/L), and are above their estimated reference or background median concentrations of 29 to 59 mg/L.

The highest VWCs of TP for the entire study period were in Ashwaubenon Creek (0.69 mg/L), followed by Baird Creek (0.55 mg/L), Apple Creek (0.50 mg/L), East River (0.39 mg/L), and Duck Creek (0.36 mg/L) (table 14). The highest annual VWC of TP occurred in Ashwaubenon Creek (0.74 mg/L) in WY 2005. Ashwaubenon Creek also had the highest VWC of DP for the entire study period (0.36 mg/L) and highest average annual value (0.39 mg/L measured in WY 2005). Variability in the VWCs of DP for the entire study period was the same as for TP, with highest concentrations in Ashwaubenon Creek (0.36 mg/L), followed by Baird Creek (0.27 mg/L), Apple Creek (0.22 mg/L), Duck Creek (0.19 mg/L), and the East River (0.18 mg/L).

Table 12. Monthly loads and percentage of the total load at the five sites in the study, for water years 2004–06.

[ft³/s, cubic feet per second]

Month	Discharge		Suspended solids		Total phosphorus	
	Total (ft³/s)	Percent	Load (tons)	Percent	Load (pounds)	Percent
Apple Creek						
Oct.	361	1.2	21	0.1	635	0.8
Nov.	2,060	7.0	3,900	25.5	14,200	17.9
Dec.	1,190	4.0	154	1.0	2,200	2.8
Jan.	1,130	3.8	81	0.5	1,580	2.0
Feb.	2,810	9.5	203	1.3	5,680	7.2
Mar.	11,200	38.0	5,340	34.9	32,600	41.3
Apr.	1,540	5.2	75	0.5	1,310	1.7
May	5,130	17.4	3,390	22.1	10,900	13.7
June	3,370	11.4	2,060	13.5	8,810	11.2
July	263	0.9	26	0.2	543	0.7
Aug.	284	1.0	42	0.3	466	0.6
Sept.	154	0.5	10	0.1	164	0.2
Ashwaubenon Creek						
Oct.	46	0.5	2	0.0	121	0.3
Nov.	429	4.3	200	3.9	1,980	5.3
Dec.	359	3.6	51	1.0	1,510	4.0
Jan.	466	4.7	35	0.7	1,810	4.8
Feb.	888	8.9	67	1.3	2,370	6.3
Mar.	3,750	37.5	1,220	23.7	13,300	35.7
Apr.	420	4.2	20	0.4	643	1.7
May	2,020	20.3	1,520	29.4	7,610	20.4
June	1,480	14.9	2,000	38.6	7,570	20.3
July	35	0.4	4	0.1	79	0.2
Aug.	72	0.7	47	0.9	284	0.8
Sept.	14	0.1	1	0.0	23	0.1
Baird Creek						
Oct.	76	0.5	2	0.0	47	0.1
Nov.	538	3.8	474	7.9	2,230	5.3
Dec.	416	3.0	54	0.9	1,070	2.6
Jan.	490	3.5	22	0.4	696	1.7
Feb.	575	4.1	33	0.5	1,110	2.6
Mar.	5,050	36.1	2,960	49.6	19,900	47.5
Apr.	1,060	7.6	54	0.9	1,440	3.4
May	3,050	21.8	1,280	21.4	7,450	17.8
June	2,480	17.7	882	14.8	7,390	17.6
July	111	0.8	51	0.9	217	0.5
Aug.	93	0.7	150	2.5	361	0.9
Sept.	42	0.3	4	0.1	28	0.1

Table 12. Monthly loads and percentage of the total load at the five sites in the study, for water years 2004–06.—Continued

[ft^3/s, cubic feet per second]

Month	Discharge		Suspended solids		Total phosphorus	
	Total (ft^3/s)	Percent	Load (tons)	Percent	Load (pounds)	Percent
			Duck Creek			
Oct.	283	0.4	8	0.1	300	0.2
Nov.	3,100	4.9	270	1.9	4,740	3.8
Dec.	1,990	3.1	57	0.4	2,080	1.7
Jan.	2,010	3.2	51	0.3	1,890	1.5
Feb.	3,640	5.7	146	1.0	7,140	5.8
Mar.	21,300	33.4	5,360	36.9	62,000	50.1
Apr.	6,740	10.5	265	1.8	5,130	4.1
May	12,000	18.8	1,960	13.5	12,000	9.7
June	12,400	19.4	6,400	44.1	28,000	22.6
July	331	0.5	9	0.1	412	0.3
Aug.	53	0.1	1	0.0	51	0.0
Sept.	42	0.1	1	0.0	20	0.0
			East River			
Oct.	2,50	1.9	481	1.5	4,090	1.7
Nov.	2,490	2.3	359	1.2	5,560	2.4
Dec.	3,870	3.5	184	0.6	4,380	1.9
Jan.	5,580	5.1	139	0.4	6,280	2.7
Feb.	6,910	6.3	155	0.5	7,680	3.3
Mar.	31,300	28.4	10,100	32.4	93,700	39.8
Apr.	8,670	7.9	884	2.8	8,990	3.8
May	22,900	20.8	6,550	21.0	43,700	18.5
June	14,900	13.5	10,500	33.8	44,300	18.8
July	4,500	4.1	578	1.9	6,700	2.8
Aug.	3,830	3.5	735	2.4	6,790	2.9
Sept.	3,120	2.8	500	1.6	3,440	1.5

[a]The average monthly loads from WY 2005 and WY2006 were used for October and November in WY 2004 for the East River.

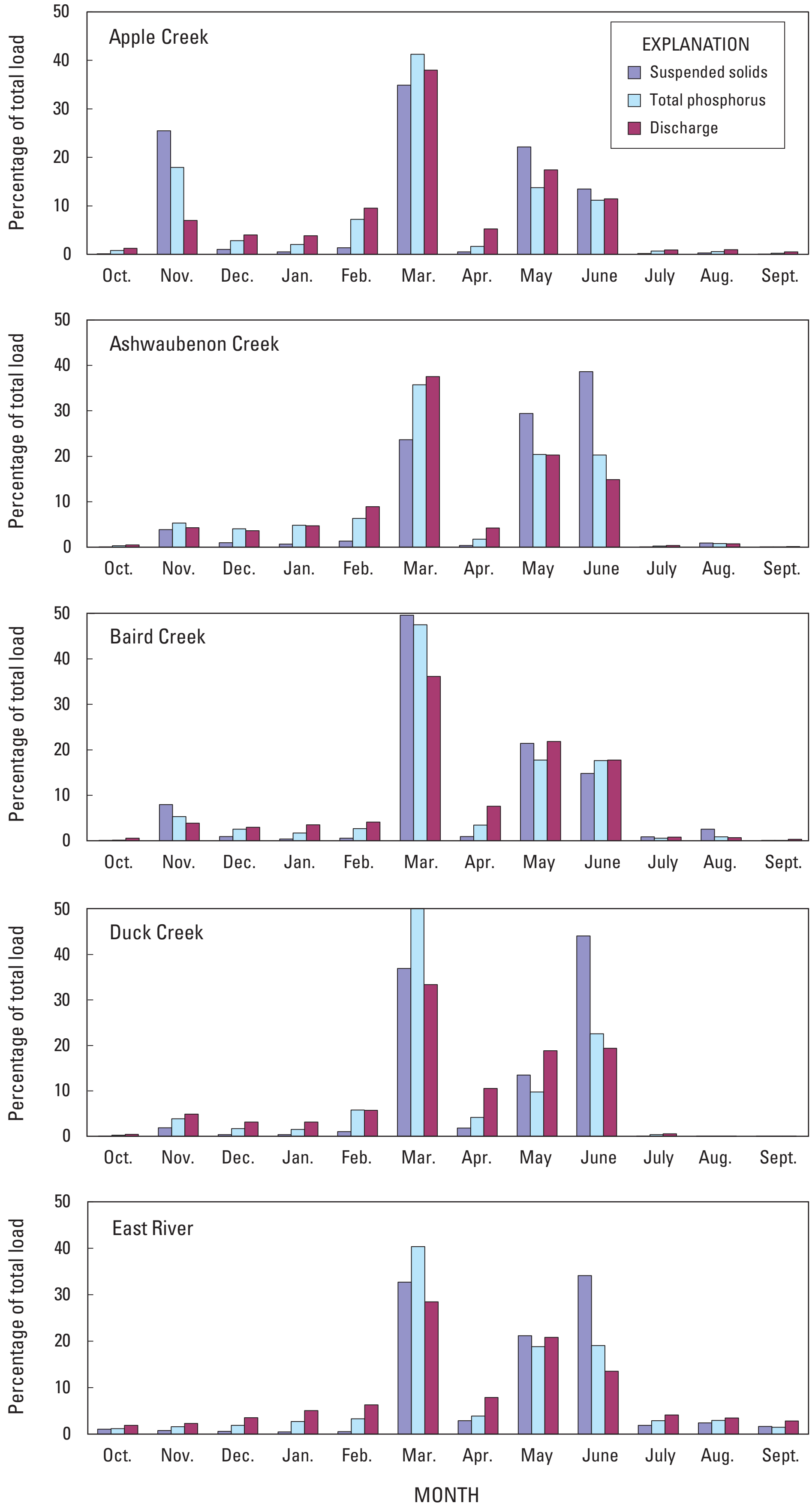

Figure 10. Percentage of annual discharge, and total suspended solids and total phosphorus load by month for Apple, Ashwaubenon, Baird, and Duck Creeks and the East River, for water years 2004–06.

Table 13. Percentage of total annual discharge, suspended sediment load, and total phosphorus load transported over a specified number of days for the five sites in the study.

Number of days	Apple Creek	Ashwaubenon Creek	Baird Creek	Duck Creek	East River	Five site average
			Stream discharge			
1	6.6	7.8	5.7	6.3	5.5	6.4
2	12.4	15.0	10.9	12.0	10.0	12.1
3	17.7	21.0	15.7	16.5	13.3	16.9
4	22.1	26.6	20.0	20.7	16.6	21.2
5	25.8	31.4	23.8	24.7	19.7	25.1
6	29.0	35.9	27.4	28.4	22.7	28.7
7	32.1	39.5	30.6	31.5	25.4	31.8
14	47.3	57.6	47.5	47.5	34.7	46.9
30	64.8	76.4	66.5	66.0	46.1	63.9
60	79.9	88.8	82.3	81.7	59.5	78.4
90	86.6	93.3	89.5	89.5	69.3	85.6
120	90.7	94.8	93.3	93.4	76.8	89.8
180	95.4	98.1	97.0	97.6	88.5	95.3
270	98.8	99.6	99.0	99.8	98.7	99.2
365	100.0	100.0	100.0	100.0	100.0	100.0
			Suspended solids			
1	21.4	22.3	21.1	22.6	19.5	21.4
2	31.5	33.7	31.6	33.8	31.7	32.4
3	41.0	42.9	41.0	44.5	40.6	42.0
4	50.3	52.0	50.3	55.2	47.8	51.1
5	57.8	59.1	57.6	62.5	53.5	58.1
6	63.8	64.6	63.3	67.6	58.0	63.5
7	68.6	69.0	67.7	71.7	61.4	67.7
14	83.1	82.9	82.6	84.6	72.7	81.2
30	94.3	94.5	94.4	94.8	83.7	92.4
60	98.4	98.6	98.5	98.6	90.5	96.9
90	99.3	99.5	99.4	99.4	93.9	98.3
120	99.7	99.8	99.8	99.7	96.2	99.0
180	99.8	99.9	99.9	99.8	96.3	99.2
270	100.0	100.0	100.0	100.0	100.0	100.0
365	100.0	100.0	100.0	100.0	100.0	100.0
			Total phosphorus			
1	16.3	16.4	16.4	22.7	11.5	16.7
2	25.2	24.7	24.3	33.2	19.3	25.3
3	32.4	32.3	31.6	40.6	25.2	32.4
4	39.2	39.6	38.7	47.3	30.1	39.0
5	45.0	45.9	44.8	53.5	34.6	44.7
6	48.4	49.7	48.2	57.1	37.6	48.2
7	51.7	52.9	51.5	60.4	40.3	51.4
14	68.0	69.6	68.3	74.7	54.2	67.0
30	82.9	84.6	83.8	86.3	67.9	81.1
60	92.3	93.7	93.1	93.7	78.6	90.3
90	95.5	96.6	96.3	96.6	84.9	94.0
120	97.0	97.9	97.8	97.9	89.2	95.9
180	98.6	97.2	98.0	99.1	95.2	97.6
270	99.7	99.8	99.8	99.9	100.3	99.9
365	100.0	100.0	100.0	100.0	100.0	100.0

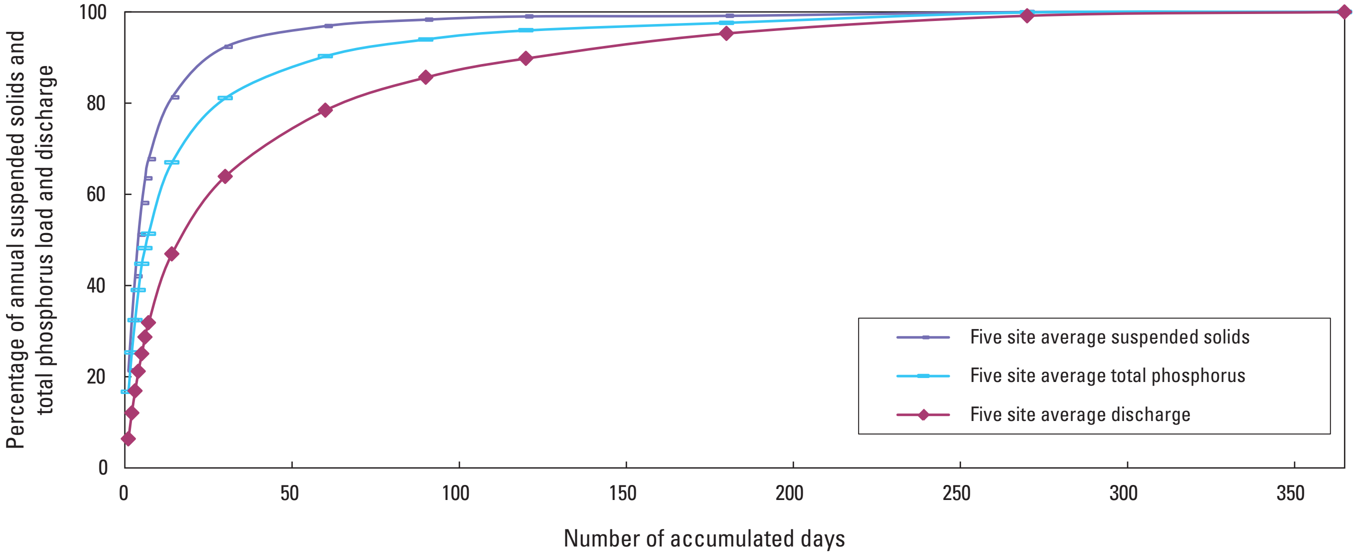

Figure 11. Percentage of annual discharge, suspended solids loads, and total phosphorus load delivered over a specified number of days for Apple, Ashwaubenon, Baird, and Duck Creeks and the East River (five site average).

Table 14. Volumetically weighted concentrations of suspended solids, total phosphorus, and dissolved phosphorus for the five sites in the study, for water years 2004–06.

[All values are in milligrams per liter]

Water year	Suspended solids	Total phosphorus	Dissolved phosphorus
	Apple Creek		
2004	289	0.59	0.24
2005	75	0.42	0.19
2006	107	0.35	0.18
2004–06	193	0.50	0.22
	Ashwaubenon Creek		
2004	256	0.73	0.37
2005	158	0.74	0.39
2006	65	0.52	0.30
2004–06	192	0.69	0.36
	Baird Creek		
2004	202	0.64	0.31
2005	89	0.42	0.21
2006	107	0.42	0.21
2004–06	158	0.55	0.27
	Duck Creek		
2004	106	0.35	0.18
2005	76	0.42	0.20
2006	28	0.28	0.20
2004–06	84	0.36	0.19
	East River		
2004[a]	163	0.50	0.21
2005	37	0.27	0.14
2006	65	0.33	0.15
2004–06[a]	104	0.39	0.18

[a]Based on data for a partial year for 2004: December 16–September 30

Comparison Among Streams

The highest TSS concentrations and yields were from Baird, Apple, and Ashwaubenon Creeks, and lowest concentrations and yields were from Duck Creek and the East River (tables 8 and 11). TP and DP concentrations followed relatively similar patterns among sites: highest concentrations were found in Ashwaubenon Creek, followed by Baird Creek, Apple Creek, East River, and Duck Creek (tables 9 and 10). Average TP and DP yields had similar patterns to those for concentrations except yields from Baird Creek were the highest, and yields from Ashwaubenon Creek were the second highest (table 11). These differences may be caused by the differences in soil and slopes of the watersheds, and the size of their watersheds. Land uses in Apple, Ashwaubenon, and Baird Creek watersheds are similar to those in the Duck Creek and East River watersheds (table 1); however, Apple, Ashwaubenon, and Baird Creek watersheds have soils with less sand and more clays than the soils in the Duck Creek and East River watersheds (table 4). Apple, Ashwaubenon, and Baird Creek watersheds also have steeper main channel slopes than those in the Duck Creek and East River (table 3). In addition, East River and Duck Creek have much larger watershed sizes, which may result in more storage and a lower proportion of sediment delivery. These differences in the watersheds collectively may account for the differences in TSS, TP, and DP concentrations and yields. Urban development may explain some of the differences observed. It might be expected that Baird Creek would have lower concentrations and yields than in Apple or Ashwaubenon Creeks, given the relatively high proportion of wetlands in its watershed (10%, table 1) and higher base flow (table 7); however, rapid urbanization within the Baird Creek watershed may have contributed a disproportionate amount of sediment from upland erosion. Development in the Baird Creek watershed may also have caused a change in the hydrologic regime that may have created unstable stream banks and an indirect sediment source to the stream (Fink, 2005).

It is likely that spatial variability in precipitation affected the distribution in annual yields among streams. For example, in April through September in 2006, precipitation near Baird Creek was 21.6 in., compared to 14.7, 15.9 and 16.6 in. near Apple, Ashwaubenon, and Duck Creeks, respectively (table 6). The fact that Baird Creek and the East River had the highest TSS, TP and DP yields in 2006 (table 11) was likely related to this large disparity in precipitation. The precipitation estimates reported in this document were based on a single rain gage in or near each watershed, rather than a network of gages within each watershed; however, the same pattern in precipitation was observed in a more detailed network of rain-gage data assembled by UWGB for each of the five watersheds.

Use of Data for Modeling Studies

The Soil and Water Assessment Tool (SWAT) is a distributed parameter, daily time-step watershed model developed by the U.S. Department of Agriculture–Agricultural Research Service that can simulate hydrologic, climatic, and related processes to predict the impact of land management on water, sediment, and nutrient export from rural and mixed-use basins (Arnold and others, 1996; Neitsch and others, 2002). The SWAT model was originally applied to the LFR after being calibrated primarily based on TSS and TP data from a single stream; however, it was more successfully calibrated and validated by UWGB (Baumgart, 2005) using some of the data for the five sites described in this report. After successful validation of the model, the SWAT model was applied by the UWGB to the entire LFR basin to allocate loads from various sources and to simulate the impact of a variety of agricultural practices on water quality in LFR streams (Blake, 2007).

Summary

A 3-year study from October 1, 2003 to September 30, 2006 was conducted by the U.S. Geological Survey and the University of Wisconsin Green Bay to characterize the hydrology and phosphorus and suspended solids in five agricultural streams in the Fox/Wolf watershed in northeastern Wisconsin and provide information to assist in the calibration of a watershed model for the area. During this study, total annual precipitation was close to the 30-year normal of 29.12 inches.

Study results were as follows:

Average streamflow was highest in the East River, followed by Duck Creek, Apple Creek, Baird Creek, and Ashwaubenon Creek; however on a yield basis, East River had the highest flow and Ashwaubenon Creek had the lowest flow. The median TSS concentration was highest in Baird Creek, and lowest in Duck Creek. The median TP concentration was highest in Ashwaubenon Creek and lowest in Duck Creek. Average annual TSS yields were highest in Apple Creek and lowest in Duck Creek, whereas average annual TP yields were highest in Baird Creek and lowest in Duck Creek.

Overall, Ashwaubenon, Baird, and Apple Creeks had higher TP and TSS concentrations and yields than Duck Creek and the East River. These differences may be caused by the differences in soil and slopes of the watersheds, and the size of their watersheds. Apple, Ashwaubenon, and Baird Creek watersheds are smaller, have soils with less sand and more clays, and steeper main channel slopes than the Duck Creek and East River watersheds.

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