Prepared in cooperation with the University of Wisconsin-Green Bay and Outagamie County, Wisconsin

Assessment of Conservation Management Practices on Water Quality and Observed Trends in the Plum Creek Basin, 2010–20

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Cover Photograph of agriculture runoff treatment practice, which combines sediment trapping and wetlands practices as part of a conservation management practice. Photograph by Sarah Kussow, Land Conservation Department, Outagamie County.

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Conversion Factors

U.S. customary units to International System of Units

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	0.4047	square hectometer (hm^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	metric ton (t)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square hectometer (hm^2)	2.471	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
	Mass	
kilogram (kg)	2.205	pound avoirdupois (lb)
metric ton (t)	1.102	ton, short [2,000 lb]

Supplemental Information

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

A water year is defined as the 12-month period from October 1 to September 30 of the following year. The water year is designated by the calendar year in which it ends.

Predictor variable	Predictor variable definition
Duration	Duration of the event.
Rain duration	Duration of rainfall during the event.
Intensity event	Rainfall intensity during the entire event duration.
Intensity 5 min	5-minute rainfall intensity.
Intensity 10 min	10-minute rainfall intensity.
Intensity 15 min	15-minute rainfall intensity.
Intensity 30 min	30-minute rainfall intensity.
Intensity 60 min	60-minute rainfall intensity.
Energy m1	Energy (method 1: McGregor [1995] supersedes Brown and Foster equation [1987], which superseded Agriculture Handbook 537 [1979]).
Erosivity m1	Erosivity (method 1: McGregor [1995] supersedes Brown and Foster equation [1987], which superseded Agriculture Handbook 537 [1979]).
Energy m2	Energy (method 2: Wischmeier, Agriculture Handbook 537 [1979, 1981], correct computation of formula 2 found in Wischmeier and Smith [1978]).
Erosivity m2	Erosivity (method 2: Wischmeier, Agriculture Handbook 537 [1979, 1981], correct computation of formula 2 found in Wischmeier and Smith [1978]).
Antecedent rain 1 day	Sum of antecedent rainfall 1 day before the event.
Antecedent rain 2 days	Sum of antecedent rainfall 2 days before the event.
Antecedent rain 3 days	Sum of antecedent rainfall 3 days before the event.
Antecedent rain 7 days	Sum of antecedent rainfall 7 days before the event.
Antecedent rain 14 days	Sum of antecedent rainfall 14 days before the event.
1-day antecedent Q	Sum of antecedent discharge 1 day before the event.
2-day antecedent Q	Sum of antecedent discharge 2 days before the event.
3-day antecedent Q	Sum of antecedent discharge 3 days before the event.
7-day antecedent Q	Sum of antecedent discharge 7 days before the event.
14-day antecedent Q	Sum of antecedent discharge 14 days before the event.
Season sine	Sine of event start date (in decimal time)—Seasonality factor that must be used in conjunction with season cosine.
Season cosine	Cosine of event start date (in decimal time)—Seasonality factor that must be used in conjunction with season sine.
Max temp	Maximum air temperature during the event.
Min temp	Minimum air temperature during the event.
Precipitation	Sum of rainfall and snow-water equivalent recorded during the event.
Period	Binary designation of whether the event occurred initial period or post-conservation management practice implementation period.

Abbreviations

CMP	conservation management practice
DP	dissolved phosphorus
GLRI	Great Lakes Restoration Initiative
HUC	Hydrologic Unit Code
LCD	Land Conservation Department
minNDTI	minimum Normalized Difference Tillage Index
P	phosphorus
TMDL	total maximum daily load
TP	total phosphorus
TSS	total suspended solids
USGS	U.S. Geological Survey
WRTDS	Weighted Regressions on Time, Season, and Discharge program
WY	water year

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Abstract

The U.S. Geological Survey and University of Wisconsin–Green Bay collected hydrologic and water-quality data to assess the effectiveness of agricultural conservation management practice (CMP) implementation at mainstem Plum Creek and west Plum Creek in northeastern Wisconsin. These two subbasins cover 88 percent of the Plum Creek Basin (Hydrologic Unit Code 12), which is a subbasin of the lower Fox River Basin. A published total maximum daily load report for the lower Fox River Basin rated Plum Creek as one of the greatest contributors of total suspended solids (TSS) and total phosphorus (TP) draining into the lower Fox River. To reduce TSS and TP exports from Plum Creek, additional cropland conservation practices and watercourse protections were applied between 2012 and 2020. To detect water-quality trends, data were collected during 2010 to 2020 at mainstem Plum Creek and 2013 to 2020 at west Plum Creek.

The project used two methods to evaluate CMP effectiveness. The first method focused on evaluating water-quality changes between initial and post-CMP implementation periods during rain- or snowmelt-induced runoff events (hereafter referred to as "events"). In this approach random-forest models were developed to account for environmental factors which influence water quality. Model residuals from the two time periods were compared to determine the significance of water-quality changes associated with CMP implementation for mainstem and west Plum Creek Basins. The second method used a Weighted Regressions on Time, Discharge, and Season time-series approach to examine changes in water quality during the entire study period in mainstem Plum Creek. Results from both methods indicated there were minimal water-quality changes in TSS concentrations and flow-normalized delivery during runoff events during the 10-year period from 2010 to 2020; however, TP concentrations during low streamflow (less than 3 cubic feet per second [ft^3/s]) may have decreased. The lack of observed improvement may be attributable to any of the following: variability in weather and hydrologic conditions, insufficient post-treatment data, additional cropland being converted to corn production, above average rainfall, streambank degradation, acute and legacy sources of phosphorus from farm fields, excessive/vulnerable manure applications and spills, and point-source discharges.

Introduction

Wisconsin communities enjoy fishable and swimmable waterways; however, recreational useability declines when waterbodies have excessive phosphorus and sediment loading (mass or rate of transport; Wisconsin Department of Natural Resources, 2022). Event-driven streamflow carries nutrients and sediment from nonpoint and point sources from agricultural and urban lands, including farm field runoff and wastewater treatment facility effluent. Great Lakes Basin assessments concluded the lower Fox River and many of its tributaries have poor water quality (Wisconsin Department of Natural Resources, 2001). The lower Fox River Basin receiving waters, which receive nutrients from nonpoint sources throughout its basin, have persistent eutrophication problems and experience extensive algal blooms. Work to address causes of water-quality degradation in Wisconsin has been ongoing for more than four decades.

Total maximum daily load (TMDL) studies were started by the U.S. Environmental Protection Agency (EPA, 1991) under the Clean Water Act (33 U.S.C. ch. 23 § 1151) Section 303(d). As part of TMDLs, all major sources of pollution are quantified. Nonpoint source pollution is addressed by implementing pollutant reduction strategies that target critical areas within basins for treatment (Wisconsin Department of Natural Resources, 2021). In 2012, the lower Fox River Basin and lower Green Bay TMDL was released (Wisconsin Department of Natural Resources, 2012). The TMDL set goals to reduce

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[3]Wisconsin Extension.

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total suspended solids (TSS) and total phosphorus (TP) through conservation management plans that address concerns related to soil erosion, manure management, and nutrient applications.

Model results from the TMDL plan characterized the Plum Creek Basin as one of the largest contributors of TSS and TP to the lower Fox River Basin (Wisconsin Department of Natural Resources, 2012). In 2010, the U.S. Geological Survey (USGS) and the University of Wisconsin–Green Bay launched a partnership to monitor TSS and TP loads from the Plum Creek Basin. Before 2010, work in the highly agricultural Plum Creek Basin only focused on voluntary conservation efforts; therefore, water-quality observations before 2010 served as baseline conditions for the Plum Creek monitoring project. In October 2010, sampling began at an automated monitoring station on mainstem Plum Creek (fig. 1) that captures flow from about 61 percent of the 35-square-mile (mi^2) Plum Creek Basin. To capture an additional 27 percent of the basin, a second automated sampling station was established on west Plum Creek (fig. 1) and sampling began there in November 2013. As a result, monitoring captured 88 percent of the Plum Creek Basin area.

Focused conservation management practice (CMP) implementation began in 2012 with funding from the Great Lakes Restoration Initiative (GLRI) through a GLRI Buffer Grant received by Outagamie County and additional GLRI funding through the Natural Resources Conservation Service; however, in 2015, CMP implementation accelerated with additional grant funding through the Fox-Wolf Watershed Alliance, which received funds from GLRI for the Hydrologic Unit Code (HUC) 12 Plum Creek Basin.

Purpose and Scope

The overall objective of this project was to evaluate changes in water quality in two Plum Creek Basins as a result of focused agricultural conservation efforts related to GLRI-funded initiatives. In 2014, the “Nonpoint Source Implementation Plan for the Plum and Kankapot Creek Watersheds” report (Outagamie County Land Conservation Department, 2015) established the “Nine-Key Element Plan” for Plum and Kankapot Creeks to achieve TMDL reduction goals. Outagamie County and other partners developed a framework intended to reduce TSS and nutrient loads from these basins. The plan identified critical areas for CMP implementation, outlined restoration or protection strategies, and set implementation targets. The plan concluded that more than 75 percent of croplands need CMPs (such as cover crops, conservation tillage, low-disturbance manure injection) in combination with innovative practices that treat cropland runoff (such as treatment wetlands and vegetative riparian buffers), to reach downstream water-quality goals. Minimizing soil disturbance and increasing vegetative cover substantially reduces soil and phosphorus losses from fields during major runoff events and during critical periods when fields are typically left uncovered (Sharpley and others, 2001). Practices such as streambank stabilization/restoration and methods of gully stabilization (grassed waterway, water and sediment control basins, and critical area plantings) were also identified as basin needs. Water-quality monitoring was a critical component of this project to describe the effect of CMP implementation on water quality within the basin.

This report describes hydrologic conditions and changes in water quality in Plum Creek, between October 2010 to September 2020, which were monitored as part of the Fox-Wolf Watershed Alliance GLRI Plum-Kankapot Creek project and GLRI Priority Watershed project. Assessment of CMP implementation in mainstem Plum Creek used data from water years (WYs) 2011–14 for the initial period and data from WYs 2019–20 for the post-CMP period (a stage of the study when many of the focused conservation approaches had been applied and were functioning). Automated water sampling to assess CMP effects in the west Plum Creek Basin did not start until 2014; therefore, data from WYs 2014–16 were used as the initial period. The same post-CMP period was used for mainstem and west Plum Creeks. The shorter period of record used for west Plum Creek likely affected the statistical evaluations of change since the initial period and may not represent true “initial” conditions because of existing focused conservation efforts during that period. Results from this study can aid watershed managers and may help identify additional impaired areas for TMDL-focused CMP implementation. All data, processes, and models are publicly available (Pronschinske and others 2023).

Physical Setting and Land Use

The lower Fox River Basin covers 638 mi^2 in northeastern Wisconsin. With a total area of 35 mi^2, Plum Creek Basin (HUC–12 040302040205) is the fourth-largest basin in the lower Fox River Basin (fig. 1). This project focused on two subbasins in Plum Creek: mainstem Plum Creek Basin, which drains 21.2 mi^2, and west Plum Creek Basin, which drains 9.5 mi^2. These basins span Brown, Calumet, and Outagamie Counties, Wisconsin. The mainstem Plum Creek station is 2 miles (mi) upstream from the lower Fox River and 10 mi upstream from the lower Green Bay and Fox River Area of Concern.

These basins are primarily agricultural with three dominant soil types. The most prevalent is Kewaunee Silt Loam, followed by Manawa Silt Loam (in wetter landscape positions), and Kewaunee Loam (U.S. Department of Agriculture Natural Resources Conservation Service Soil Survey Staff, 2020a). Many of the soils fall into hydrologic soil group D (62 percent) followed by group C (34 percent; U.S. Department of Agriculture Natural Resources Conservation Service Soil Survey Staff, 2020b). Soils in hydrologic groups C and D have high runoff potentials because of their low infiltration capacities. Croplands across the basin have a mean slope of 3.7 percent and consist of moderately high and

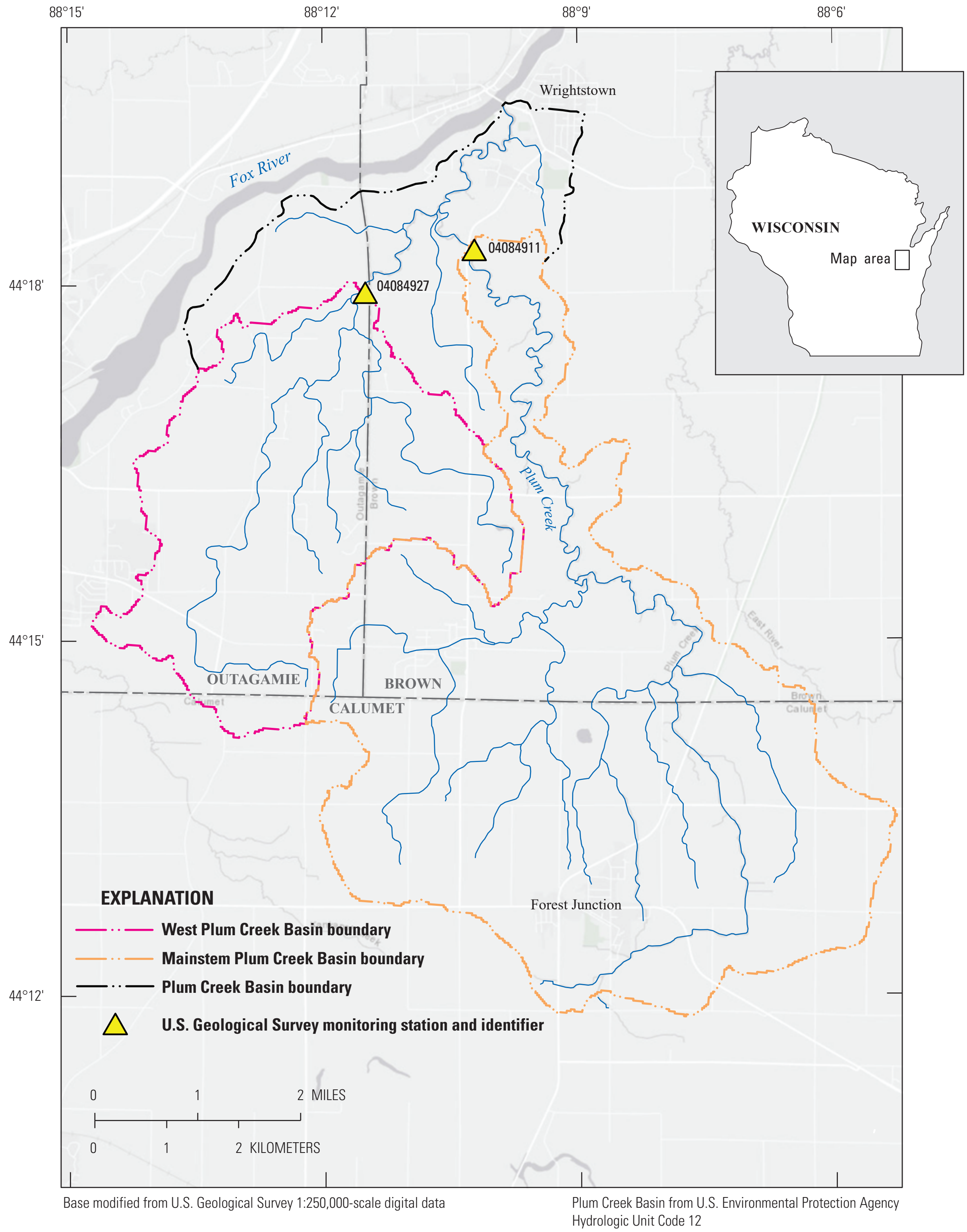

Figure 1. Location of two automated data collection sites on mainstem and west Plum Creeks within the Hydrologic Unit Code 12 Plum Creek Basin, Brown, Calumet, and Outagamie Counties, Wisconsin.

highly erodible soils (U.S. Department of Agriculture Natural Resources Conservation Service Soil Survey Staff, 2020c). Because these croplands have poorly drained soils, farmers often install drainage tiles to reduce saturated subsoil conditions; the tiled percentage is 81 percent in the west Plum Creek Basin and 41 percent in the mainstem Plum Creek Basin.

Of the 13,000 acres in the mainstem Plum Creek Basin, 78 percent is agriculture (sorghum, corn, soybeans, grassland/pasture), 15 percent is natural (barren, forest, wetlands, shrubland), and 8 percent is classified as developed (table 1, fig. 2; U.S. Department of Agriculture, 2021). Of the 6,100 acres in the west Plum Creek Basin, 84 percent is agriculture, followed by 10 percent urban/developed, and 7 percent natural. Corn and alfalfa/other hay/grassland/pasture were the primary crop types in both basins in 2014 and 2020 (table 1). The alfalfa/other hay/grassland/pasture cover decreased 7 percent in both the mainstem and west Plum Creek Basins from 2014 to 2020. The amount of land used for corn increased 6 percent for mainstem Plum Creek Basin and 8 percent in west Plum Creek Basin for this same period. The proportion of land in other land cover categories changed by 3 percent or less from 2014 to 2020.

There were 24 and 8 livestock operations in the mainstem and west Plum Creek Basins, respectively. Two of the operations in west Plum Creek Basin have greater than 1,000 dairy cows and, therefore, were required to have a Concentrated Animal Feeding Operation (CAFO) Wisconsin Pollutant Discharge Elimination System permit. Similar to other intensive dairy areas, manure spreading frequency and quantity in the Plum Creek Basin depended on the crop planted and producer nutrient management plans. Available fields also received manure imported from facilities outside these two basins. Jacobson (2012) summarized data from several representative fields in Plum Creek and reported an area-weighted soil test phosphorus concentration of 42 parts per million (ppm) with several fields greater than 50 ppm, which clearly exceeded the optimal value for corn at 16–20 ppm (Laboski and Peters, 2012).

Streambank erosion is common throughout mainstream corridors of Plum Creek. Outagamie County land conservation staff completed a partial streambank inventory in 2014 to quantify these critical areas (Outagamie County Land Conservation Department, 2015). In mainstem Plum Creek, 11.6 mi of 17.8 mi of streambanks examined were classified as degraded, and in west Plum Creek, 1.6 mi of 3.5 mi of streambanks examined were classified as degraded (in other words, the fluvial surface had been lowered through erosion). The geomorphic setting of the mainstem Plum Creek corridor makes it susceptible to channel erosion; its dendritic drainage pattern in the upper basin funnels to a relatively narrow and steep incised stream channel in its lower reaches (fig. 1). A sediment fingerprinting study, conducted during 2016–18, found streambank erosion was a significant source of sediment in the creeks (Fitzpatrick and others, 2019). In addition to geomorphic conditions, land use changes since settlement (wetland and forest loss, ditching, intensive agriculture, and so on) have likely affected the hydrology of the basin and the stability of the drainage network; therefore, in addition to cropland CMPs, CMPs that restore hydrology, such as wetland restorations and agriculture runoff treatment systems, could help meet water-quality objectives and were included in implementation plans.

Basin Conservation Management Practice Implementation

The Outagamie, Brown, and Calumet County Land and Water Conservation Department and Land Conservation Departments (LCD) and the Natural Resources Conservation Service began contributing to the implementation of CMPs in the Plum Creek Basin in 2012. Traditional practices included barnyard runoff management systems, riparian buffers, cover crops, conservation tillage, grassed waterways, and streambank protection. Innovative practices, such as agricultural runoff treatment wetland systems, two-stage ditch designs, and new methods of manure application, were also implemented in the basin. The Outagamie County LCD tracked land use and CMP inventories in a geographic information system database (fig. 3). Because of privacy policies, the Natural Resources Conservation Service only reported a summary of installed

Table 1. Land cover for mainstem and west Plum Creek Basins, Brown, Calumet, and Outagamie Counties, Wisconsin.

Land cover category (U.S. Department of Agriculture, 2021)	Land cover, in percent			
	Mainstem Plum Creek Basin		West Plum Creek Basin	
	2014	2020	2014	2020
Sorghum, corn	26	32	27	35
Soybeans	9	10	6	3
Alfalfa/other hay/grassland/pasture	39	31	51	43
Other crops (winter wheat, rye, oats)	5	4	2	2
Natural background (forest, wetlands, shrubland, barren)	12	15	5	7
Developed	9	8	9	10

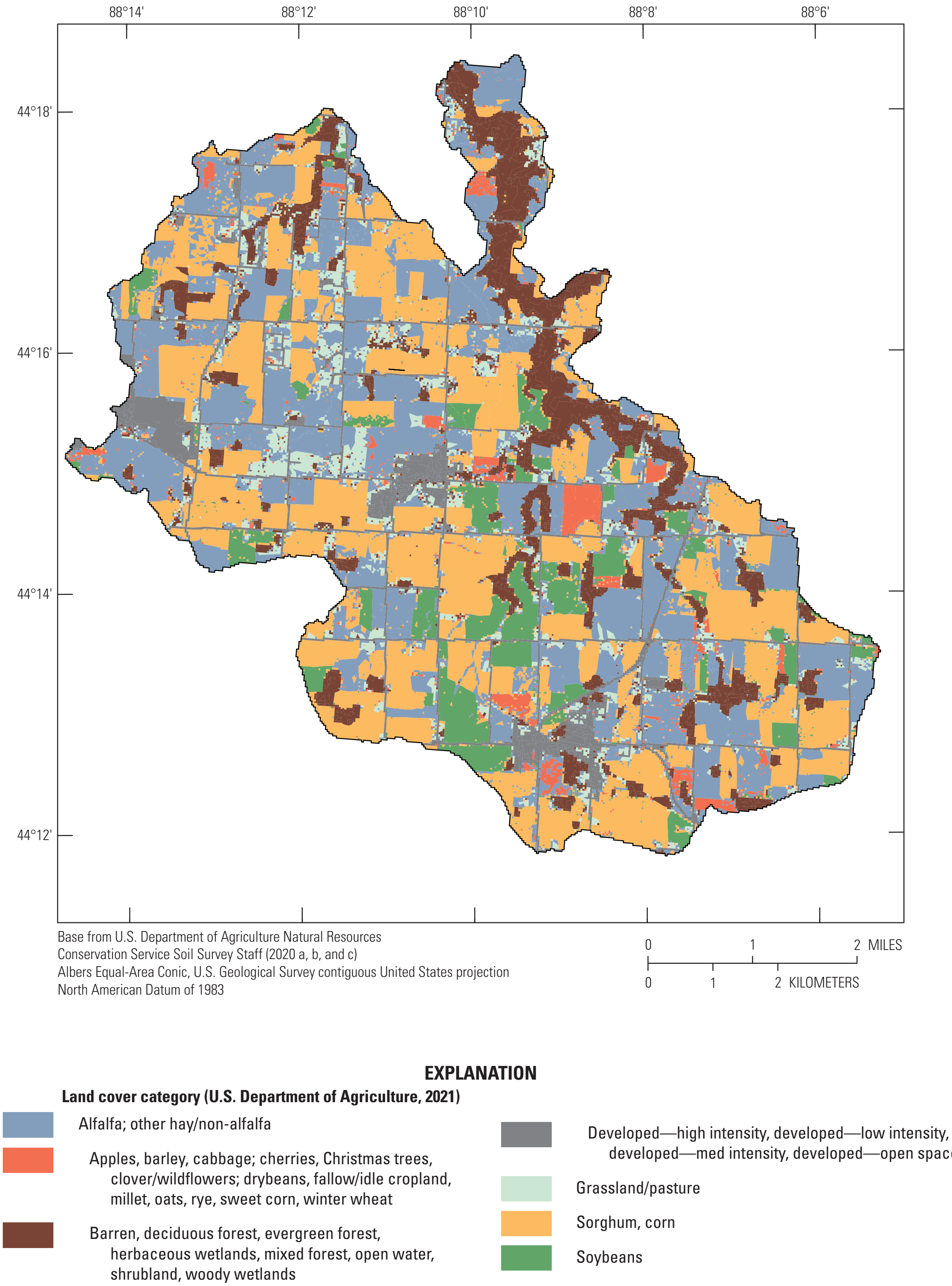

Figure 2. Land use and land cover in 2020 for the mainstem and west Plum Creek Basins, Wisconsin.

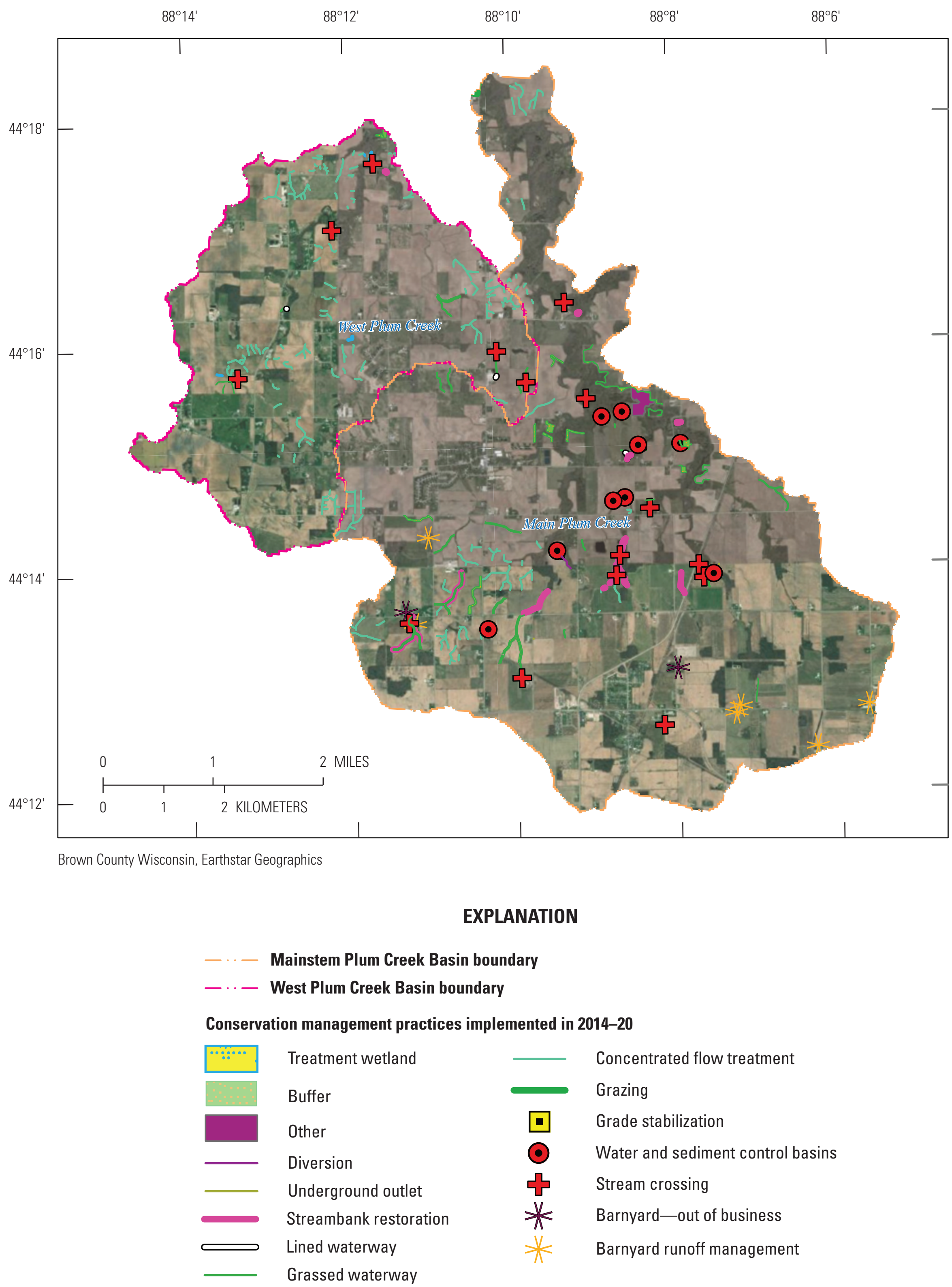

Figure 3. Conservation management practices implemented in 2014–20 in mainstem Plum and west Plum Creek Basins, Wisconsin. [Note: The map excludes annual cropping practices implemented during this period or those completed by Natural Resources Conservation Service.]

Table 2. Type, quantity, and basin location of agricultural conservation management practices installed between 2012 and 2020 in the Plum Creek Basin, Wisconsin.

[Numbers in brackets are conservation practice standard codes from Natural Resources Conservation Service Practice standards and technical guidelines. HUC–12, Hydrologic Unit Code 12; —, no data].

Conservation management practice (unit of measurement)	Quantity installed in 2012–20		
	West Plum Creek Basin	Mainstem Plum Creek Basin	[1]HUC–12 Plum Creek Basin
Nutrient management [590][1](acre)	197	—	4,789
Riparian buffer [393][1](acre)	81	67	—
Streambank restoration [580][1](foot)	390	27,800	—
Grassed waterway [412][1](foot)	5,430	11,600	—
Concentrated flow [342][1](foot)	53,100	40,700	—
Treatment wetland [656][1](count)	3	1	—
Land conversion (degraded forest to grazing) [528][1](acre)	—	32	—
Water and sediment control basin [638][1](count)	—	9	—
Lined waterway [468][1](foot)	103	690	—
Barnyard runoff management systems [561,558, 635][1](count)	—	8	—

[1]Practices cost shared through the Natural Resources Conservation Service and landowners in the HUC–12 Plum Creek Basin; however, their implementation location is confidential.

Table 3. Acres of conservation cropping practices cost shared as part of county, State, and Federal programs and percentage of row crop containing these practices in the Plum Creek Basin during calendar years 2012 through 2020.

[Numbers in brackets are conservation practice standard codes from Natural Resources Conservation Service Practice standards and technical guidelines]

Cropping practice implementation (unit of measurement)	2012	2013	2014	2015	2016	2017	2018	2019	2020
Residue management [329,345][1](acre)	595	194	37	557	599	805	692	485	929
Residue management implementation on row crops (percent)	8	3	1	9	9	12	9	7	12
Cover crops [340][1](acre)	261	196	875	1,170	966	1,740	1,662	1,260	1,790
Cover crop implementation on row crops (percent)	4	3	13	19	15	25	22	19	23
Row crop—Corn and soybean (acre)	7,440	6,760	6,530	6,290	6,440	6,870	7,520	6,760	7,690

[1]Practices cost shared through the Natural Resources Conservation Service and landowners in the Hydrologic Unit Code 12 Plum Creek Basin; however, their implementation location is confidential.

practices at the HUC–12 scale; therefore, some CMPs reported here may exist downstream from the two monitored stations (tables 2 and 3).

Streambank restoration and buffers were installed beginning 2012 (fig. 3, table 2); however, the majority were installed after 2016 and continuing through 2021. More than 26 miles of stream and waterway segments received these practices in the mainstem and west Plum Creek Basins. During 2015–20, between approximately 1 and 10 percent of the cropland in mainstem and west Plum Creek Basins implemented a combination of cover crops and residue management each year (table 3). Nutrient management strategies (such as low-disturbance manure injection and improved timing of manure applications) were also implemented on a few acres (less than [<] 100) through the Fox-Wolf Watershed Alliance GLRI project. Ideally, all CMPs would have been implemented before the post-CMP assessment period; however, practice installation continues beyond 2020. In fact, a record number of acres were dedicated to cover crops and residue management in fall 2020 (table 3).

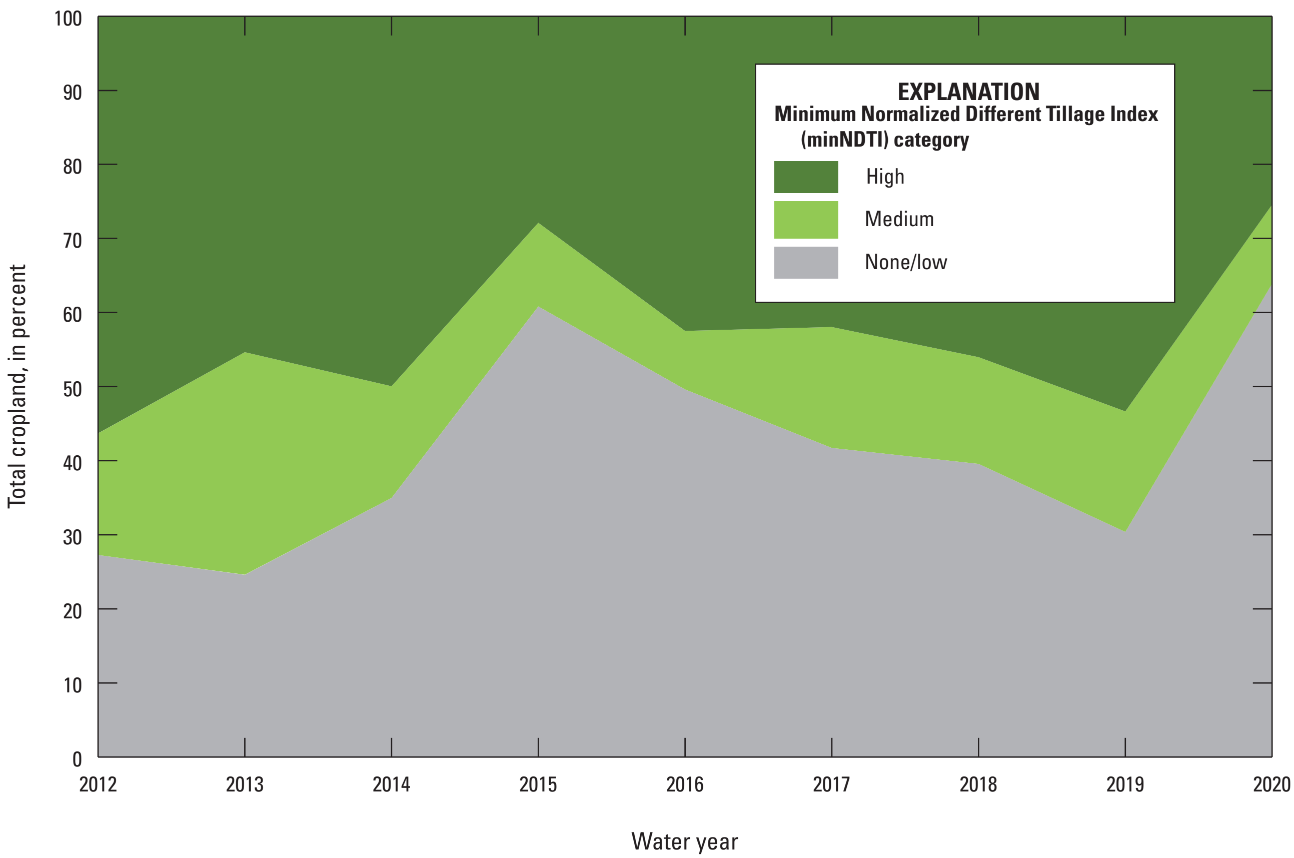

Figure 4. Minimum Normalized Difference Tillage Index (minNDTI) to detect crop residue and green cover by water years 2013–20 for Plum Creek Basin.

Land Cover Change

The minimum Normalized Difference Tillage Index (minNDTI) approach was used to track field-scale cover (crop residue and vegetative cover) of croplands in the Plum Creek Basin. The NDTI was calculated using Landsat and Sentinel satellite imagery. Satellite imagery from multiple days during the spring and fall were analyzed to calculate the minNDTI by WY for each basin (using a minimum of three images per WY; fig. 4). The NDTI is positively correlated with crop residue and green cover (Zheng and others, 2012), so it can be used to assess the potential areal extent of cover crop and residue management CMPs and indicate cropland vulnerability to erosion. There was no consistent trend in minNDTI-based cropland cover during 2012–20 in mainstem (fig. 4) or west Plum Creek Basins (data not shown). The percentage of cropland in mainstem Plum Creek Basin with no or low cover ranged from 25 to 60 percent (fig. 4).

In addition to the effects of annual cover crop and residue management on minNDTI, the proportion of certain crop types in the basin can affect basin vulnerability depicted by minNDTI. According to the U.S. Department of Agriculture National Agricultural Statistics Service Cropland Data layer (2021), crop types planted in the basins during 2011–20 varied by year but were consistently dominated by corn and alfalfa/grass crop types (fig. 5). In 2019, about 10–15 percent of the cropland was fallow/idle because of poor weather conditions for cropping. The proportion of cropland in the pasture/grassland category declined during the study period (figs. 5*A* and 5*B*). In the mainstem basin, corn acreage increased 13 percent and perennial cropland vegetation decreased 14 percent from 2011–12 to 2019–20 (fig. 5*A*); a similar shift in cropping happened in the west basin (fig. 5*B*).

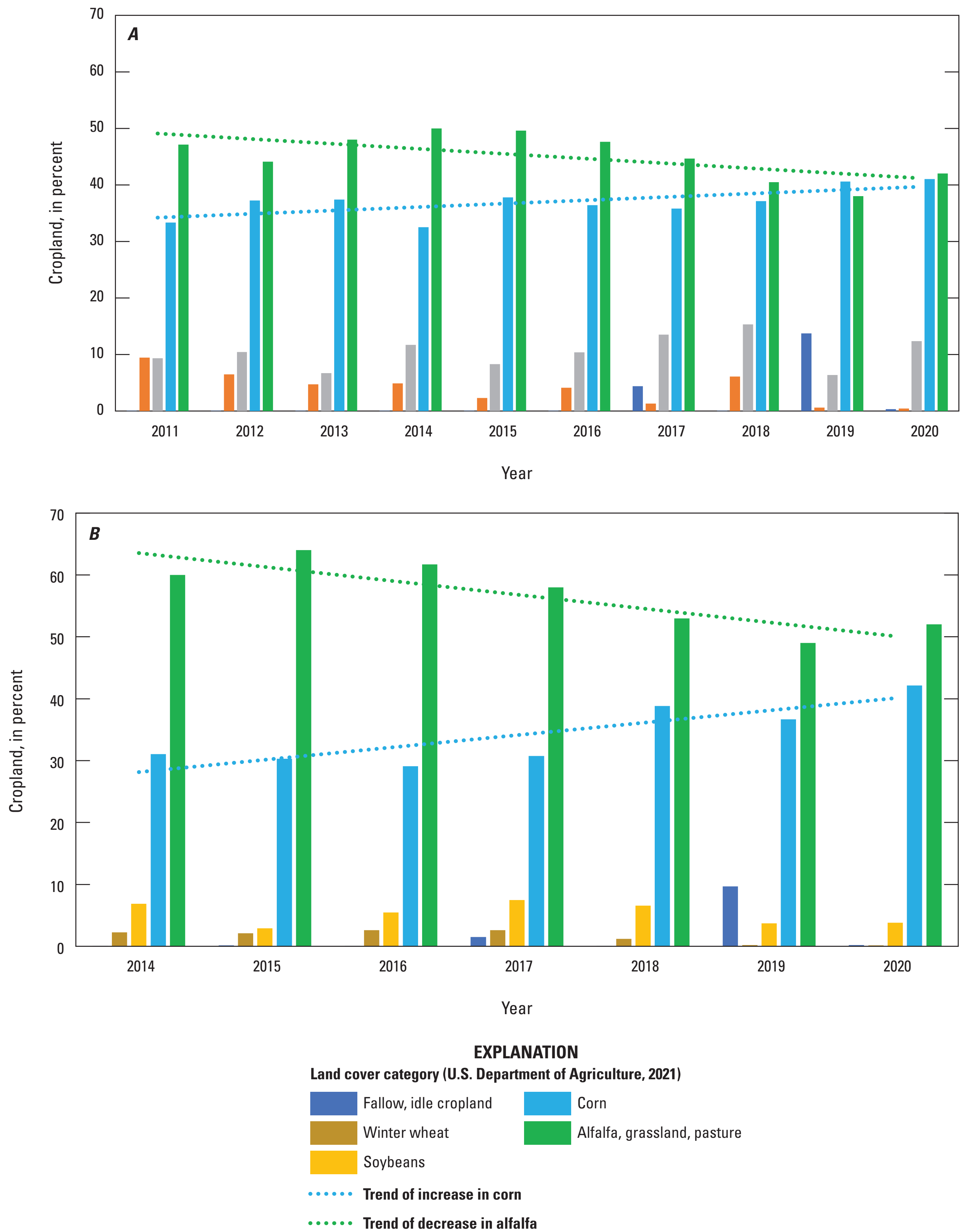

Figure 5. U.S. Department of Agriculture cropland data for, *A*, mainstem Plum Creek and, *B*, west Plum Creek Basins, Wisconsin.

Methods

This section of the report describes the methods used for water data collection, data compilation, and load computation. The statistical approaches used to quantify changes in water quality between the initial period and post-CMP implementation and the changes in water quality during the entire period of data collection in the Plum Creek Basins are also described.

Hydrologic and Water-Quality Data-Collection Network

A monitoring station on mainstem Plum Creek near Wrightstown, Wisconsin (station no. 04084911), was established in October 2010, and a monitoring station on west Plum Creek at New Road near Wrightstown, Wis. (station no. 04084927), was established in November 2013, before the onset of the focused conservation efforts. Data followed a WY, defined as October 1 to September 30 and designated as the year in which it ends. Both stations were configured to collect continuous (5-minute interval) stage data to calculate streamflow (discharge) and used automated refrigerated samplers to capture samples from their respective streams. Each station sampler could collect 24 discrete 1-liter samples. Only the mainstem station recorded precipitation. At least twice per day, the station's datalogger communicated data to the USGS office in Middleton, Wis.

Multiple samples were collected at both sites during individual events based on changes in water level (stage) and time between samples. A datalogger program initiated the automatic sampling when the stage increased more than 0.4–0.6 foot (ft) above base flow conditions. Once in sampling mode, samples were collected based on time or when the stage rose by 0.65 ft or fell by 0.85 ft. A subset of 5–12 of the samples collected during each event were selected for chemical and physical analyses to characterize each event's discharge-concentration relation.

Additionally, to characterize stream water quality during base flow conditions, periodic discrete automatic samples were collected when the largest component of streamflow was assumed to be contributed by the shallow groundwater system. Routine base flow samples were collected biweekly from March to November and monthly during the winter months (December through February).

Field personnel serviced samplers within 24 hours of each event's end and transported all water samples in coolers for processing and preservation. The selected samples were processed using a Dekaport cone splitter to divide the samples into subsamples for TSS, TP, and total dissolved phosphorus (DP) analyses. All the subsamples, except those for TSS analysis, were preserved with sulfuric acid. All processed subsamples were transported on ice to the NEW Water (Green Bay Metropolitan Sewerage District's brand) certified laboratory in Green Bay, Wis., for analysis. TP and DP were analyzed according to method EPA 365.4 (American Public Health Association, 1989, 1992). Analysis of some samples collected in 2020 were delayed due to COVID–19 restrictions; however, all samples were analyzed by October 23, 2020.

Rainfall in the study area was estimated from several stations near Plum Creek. During the first year of the study (2011), data from the mainstem station was used, and for the next 9 years, data from a station on the East River on Highway ZZ (station 04085108, approximately 3 mi from the Plum Creek Basin; not shown) was used. The rain gage record at the mainstem station started in March 2011, and the rain gage record at the East River station started in March 2012. The rain gages are 8 inches (in.) in diameter. Additional precipitation, snow depth, and air temperature data were obtained from a nearby National Oceanic and Atmospheric Administration (National Centers for Environmental Information, 2020) weather site at the Green Bay Airport (station USW00014898, approximately 12 mi from the Plum Creek Basin; not shown).

Stream Sample Concentration Comparisons

The Wilcoxon rank-sum test was used to determine if there were statistically significant differences in TSS, TP, and DP concentrations between the mainstem and west Plum Creek tributaries during base flow and event (DP only) conditions for WYs 2014–20. To avoid potential serial correlation issues during events, statistical analysis was not used to compare TSS and TP concentrations. During most events, only a single sample was analyzed for DP, so serial correlation was not a concern.

Load Computation

The continuous discharge data were combined with the discrete base flow and event water-quality data to compute daily, monthly, and annual TSS and TP loads and concentrations using the Graphical Constituent Loading Analysis System (Koltun and others, 2006). Sampled concentrations were linearly interpolated from the collected samples except at the beginning and end of runoff events when the representative base flow sample concentration was defined. Estimated concentrations were added to the record during unsampled runoff events or when additional granularity of data would result in a better representation of load. These concentrations were estimated based on flow-concentration relations that varied seasonally. Unit-area yields were computed by dividing the constituent loads by the basin area upstream from the gaging station. Unit-area yields were computed to compensate for the difference in the sizes of the mainstem and west Plum Creek Basins which enabled the loads to be more properly compared.

The Graphical Constituent Loading Analysis System computes loads and average concentrations based on specified event start and end times then linearly interpolates individual event loads transported in streams, excluding transport rate (Koltun and others, 2006). To characterize the timing of each event, the start time of each event was defined by the first rise in stage above base flow conditions. The end time of each event is somewhat subjective because stream-runoff events are generally prolonged and blend into the base flow. For this project, a simple graphical approach was used. Line 1 was drawn starting after the recession of each event (starting 6 hours or more after previous event) when overland flow was assumed to have stopped. Where line 1 diverged from each recession plot, line 2 was drawn along the slope of each hydrograph towards the peak of each event. The end time of each event was then defined as the time when line 2 started to diverge from the hydrograph. Each unit streamflow value was combined with the interpolated concentration for each constituent to calculate a unit load. All unit loads for the event were summed to compute the individual event loads.

Quantifying Temporal Changes in Water Quality

The effects of focused CMP implementation on TSS and TP concentrations and loads at the basin scale were first assessed by comparing changes during runoff events between the two periods (initial period and post-CMP implementation period). Most of the implemented conservation strategies are designed to address surface runoff that would happen during events. The initial period was represented by WYs 2011–14 for mainstem and WYs 2014–16 for west Plum Creek Basins. The post-implementation period data for both basins were represented by data collected during WYs 2019–2020. To account for the effects of different weather conditions during the initial period and post-CMP implementation periods, a random-forest modeling approach was used that incorporated weather and hydrologic factors to assess the effects of conservation actions on TSS and TP concentrations and loads.

A random-forest modeling approach (Breiman, 2001) was selected to quantify significant differences in water quality between the initial period and post-CMP implementation because this approach permitted both categorical and continuous predictor variables to be included. This modeling approach permitted unbalanced data (different amounts of data between periods) to be used, and it permitted nonlinear responses in the data to be evaluated. The random-forest modeling approach was used to account for the effects of changes in weather conditions by including environmental data associated with each runoff event as explanatory variables, including rainfall metrics, rainfall plus snow-water equivalent, antecedent discharge, sine and cosine transformations of decimal time (seasonality), and air temperature. All of these environmental variables served as predictor variables in the random-forest models, and they are defined in the “Abbreviations” section. Response variables (concentrations, loads, peak discharge, and total event discharge) were logarithmically transformed before modeling. To reduce model skewness, predictor variables were transformed using natural logarithms if doing so increased the value coefficient of variation of the simple linear relation between the predictor and response by greater than 0.05 and/or by greater than 20 percent. Natural logarithm transformations of predictor variables are denoted by (log). The random-forest modeling approach used different subsets of explanatory variables to generate many individual decision trees (in this study n=1,000). From these 1,000 trees, commonly chosen predictor variables were given greater importance and response variable values were predicted. The mean predicted response value was used to calculate model residuals. Residuals from the model should be symmetric around zero. A two-sided Wilcoxon rank-sum test was then used to evaluate the differences in residuals for individual events from the initial period and post-CMP implementation periods from all branches in the best-fit model. Differences in the two periods were deemed statistically significant if the p-value was <0.1. Both the one-sided and two-sided Wilcoxon rank-sum test significance values were reported. Because none of the explanatory variables in the analyses included land-management variables, a significant difference in the residuals between the initial period and post-CMP implementation periods was assumed to represent a significant change attributable to focused CMP implementation.

For each response variable with a statistically significant increase or decrease (based on the Wilcoxon rank-sum residual test), the estimated percent change from the initial period to the post-CMP implementation period was calculated by creating multilinear models. To determine which variables to potentially include in the multilinear models, two random-forest models were generated: one that used data only from the initial period and the other that used data only from the post-CMP period. This selected the top five predictors for each period as potential variables for the multilinear models for each response variable. In addition to these predictor variables, a categorical term noting the period (initial period or post-CMP) of each event was also included in the multilinear model. The potential variables for each multilinear model were then included in a forward and backward stepwise regression routine using Bayesian information criteria to eliminate redundant variables and reduce model overfitting. If the p-value of the coefficient of the categorical period term in this final regression was statistically significant (p-value<0.1), it was used to estimate the percent change, and its standard error was used to estimate uncertainty. All data, processes, and models are publicly available (Pronschinske and others 2023).

It is important to note that the random-forest method of comparison only focused on changes during runoff events. To evaluate changes in water quality during base flow, the EcoHydRology R package (Fuka and others, 2018) was used to separate base flows and baseloads from the total flows and total loads. Then, a two-sample T-test was performed on samples collected during base flow conditions during the initial period and the post-CMP period to determine if there were significant changes in TSS, TP, and DP concentrations.

In addition to examining differences in concentrations and loads from the initial period and post-CMP implementation period, a second trend analysis was conducted for the entire period (2010–20) using the Weighted Regressions on Time, Season, and Discharge program (WRTDS; Hirsch and

De Cicco, 2015) for TSS and TP data from mainstem Plum Creek. Typically, WRTDS develops nonlinear, time-varying relations between the logarithm of concentration and explanatory variables consisting of decimal time, the logarithm of daily discharge, and sine and cosine transformations of decimal time (Hirsch and others, 2010; Lee and others, 2016). WRTDS derives flexible relations using a unique weighted regression for each day of the estimation period. The regression coefficients in the time-varying relations in WRTDS are computed from a weighted regression. In the weighted regression, the weights are equal to 1.0 for the observation year in which the estimate is being made and decay to 0.0 at a time or flow separation defined in the model setup. WRTDS uses a bias correction factor specific to each year, day, and discharge to adjust for any retransformation bias (Hirsch and De Cicco, 2015). WRTDS was implemented using the R package Exploration and Graphics for RivEr Trends (EGRET) using all default specifications, except a 3-year half window was used for time because of the short length of record and the high intensity of samples that were collected. The WRTDS analysis provided a second approach to analyze changes in water quality that incorporated flow normalization to account for varying flow conditions driven by differences in annual precipitation.

Hydrologic Conditions During the Study Period

During the study period, precipitation was above the long-term, 30-year mean annual value (normal 1991–2020) of 31.6 in. (National Oceanic and Atmospheric Administration, 2020), except in 2012 and 2015 (fig. 6). Even though the precipitation data collected as part of this study for WY 2011 were incomplete, data from nearby sites (National Weather Service sites at Green Bay station USW00014898 and Appleton station USC00470265, Wisconsin; National Centers for Environmental Information, 2020) indicated annual precipitation (36.5 in.) was greater than the long-term mean. The mean annual precipitation at Appleton, Wis. (4 mi southwest of the study area), during the 10-year study period was 37.8 in., which is 6.2 in. per year greater than the 30-year long-term mean for 1981–2010 and 4.6 in. per year greater than the updated 30-year long-term mean from 1991–2020. During the post-CMP implementation period, WYs 2019 and 2020 exceeded average annual precipitation totals at the Green Bay and Appleton stations (National Centers for Environmental Information, 2020).

During the study period (WYs 2011–20), mean annual discharge in the mainstem Plum Creek station varied by more than a factor of four with mean annual discharge lowest in WY 2012 and highest in WY 2019 (fig. 7*A*). During the WYs 2014–20 at the west Plum Creek station, discharge was lowest in WY 2015 and highest in WY 2019 (fig. 7*B*). Overall, the interannual variation in discharge reflected the interannual variation in precipitation (fig. 6); however, the unusually high precipitation in WYs 2019 and 2020 resulted in very high annual discharge, likely because of the precipitation leading to saturated soils and because of the precipitation further exceeding the evapotranspiration in the area.

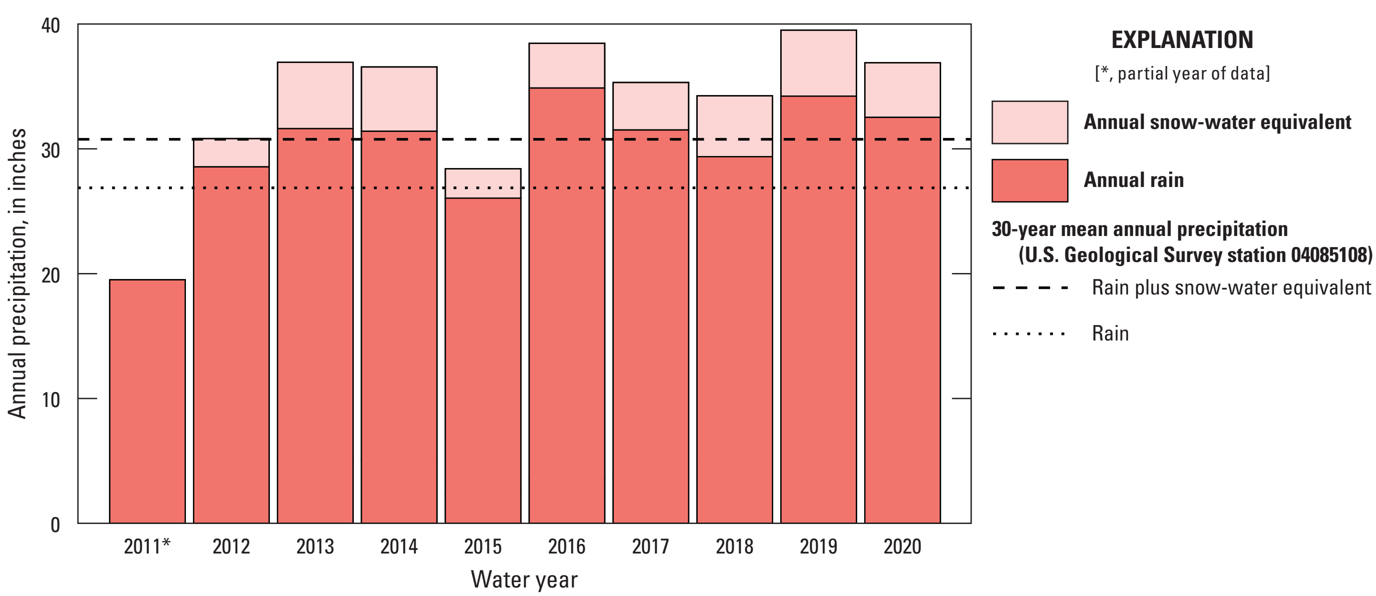

Figure 6. Mean annual precipitation throughout the study period at the U.S. Geological Survey East River station 04085108, and annual precipitation from the Green Bay National Weather Service station.

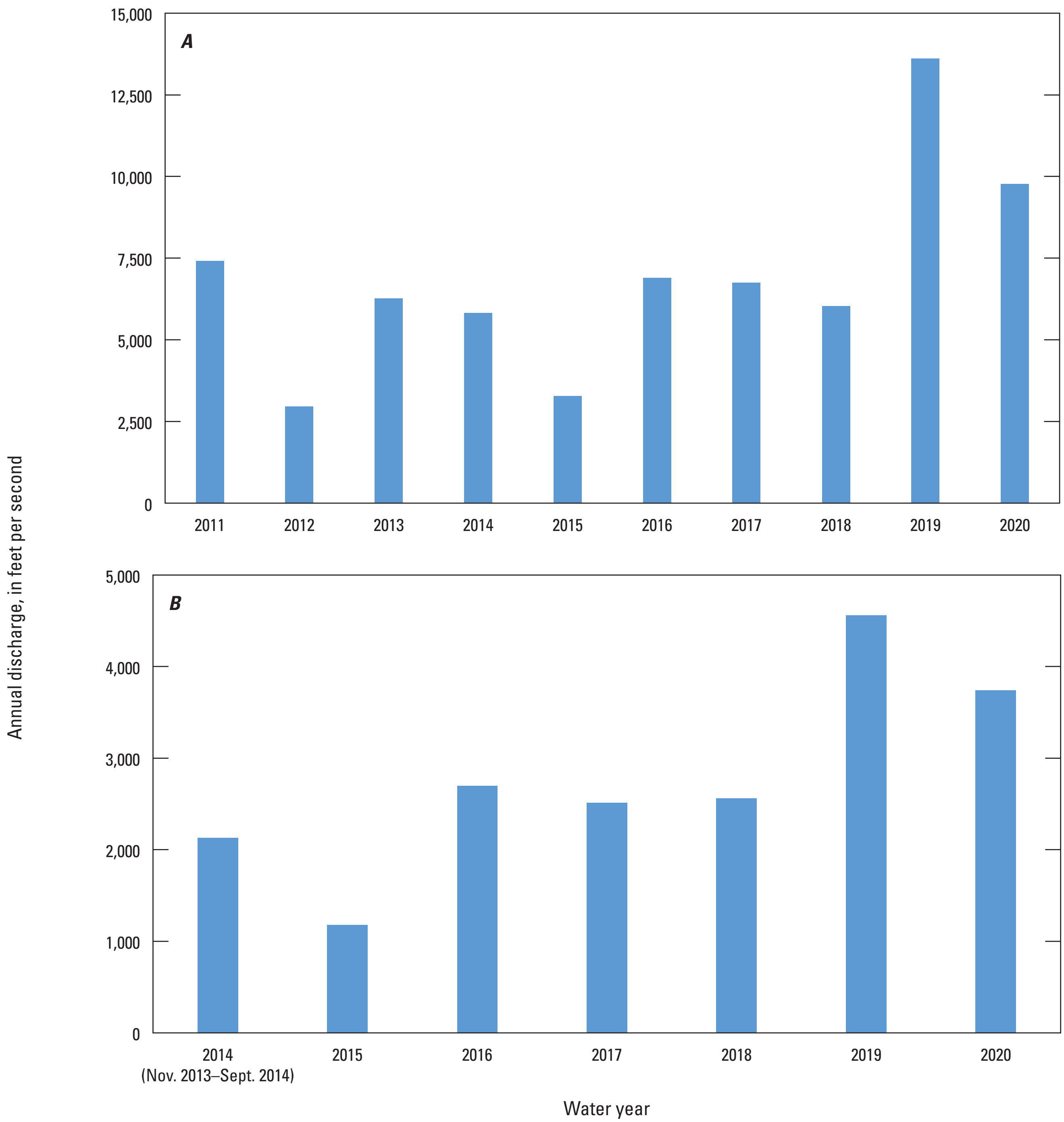

Figure 7. Annual total discharge by water year at, *A*, the mainstem Plum Creek station, water years 2011–20; and, *B*, the west Plum Creek station, partial water year 2014 and water years 2015–20.

Water Quality During the Study Period

Concentrations

TSS, TP, and DP concentrations are summarized in figures 8*A*, 8*B*, and 8*C*, respectively, for WYs 2014–20. Median TSS concentrations from all samples (event and base flow) were 283 milligrams per liter (mg/L) at mainstem Plum Creek and 134 mg/L at west Plum Creek. During base flow conditions, the median TSS concentration was significantly higher at mainstem Plum Creek (19 mg/L) compared to west (13.5 mg/L; $p<0.1$) Plum Creek. Median TP concentrations were virtually the same for both streams at 0.81 mg/L; however, the median TP concentration at mainstem Plum Creek was significantly lower during base flow when compared to west Plum Creek (TP=0.32 mg/L and 0.43, respectively; $p<0.1$; fig. 8*B*). Median DP concentrations were 1.5–1.7 times higher at west (0.39 mg/L) compared to mainstem (0.23 mg/L) Plum Creek during all flow conditions and significantly higher under base flow (0.34 mg/L versus 0.23 mg/L) as well as event flow (0.41 mg/L versus 0.23 mg/L; $p<0.1$; fig. 8*C*) conditions. Both streams had about the same median DP/TP concentration ratio for base flow samples (0.77–0.80), but the median DP/TP ratio for event samples at west Plum Creek (0.50) was more than two times that for event samples at mainstem Plum Creek (0.23). It should be noted DP was not included in further computations because it was infrequently sampled, but concentrations are used in discussion sections. Also, figure 8 can also be used by researchers to compare concentrations from previous and future reports

Loads and Yields

During WYs 2011–20, the mean annual TSS loading at mainstem Plum Creek was 9,420 tons and ranged from 2,950 tons (2015) to 13,600 tons (2019); mean annual TP loading was 35,100 pounds (lb) and ranged from 13,500 lb (2012) to 60,000 lb (2020). During WYs 2015–20, the mean annual TSS loading at west Plum Creek was 2,320 tons (excluding incomplete data from WY 2014) and ranged from 720 tons (2015) to 3,720 tons (2020); the mean annual TP loading was 13,850 lb and ranged from 4,750 lb (2015) to 20,100 lb (2020).

Mainstem and west Plum Creek mean monthly yields for flow, TSS, and TP are shown in figure 9*A* and 9*B*, respectively (the partial year of data in 2014 for west Plum Creek was included in the monthly comparisons). In general, the greatest contributions of TP and TSS happened between March and June; however, major loading events also occasionally happened in other months. The greatest mean monthly yields for flow and TP at mainstem and west Plum Creek happened in March, but there were also consistently high yields of TP and TSS in June. Yields from mainstem Plum Creek tended to be greater than those from west Plum Creek in all years.

The annual yields of flow, TP, and TSS varied by more than a factor of four among years during the study period. Record breaking precipitation from late 2018 through spring 2020 resulted in the greatest annual discharges (fig. 10*A*), TSS loads (fig. 10*B*), and TP loads (fig. 10*C*) in mainstem and west Plum Creeks during the study period. Annual TSS yields from mainstem Plum Creek were consistently greater than those from west Plum Creek. Annual TP yields from the mainstem Plum Creek ranged from 1.0 pound per acre (lb/acre) in WY 2012 to 4.4 lb/acre in WY 2020. Annual TP yields from west Plum Creek were slightly lower than the mainstem, except in 2017.

The mean annual TP yields from mainstem Plum Creek (2.6 lb/acre) and west Plum Creek (2.3 lb/acre) were greater than the median yield (0.44 lb/acre) from previously monitored streams in the Southeastern Wisconsin Till Plains ecoregion and the statewide median yield (1.0 lb/acre) from previously monitored streams (Corsi and others, 1997). The mean annual TSS yield from mainstem Plum Creek (0.69 ton/acre) and west Plum Creek (0.38 ton/acre) were greater than the statewide median yield (0.17 ton/acre) from previously monitored streams (Corsi and others, 1997). The mean annual TP and TSS yields from mainstem Plum Creek and west Plum Creek were also higher than the yields from all five agricultural streams previously monitored in the lower Fox River subbasins from 2004 to 2006 (Graczyk and others, 2012); however, as previously noted, precipitation and discharge during the study period were considerably greater than the long-term mean precipitation for this area.

Base flow Loads and Concentrations

Using the daily discharge time-series and the base flow separation function in the EcoHydRology R-package (Fuka and others, 2018), daily base flow was separated from daily discharge (essentially removing event-driven, direct runoff from the daily discharge values). The function was applied using the default parameters recommended by Nathan and McMahon (1990). On average, base flow constituted 14 percent of the total annual discharge at mainstem Plum Creek throughout the study period and 10 percent of the total annual discharge at west Plum Creek during the study period. When the base flow separation function was used on daily load data (as computed by the Graphical Constituent Loading Analysis System), it indicated that only 1 percent of the annual TSS load and 4 percent of annual TP load was attributable to base flow at mainstem Plum Creek during the study period.

Temporal Changes in Concentrations and Loads

Base Flow Changes

To evaluate changes in base flow concentrations between the initial period (WYs 2011–14 at mainstem and WYs 2014–16 at west Plum Creeks) and post-period (WYs 2019–20 at both sites), concentration values from base flow samples were compared using two-sample T-tests for each constituent (fig. 11). At mainstem Plum Creek, there was no significant change in the mean TSS concentration from the initial period to the post-CMP period, but there was a significant reduction in the mean TP concentration. At west Plum Creek, there was a statistically significant increase ($p<0.1$) in mean TSS concentrations during base flow; however, base flow TSS concentrations were typically an order of magnitude lower than TSS concentrations during events (fig. 8) and contributed little to the total loads.

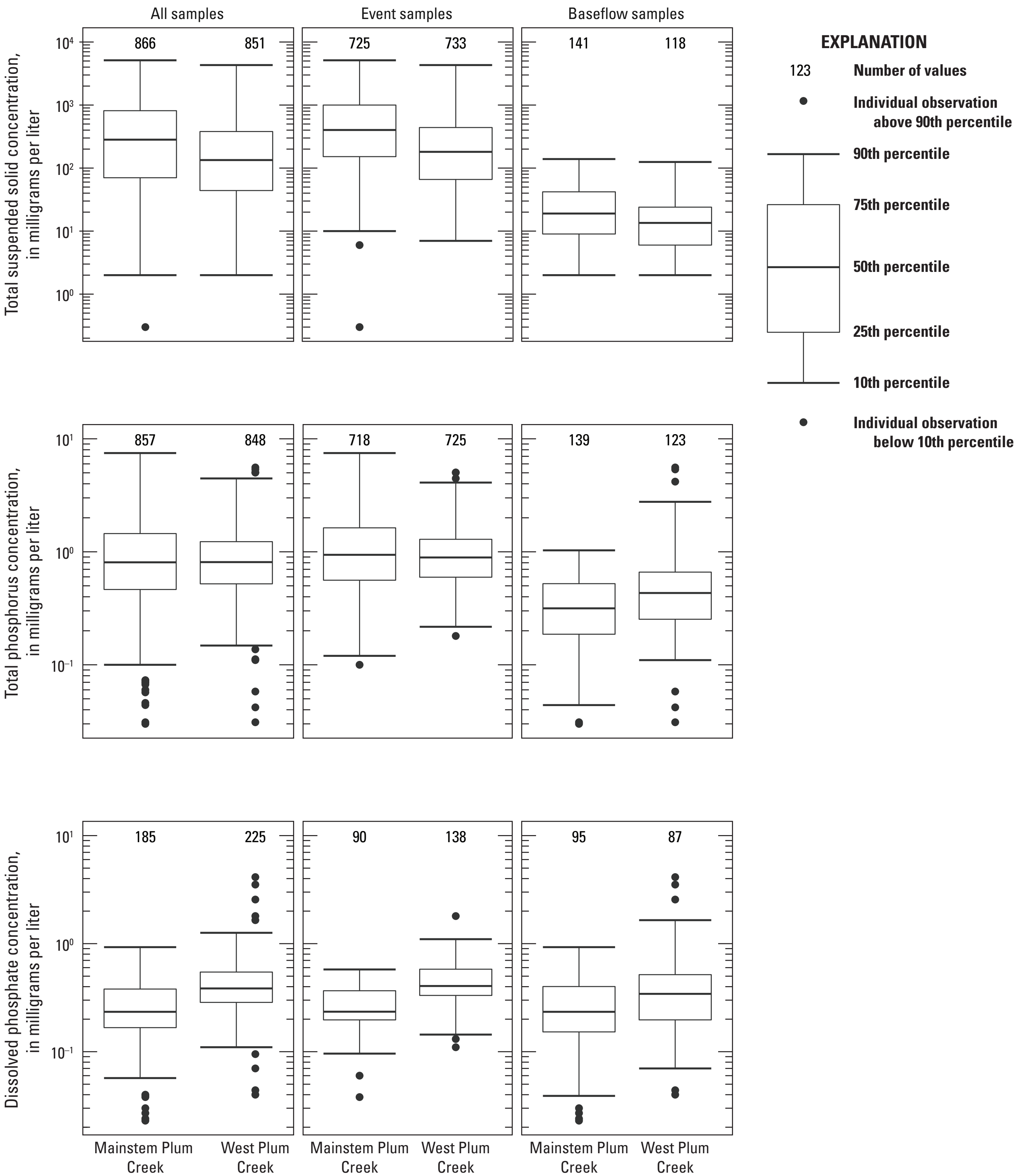

Figure 8. Comparisons of total suspended solids, total phosphorus, and dissolved phosphorus concentrations at mainstem and West Plum Creeks, during events, base flow, and all flow conditions, water years 2014–20.

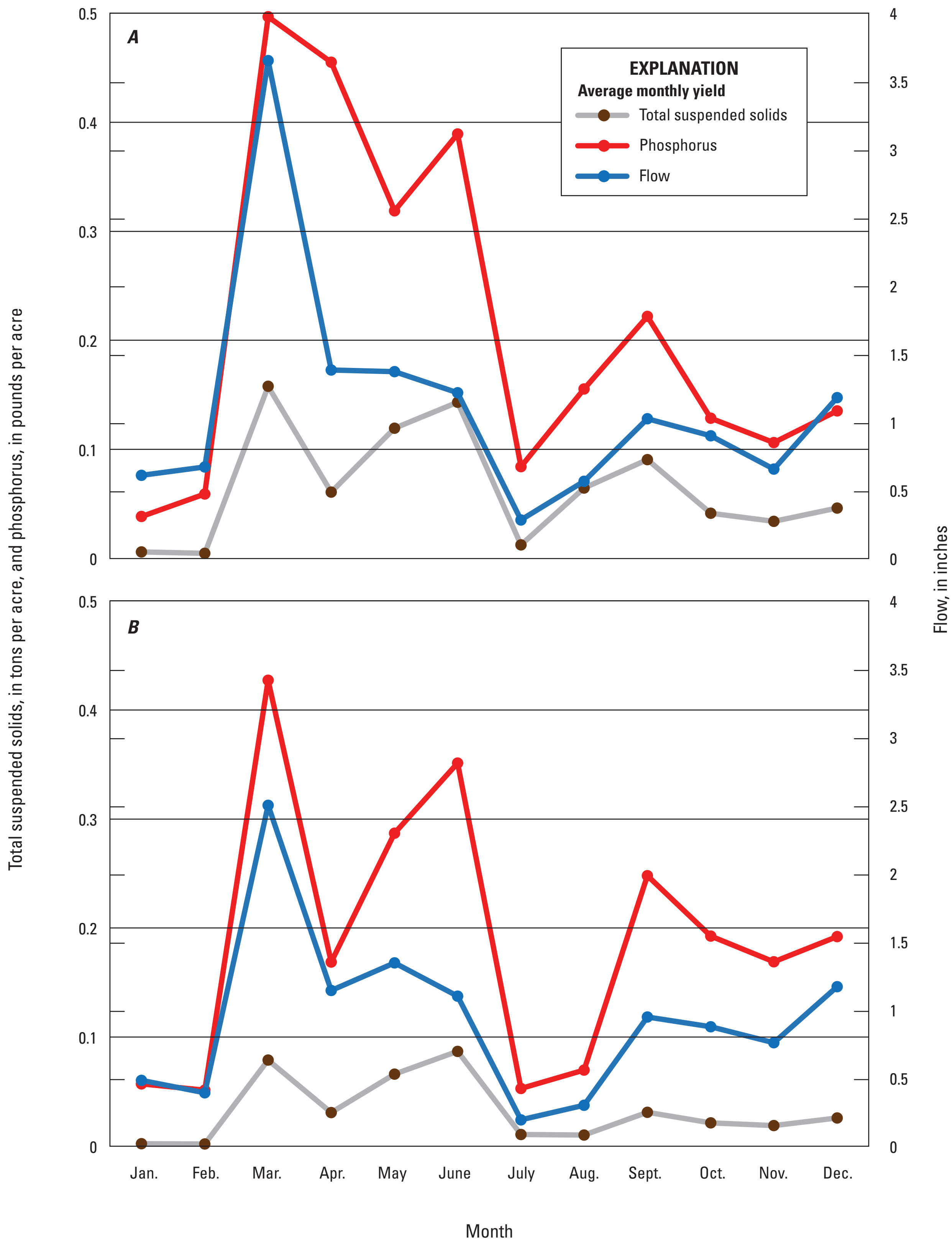

Figure 9. Average monthly (2014–20) flow, total suspended solids, and total phosphorus yields at, *A*, mainstem and, *B*, west Plum Creeks.

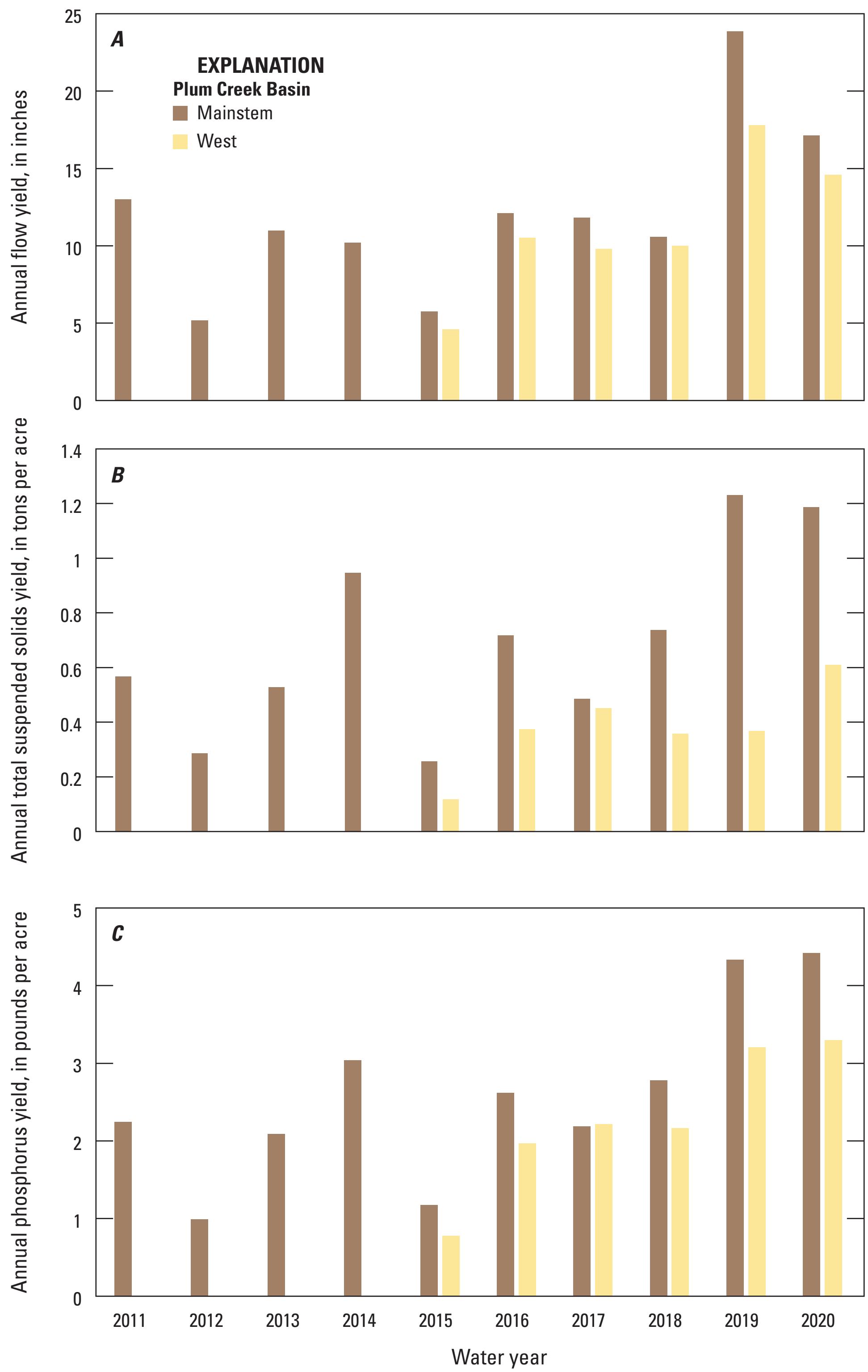

Figure 10. Annual yields of, *A*, flow, *B*, total suspended solids, and *C*, total phosphorus at mainstem Plum Creek during water years 2011–20 and west Plum Creek during water years 2015–20.

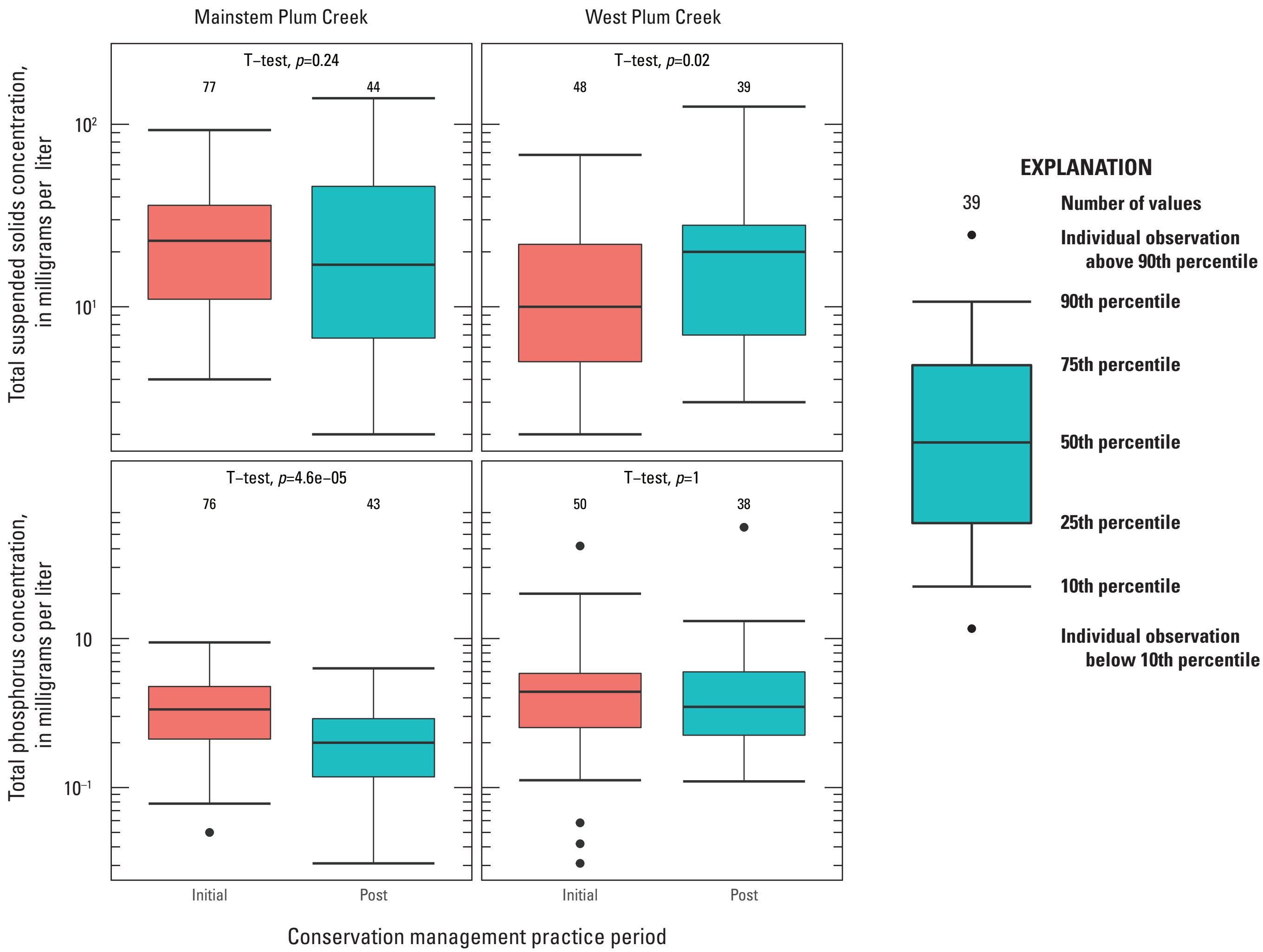

Figure 11. Comparison of total suspended solids and total phosphorus concentrations in base flow samples collected during the initial period (water years [WYs] 2011–14 at mainstem Plum Creek; WYs 2014–16 at west Plum Creek) and post-conservation management plan implementation period (WYs 2019–20 for both sites) using two-sample T-tests.

Event Load and Concentration Changes

The evaluation of water-quality changes between the initial and post-CMP implementation periods at mainstem Plum Creek included 139 events during the 10-year period; 46 events happened during the initial period (WYs 2011–14), and 39 events happened during the post-CMP implementation period (WYs 2019–20; fig. 12). After attempting to control for environmental factors, the following results were observed. At mainstem Plum Creek, the peak discharge during events increased from the initial period to the post-CMP implementation period (two-tailed T-test, p-value<0.1). TSS concentrations increased significantly during events (two-tailed T-test, p-value<0.1), but there were no statistically significant changes in TSS or TP loads during events from the initial period or post-CMP implementation period (table 4). It is important to note poorly fitting models affect the changes observed, especially in the cases of the TSS and TP concentrations results whose random-forest models explained only 26 and 18 percent of the variation, respectively (table 4). Because these models only explained about 20 percent of the variability, changes in the hydrologic and environmental conditions between the initial and post periods maintain an influence on the modeled water-quality. As a result, changes observed in water-quality responses with poorly fitting models may be attributable to factors other than focused CMP implementation. Therefore, caution should be used when evaluating results for models with poor fit.

The percent change of each response variable that changed significantly was estimated when possible; however, a lack of significance in the subsequent analyses inhibited the quantification of change estimates. An increase in peak discharges and TSS concentrations was detected, but the percent change between the two periods could not be determined for these responses due to a lack of significance for the “period” term (table 5).

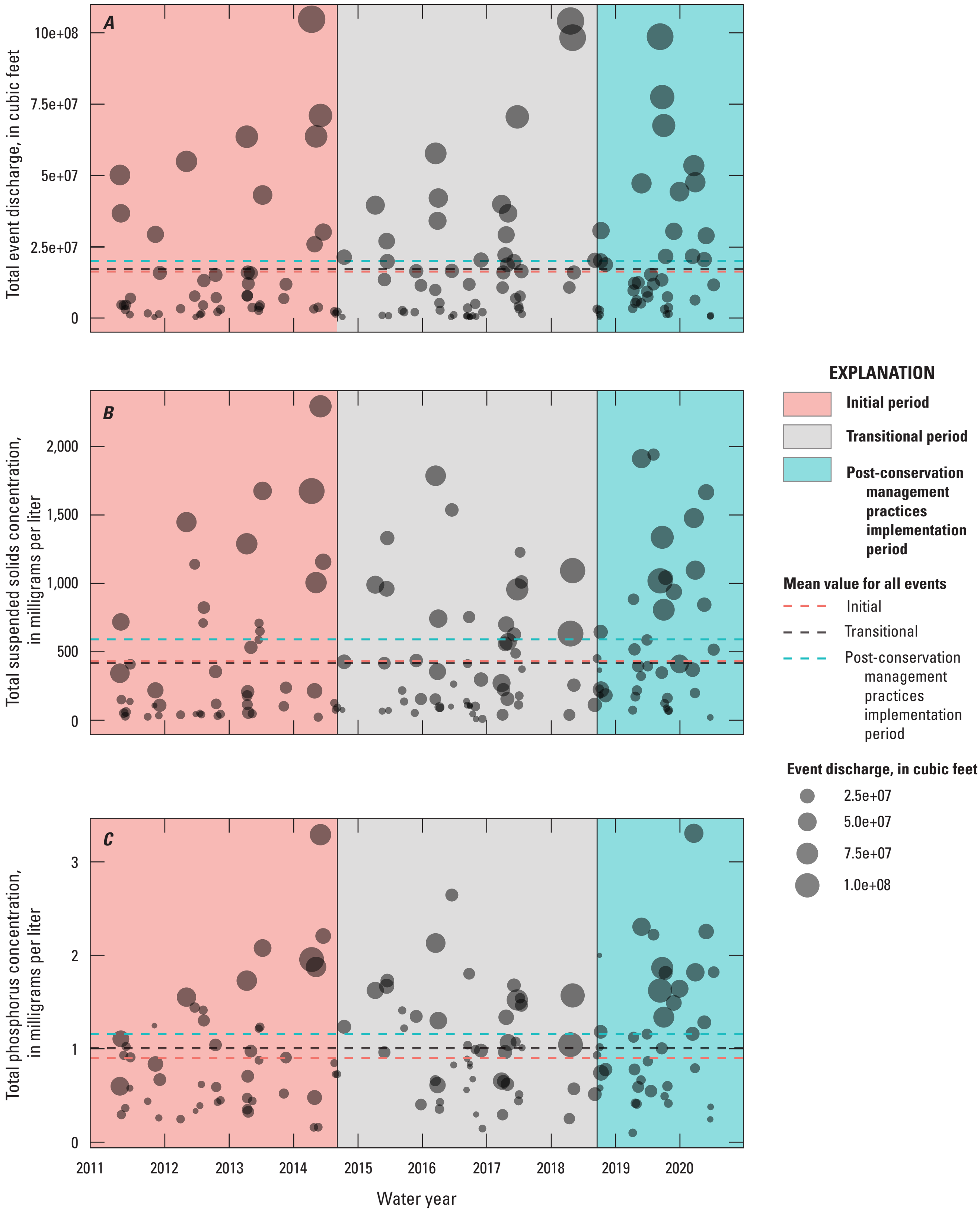

Figure 12. *A*, total discharge and, *B*, flow-weighted mean concentrations of total suspended solids, and, *C*, total phosphorus for events throughout water years 2011–20 at mainstem Plum Creek.

Table 4. Random-forest models and residual-test results for response variables from the initial period (water years 2011–14) and post-conservation management practice implementation period (water years 2019–20) at mainstem Plum Creek, Wisconsin.

[*p*-value, significance value; R^2, coefficient of determination; —, one-tailed test omitted because change was not significant; <, less than; TSS, total suspended solids; TP, total phosphorus]

Response variable	Significance of change	Two-tailed *p*-value[1]	One-tailed *p*-value	R^2	Top predictor variables (see predictor variables table)[2]
Event discharge	Not significant	0.384	—	48	Precipitation, 1-day antecedent Q (log), erosivity m1, intensity 60 min, 2-day antecedent Q (log).
Peak discharge	*p*-value<0.1 (increase)	0.028	0.014 (increase)	39.7	Precipitation, 1-day antecedent Q (log), 2-day antecedent Q (log), 3-day antecedent Q (log), erosivity m1.
TSS load	Not significant	0.124	—	37.7	Precipitation, 1-day antecedent Q (log), 2-day antecedent Q (log), erosivity m1, intensity 60 min.
TSS concentration	*p*-value<0.1 (increase)	0.085	0.043 (increase)	26.1	Precipitation, 1-day antecedent Q (log), 2-day antecedent Q (log), erosivity m1, intensity 60 min.
TP load	Not significant	0.192	—	41.5	Precipitation, 1-day antecedent Q (log), erosivity m1, intensity 60 min, 3-day antecedent Q (log).
TP concentration	Not significant	0.131	0.066	18.3	Precipitation, erosivity m1, intensity 60 min, 1-day antecedent Q (log), 14-day antecedent Q.

[1]The residual values from additional random-forest models were used to test for significant change (two-tailed *p*-value<0.1).

[2]Explanatory variables represent those most frequently selected by the initial random-forest model decision trees for each response variable.

Table 5. Multilinear regressions and percent change results for response variables with significant changes (as determined by the random-forest residual tests) from the initial period (water years 2011–14) and post-conservation management practices implementation period (water years 2019–20) at mainstem Plum Creek, Wisconsin.

[*p*-value, significance value; R^2, coefficient of determination; TSS, total suspended solids]

Response variable	*p*-value	Mean percent change[1]	Range of percent change[1]	Adjusted R^2	Model equation (see predictor variables table)[2]
Peak discharge	0.251	28	3 to 57	56.4	Peak discharge ~ precipitation + 1-day antecedent Q (log) + period[3]
TSS concentration	0.141	43	13 to 84	37.1	TSS concentration ~ precipitation + 1-day antecedent Q (log) + period[3]

[1]The binary variable indicating the initial and post-conservation management practices implementation periods was used to calculate percent change in the response. The range of percent change represents the mean percent change plus or minus the standard error associated with the period variable with the mean percent change listed in parentheses. The minimum percent change represents the mean percent change minus the standard error.

[2]Model equations represent the explanatory variables selected from additional random-forest models for the multilinear model for each response variable.

[3]Period represents a binary term added to the end of the multilinear model formula that was used to calculate percent change

Of the 116 events at west Plum Creek, 41 happened during the initial period (WYs 2014–16), and 43 happened during the post-CMP implementation period (WYs 2019–20; fig. 13). As with mainstem Plum Creek, events that happened during these two periods were compared using random-forest regressions and residual tests; however, at west Plum Creek, no statistically significant changes were detected using this approach (table 6). The random-forest models developed for west Plum Creek explained more of the variability than the models developed for mainstem Plum Creek.

To understand changes in the hydrologic conditions between the initial and post-CMP implementation periods, a comparison between precipitation, precipitation intensity (erosivity m1), and antecedent discharge (1-day antecedent Q) for the individual events was constructed (fig. 14). These predictor variables were identified as important in the regression equations (tables 4 and 6), and this analysis relied on an assumption that predictor variables would have similar distributions between each period. Despite having higher total annual precipitation amounts in the post implementation period, the precipitation and intensity of precipitation was similar for the individual events in each period; however, the

Table 6. Random-forest regressions and residual-test results for response variables from the initial period (water years 2014–16) and post-conservation management practices implementation period (water years 2019–20) at west Plum Creek, Wisconsin.

[*p*-value, significance value; R^2, coefficient of determination; —, one-tailed test omitted because change was not significant; TSS; total suspended solids; TP, total phosphorus]

Response variable	Significance of change	Two-tailed *p*-value[1]	One-tailed *p*-value	R^2	Top predictor variables (see predictor variables table)[2]
Event discharge	Not significant	0.637	—	66	1-day antecedent Q (log), precipitation, 2-day antecedent Q (log), erosivity m2, 3-day antecedent Q (log).
Peak discharge	Not significant	0.563	—	66.7	1-day antecedent Q (log), 2-day antecedent Q (log), precipitation, erosivity m2, 3-day antecedent Q (log).
TSS load	Not significant	0.742	—	60.7	1-day antecedent Q (log), 2-day antecedent Q (log), erosivity m2, precipitation, 3-day antecedent Q (log).
TSS concentration	Not significant	0.368	—	53.1	1-day antecedent Q (log), 2-day antecedent Q (log), min temp, 3-day antecedent Q (log), precipitation.
TP load	Not significant	0.966	—	56.9	1-day antecedent Q (log), erosivity m2, precipitation, 2-day antecedent Q (log), intensity 5 min.
TP concentration	Not significant	0.889	—	54.3	Season sine, 1-day antecedent Q, min temp, erosivity m2, max temp.

[1]The residual values from additional random-forest models were used to test for significant change (two-tailed *p*-value less than 0.1).

[2]Explanatory variables represent those most frequently selected by the initial random-forest model decision trees for each response variable.

antecedent discharge, which is an indicator of soil moisture, was higher for those events in the post implementation period. This highlights that despite the comparable precipitation and intensity metrics for events in both periods, streamflow was elevated at the onset of events that occurred during the post-CMP implementation period, potentially because of wetter fields and wetter antecedent conditions.

Trend Analysis

WRTDS was used to further examine the changes in concentrations and loads of TSS and TP at mainstem Plum Creek using all available water-quality data during WYs 2010–20. WRTDS analysis was only used to examine changes in the mainstem Plum Creek because this approach is best suited for sites that have been monitored for at least 10 years (Hirsch and others, 2010). WRTDS adjusts for year-to-year variability in flows when quantifying temporal changes in water quality by computing flow-normalized loads and concentrations. In other words, WRTDS computes the actual loads and concentrations in each year and the loads and concentrations that would be expected in each year if similar flows happened in all the years being examined (referred to as flow-normalized loads). Results from these analyses indicate that the flow-normalized annual loads (mass fluxes) of TSS and TP have changed very little from 2010 to 2020 (fig. 15). The 90-percent confidence interval on the flow-normalized annual loads demonstrate that there were not statistically significant (p-value<0.10) changes in the flow-normalized annual loads of TSS or TP. The lack of significant changes in the flow-normalized fluxes indicate that the increases in loads and yields shown in figure 10 were primarily caused by increases in flow rather than increases in TSS and TP concentrations.

To further examine how mean TP concentrations changed from 2010 to 2020, the mean TP concentrations for three specific flows (base flow:10th percentile, 0.042 ft^3/s; median flow: 50th percentile, 2.83 ft^3/s; and high flow: 99th percentile, 318 ft^3/s) for the midpoint of each of the four seasons were estimated with WRTDS for this period (fig. 16). Results in figure 15 suggest that TP concentrations during the highest flows (red lines) have changed very little, except during spring; however, TP concentrations during most medium (blue lines) and lower (black lines) flows may have decreased during this 10-year period. These results are consistent with those found using random-forest and regression statistics to compare the initial and post-CMP implementation periods.

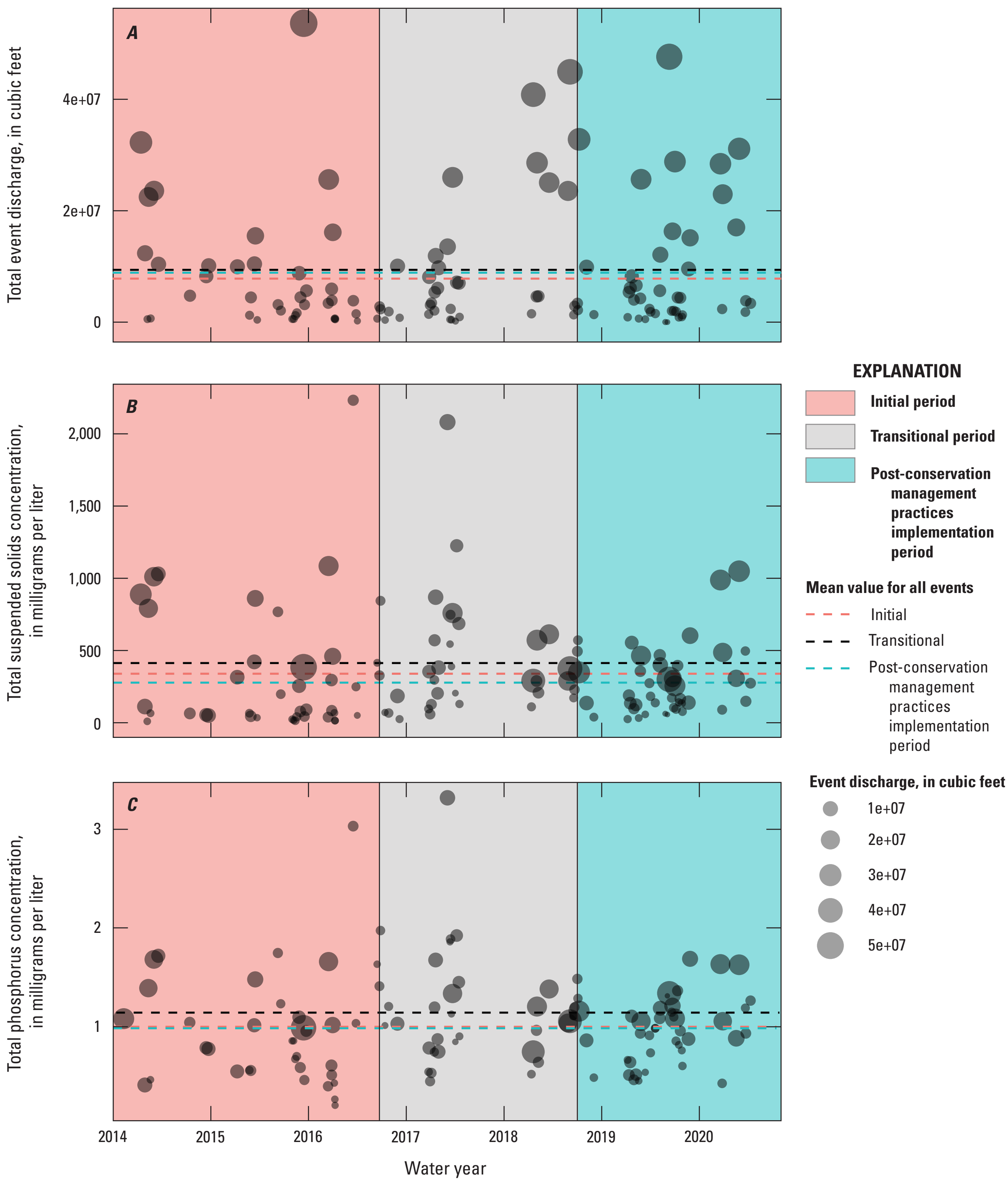

Figure 13. *A,* total discharge and, *B*, flow-weighted mean concentrations of total suspended solids, and, *C*, total phosphorus) samples for stormflow events throughout water years 2014–20 at west Plum Creek.

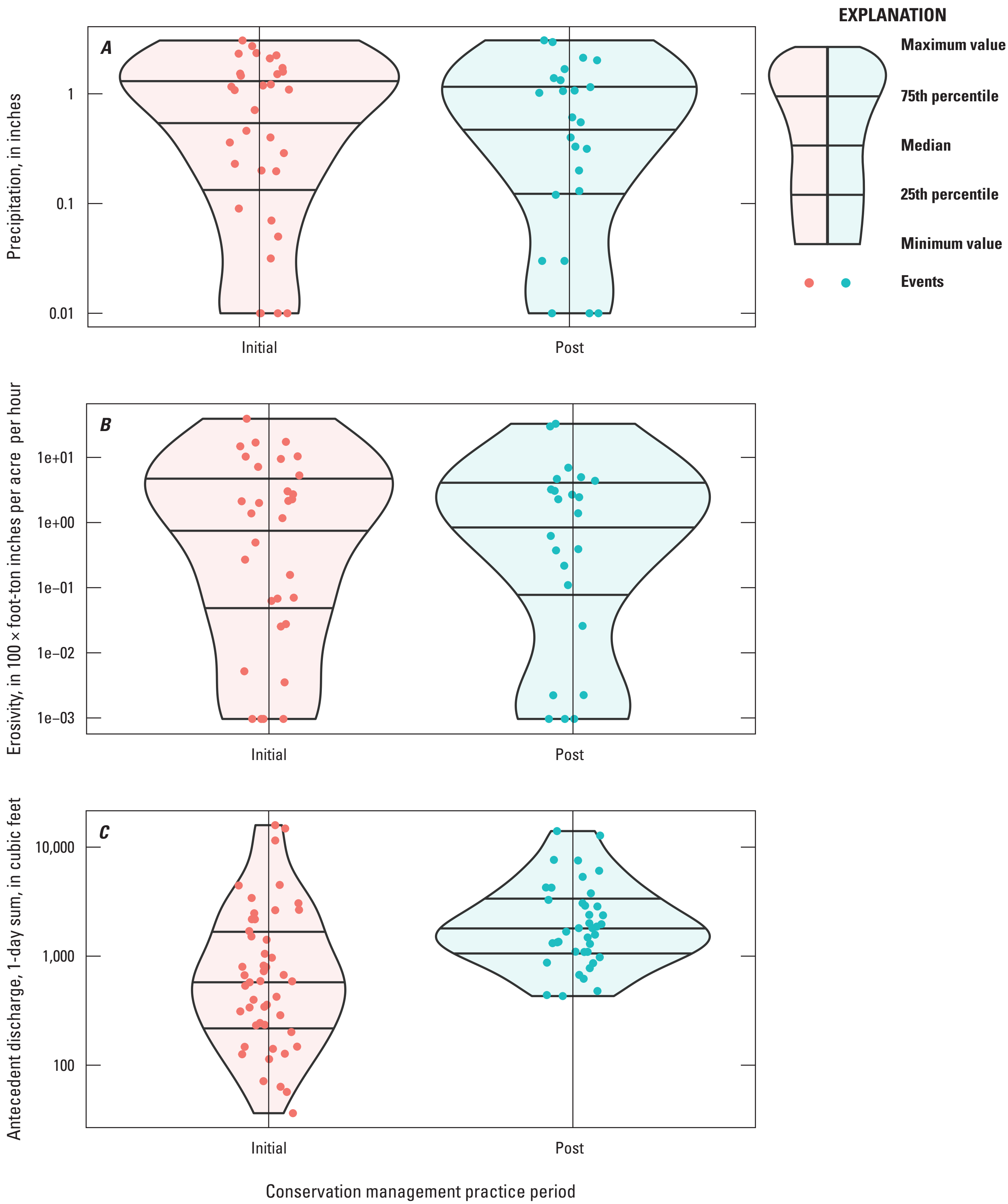

Figure 14. Event comparisons of, *A*, precipitation, *B*, erosivity, and, *C*, the 1-day sum of antecedent discharge between the initial period and post-conservation management practices period.

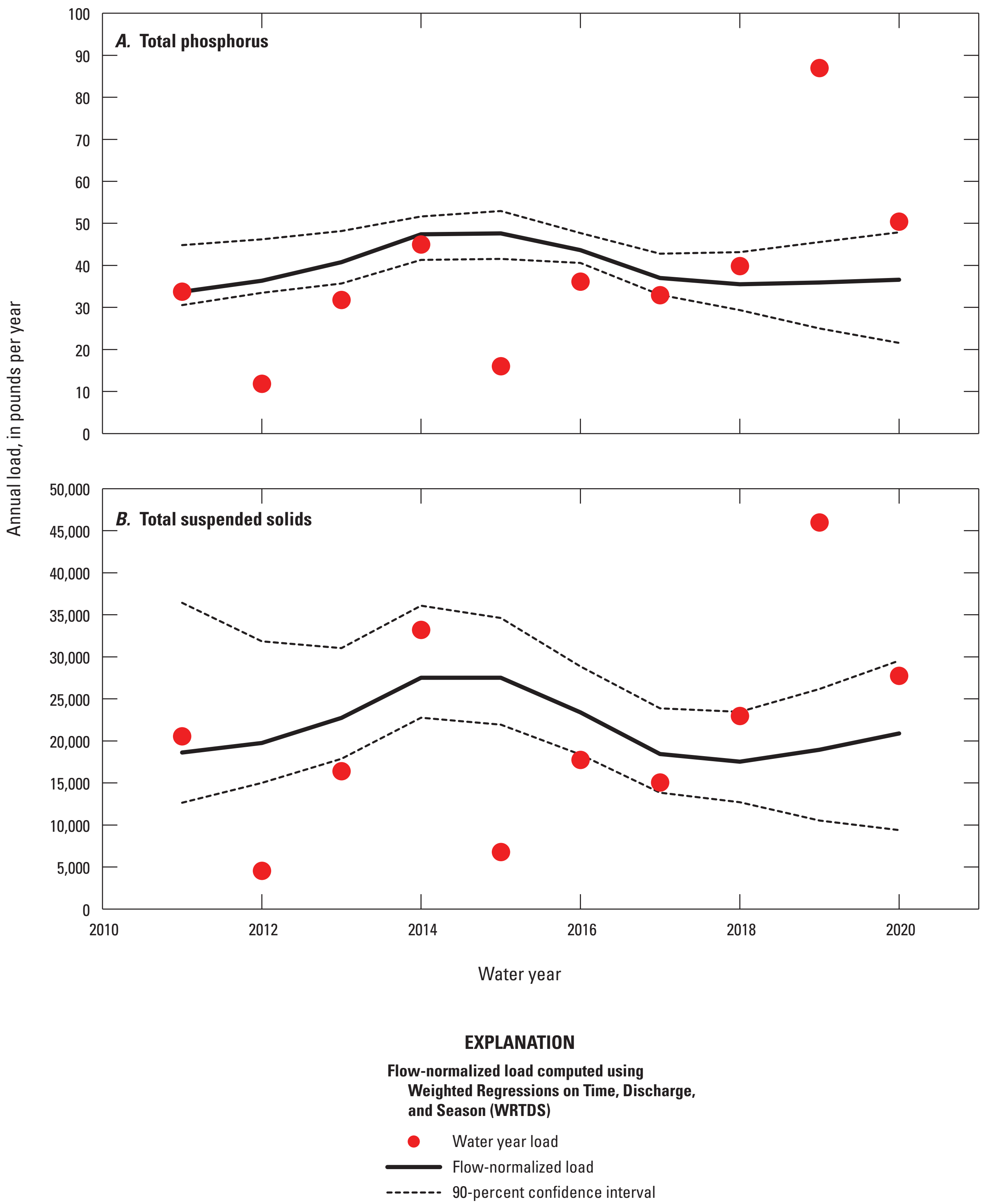

Figure 15. Flow- and nonflow-normalized annual water year loads of, *A*, total phosphorus and, *B*, total suspended solids at the mainstem Plum Creek station, Wisconsin.

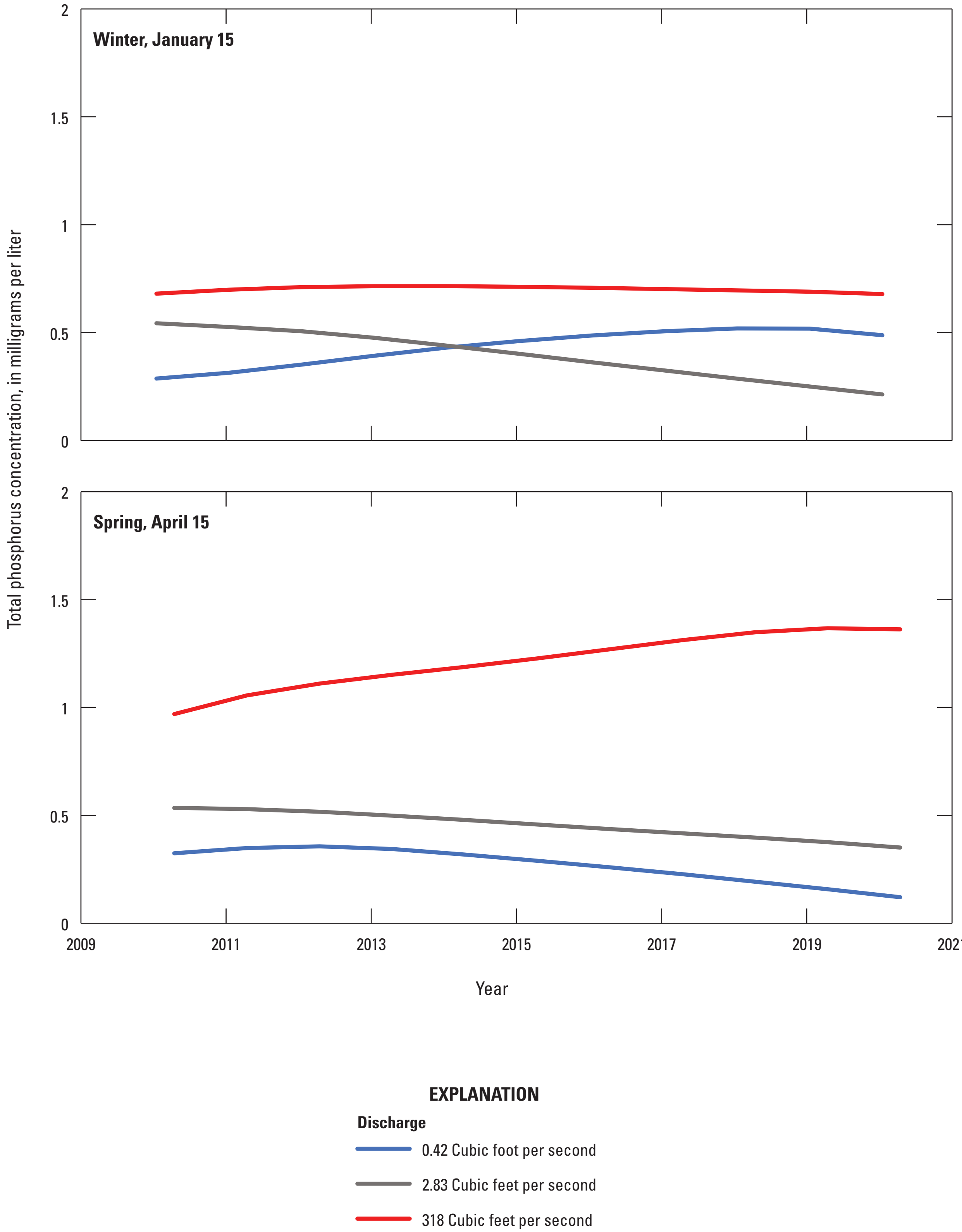

Figure 16. Changes in total phosphorus concentrations at mainstem Plum Creek, Wisconsin, for base flow, median flow, and high flow during the four seasons estimated by Weighted Regressions on Time, Discharge, and Season, water years 2011–20.

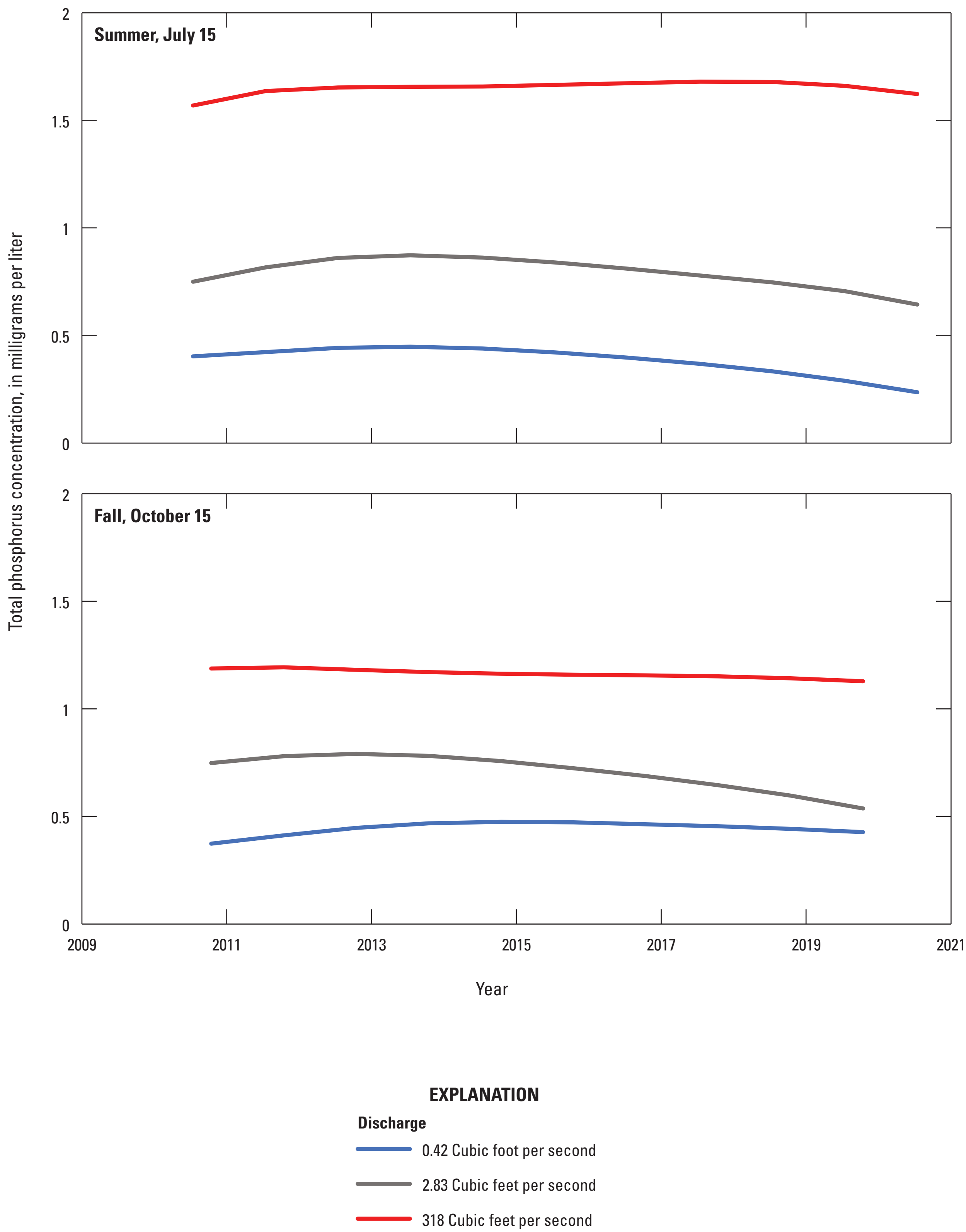

Figure 16.—Continued

Other Factors Affecting Water Quality

The cropland- and riparian-focused CMPs installed thus far (2020) in the Plum Creek Basin have not resulted in significant load reductions relative to the 2011–14 initial period of the study, even after accounting for the effects of increased precipitation. There are several factors that may explain this lack of observable water-quality improvement, including land use changes in the basin, insufficient quantity and/or efficacy of conservation cropping practices, legacy sources of phosphorus and sediment, contributions of sediment and phosphorus from streambank degradation, and hydrologic changes.

Outagamie LCD (S. Kussow and J. Freund, oral commun., 2021) acknowledged cropland protection increases during the GLRI project period, as evidenced by a decrease in the proportion of cropland with low or no cover in the mainstem basin from 2015 to 2019; however, there were no apparent improvements in soil cover from fall 2012 through September 2020, according to the minNDTI analysis (fig. 4). Several factors may account for this, including a lack of available cloud-free satellite imagery, adverse weather affecting cover crop success in some years, or changes in crop type quantities planted from year to year. For example, the greater proportion of cropland in the none/low cover category during WYs 2019–20 likely reflects poor field conditions in fall 2019 and spring 2020 following record rainfall in 2019. In addition, the potential improvements in water quality associated with land protection resulting from reduced tillage and increased cover crops may have been offset by the 10- to 15-percent increase in corn crop acres (particularly acreage of corn silage) and an equivalent reduction in acres of perennial vegetation within the monitored basins (fig. 5).

The extent and effectiveness of cropland CMPs near the end of the post implementation period was confounded by record precipitation and increased flow. The extremely wet conditions in 2019 may have hindered the success of cover crops and necessitated that farmers till their fields to repair damage from rutting caused by harvest machinery and erosion during the wet conditions in 2019 and spring 2020. The minNDTI data indicate that 64 percent of the cropland acres had no or low cover during fall 2019 through spring 2020 (fig. 4) despite similar amounts of cover crops being applied (table 3). Additionally, based on local observations and Outagamie LCD staff (S. Kussow and J. Freund, oral commun., 2021) working with farmers in the basin, agricultural tile-drain systems (installed by producers to improve agricultural field drainage for crop production) may be partially offsetting the effects of CMP implementation.

The explicit contribution of streambank erosion processes to the observed TSS and TP loads was not assessed in this study but may have had an effect. The stream inventory performed by Outagamie County LCD staff (Outagamie County Land Conservation Department, 2015) and the sediment fingerprinting study by Fitzpatrick and others (2019) indicated that streambank erosion may be a significant source of TSS and TP in Plum Creek. The steep, funnel-shaped geomorphology of mainstem Plum Creek and the large proportion of degraded stream corridor (12 of 18 mi inventoried) make the channel particularly susceptible to streambank erosion processes, especially under high-flow conditions, such as those observed during the latter part of the study period; however, the annual streamflow yield was relatively similar between the mainstem Plum Creek and west Plum Creek (fig. 10*A*). From 2015 to 2020, computed unit-area TSS loads at mainstem Plum Creek were more than two times greater than those of west Plum Creek for five of the six paired WYs (fig. 10*B*). Additionally, these differences were observed despite the basins having relatively similar proportions of crop types (table 1, fig. 5), minNDTI, and cropland CMPs, suggesting that mainstem Plum Creek may be more susceptible to TSS losses. Further modeling and mass-balance analyses may be necessary to quantify the relative magnitude of streambank sources of TSS more accurately and TP attributable to streambank degradation. Another factor to consider is that reductions in TSS and TP loads may not be observable without the implementation of CMPs designed to restore basin hydrology and improve the stability of drainage network.

Incidents of runoff with high manure inputs may have also affected our results, especially in west Plum Creek. West Plum Creek had many more samples with high TP concentrations (three to seven times greater) during base flow conditions (figs. 8 and 11) compared to the mainstem. The high TP concentrations were primarily attributable to high DP concentrations. These high TP concentrations during base flow periods may be a result of input from previous runoff events that were transported poorly and incorporated with surface-applied manure, manure from barnyards, and manure from spills or a combination of these inputs. Wisconsin Department of Natural Resources and other government agencies documented two incidents of manure spills into tributaries of west Plum Creek and three incidents of manure spills into tributaries of mainstem Plum Creek during the study period (E. Lorenzen, Wisconsin Department of Natural Resources, oral commun., 2020; S. Kussow and J. Freund, Outagamie LCD, oral commun., 2020). In addition, staff from the USGS and the University of Wisconsin–Green Bay (K. Fermanich, oral commun., 2021) observed discolored water and odor indicative of manure in samples from mainstem and west Plum Creeks on several occasions. Besides elevating TP concentrations in base flows, these incidents and other losses of manure via runoff may have affected TP concentrations and loads during events. Typically, high TP concentrations during events are associated with high TSS concentrations from erosion and transport of soil and sediment. Situations when TP concentrations are relatively high compared to TSS concentrations during events may indicate contributions of significant labile TP from manure or other sources. In an analysis of TP and TSS concentrations during events, 4–5 percent of event samples from both creeks were estimated to be influenced by high P sources, such as manure. These samples had greater than 2 mg/L of TP and TP/

TSS ratios >0.0015. The determination of the specific sources of high TP or their contributions to the total loads was not within the scope of this study.

TP concentrations in the mainstem may also have been affected by inputs from point sources during the study period. Based on information from the Wisconsin Department of Natural Resources (E. Lorenzen, written commun., 2020) during WYs 2011–20, effluent from a wastewater treatment facility about 7 mi upstream from mainstem Plum Creek sampling location exceeded permitted TP discharge limits on 57 occasions. In total, 75 effluent samples had TP concentrations >3 mg/L. These high TP concentrations may have influenced concentrations at the Mainstem station; however, it was beyond the scope of this study to fully investigate this issue because such an investigation would require a mass balance evaluation to account for water and TP contributions from all sources.

Overall, the potential positive effects of the additional CMPs applied after 2014 in mainstem Plum Creek and after 2016 in west Plum Creek were not sufficient to overcome the detrimental effects of increased rainfall, acute runoff of manure, wastewater treatment effluent, and other factors that changed in the basin. Additional CMPs are continuing to be applied throughout the Plum Creek Basin, and continued monitoring and future evaluations may enable the isolation of water-quality effects attributable to CMP implementation from other confounding factors in the basin.

Comparison of Measured Changes in Water Quality to Basin Improvement Objectives

The lower Fox River Basin TMDL states that in-stream TP and TSS concentrations must be reduced in the basin to remove in-stream water quality impairments. TP and TSS load reduction targets in the TMDL were derived using a 25-year baseline climatological period (1976–2000) that had an average annual precipitation of 29.9 in. (Wisconsin Department of Natural Resources, 2012). In contrast, the average annual precipitation recorded at the Appleton station (National Centers for Environmental Information, 2020) during the study period was 37.8 in., and annual precipitation was above the average during 8 of the 10 years and broke the long-term record in 2019. This above average precipitation resulted in high runoff as well as high TP and TSS loads, particularly in the latter part of the study period. To compare to the TMDL, monitored loads from mainstem and west Plum Creek Basins were extrapolated to the entire Plum Creek Basin by calculating area-weighted average annual TP and TSS yields. The overall annual average yields of TP and TSS were 2.56 lb/acre and 0.61 ton/acre, respectively, which were much higher than those reported by Corsi and others (1997) and Graczyk and others (2012) for other basins in Wisconsin; furthermore, these average annual TSS and TP loads were about two times larger than the baseline loads estimated in the lower Fox River and lower Green Bay TMDL for the Plum Creek Basin (Wisconsin Department of Natural Resources, 2012). It was evident that the above average precipitation and subsequent runoff contributed to the relatively large loads observed during this study as compared to the TMDL baseline estimates. In addition, part of the difference between the TMDL baseline loads and those observed in this study may be because of TSS and TP loads being underestimated in the TMDL basin model for Plum Creek and the potential effect of acute manure losses, point sources, and accelerated streambank erosion.

Summary and Conclusions

The quantity and quality of Plum Creek water discharged to the lower Fox River at Wrightstown, Wisconsin, are the cumulative result of natural and human-effected waterflows from a 35-square-mile, intensively agricultural basin draining parts of three counties. Control and reduction of sediment and phosphorus discharge from Plum Creek is a key objective of the lower Fox River and lower Green Bay total maximum daily load. In 2012, several local, State, and Federal programs and partnerships began to enhance the implementation of a variety of sediment and phosphorus runoff agricultural conservation management practices (CMPs). These CMPs included conventional practices (such as conservation tillage, nutrient management, and vegetated buffers, and others), innovative practices to plant and sustain cover crops and to reduce the effects of field manure applications on water quality (for example, low-disturbance manure injection), and new technologies to treat cropland runoff (for example, constructed wetlands). Although CMPs were implemented on thousands of acres of cropland and watercourse protections were installed on many creek miles between 2012 and 2020, CMP implementation was far from achieving the 75 percent of croplands required, according to estimates in the “Nine-Key Element” plan.

Mainstem and west Plum Creeks had considerably high median total phosphorus (TP) concentrations (0.81 milligram per liter). West Plum Creek had significantly higher dissolved phosphorus concentrations than the mainstem but had lower total suspended solids (TSS) concentrations. Potential causes for these differences include the presence of higher number of tile drains and possibly more effects of manure runoff in the west Plum Creek Basin relative to the mainstem basin and potentially greater sources of TSS and particulate phosphorus from mainstem Plum Creek channels than the west Plum Creek channels.

Flow and water-quality data collected at mainstem (water years 2011–20) and west (water years 2014–20) Plum Creek were used to assess the effects of focused implementation of agricultural CMPs. The data analysis approaches used in this study attempted to account for variability in precipitation and other hydroclimate drivers to elucidate the influence of CMP implementation on water quality at these two locations. Residual tests of random-forest model results indicated a significant increase in peak discharge and flow-weighted mean concentrations for TSS during events in the post-CMP implementation period at mainstem Plum Creek but no significant change in total event discharges, TP concentrations, TP loads, or TSS event loads. The models only explained about 20 percent of the variability in concentrations, so the detected changes in the TSS concentrations may be attributable to other hydrologic drivers. No statistically significant changes during events were detected using random-forest analyses and residual tests at west Plum Creek between the initial and post-CMP implementation periods of the 7-year dataset. Results from weighted regressions on time, discharge, and season (WRTDS) analyses for the 10-year mainstem Plum Creek dataset showed that flow-normalized loads of TP and TSS remained relatively steady despite very high precipitation from mid-2018 to spring 2020. Results from the WRTDS analyses also demonstrated that TP concentrations during moderate and low flows have decreased throughout the study period at mainstem Plum Creek. The lack of statistically significant water-quality improvements, despite focused CMP implementation in the Plum Creek Basin, may be the result of other factors, such as variability in weather and hydrologic conditions, changes in cropping practices resulting in less perennial vegetation, and increased corn cropping (particularly corn silage acres) which may have offset improvements made elsewhere in the basin.

Previous studies have shown that a reduction of 30–80 percent in median event loads may be necessary to detect a significant change given the variability that exists in Wisconsin streams. An analysis approach that evaluates only events that meet the specifications for which the installed CMPs were designed to be effective may provide insights into the real, but currently undetectable, water-quality benefits of conservation implementation in the Plum Creek Basin. Clearly, based on the results from this study, large events are substantial contributors to annual losses and losses during these events need to be mitigated through CMPs designed to be effective during large events, widespread cropland protection, and methods designed to restore and enhance the hydrologic function of the basin.

This report summarized water quality in response to basin conditions and CMPs installed between 2014 and 2020; however, CMPs are still being added to the basins and are expected to continue through 2030. Continued basin monitoring is essential to enable data analysis to better understand the multiyear effects and interplay of changing crop types, variety of conservation measures implemented, legacy sources of phosphorus and sediment, and variations in hydrologic conditions.

References Cited

American Public Health Association, 1989, Standard methods for the examination of water and wastewater (17th ed.): Washington, D.C., American Public Health Association, [variously paged].

American Public Health Association, 1992, Standard methods for the examination of water and wastewater (18th ed.): Washington, D.C., American Public Health Association,[variously paged].

Breiman, L., 2001, Random forests: Machine Learning v. 5, p. 5–32. [Also available at https://doi.org/10.1023/A:1010933404324.]

Corsi, S.R., Graczyk, D.J., Owens, D.W., and Bannerman, R.T., 1997, Unit-area loads of suspended sediment, suspended solids, and total phosphorus from small watersheds in Wisconsin: U.S. Geological Survey Fact Sheet195–97, 4 p. [Also available at https://doi.org/10.3133/fs19597.]

Corsi, S.R., Horwatich, J.A., Rutter, T.D., and Bannerman, R.T., 2013, Effects of best-management practices in Bower Creek in the East River priority watershed, Wisconsin, 1991–2009: U.S. Geological Survey Scientific Investigations Report 2012–5217, 21 p., accessed April, 12,2021, at https://pubs.usgs.gov/sir/2012/5217/.

Fitzpatrick, F.A., Blount, J.D., Kammel, L.E., Hoover, D.L., Gellis, A.C., and Eikenberry, B.C., 2019, Stream corridor sources of suspended sediment and phosphorus from an agricultural tributary to the Great Lakes: SEDHYD 2019 Proceedings, v. 4, p. 15 p. [Also available at https://pubs.er.usgs.gov/publication/70217015.]

Fuka, D.R., Walter, M.T., Archibald, J.A., Steenhuis, T.A., and Easton, Z.M., 2018, EcoHydRology—A community modeling foundation for eco-hydrology (ver. 0.4.12.1) [R package]: The Comprehensive R Archive Network web page, accessed June 12, 2020, at https://CRAN.R-project.org/package=EcoHydRology.

Graczyk, D.J., Robertson, D.M., Baumgart, P.D., and Fermanich, K.J., 2012a, Hydrology, phosphorus, and suspended solids in five agricultural streams in the lower Fox River and Green Bay watersheds, Wisconsin, water years 2004–06: U.S. Geological Survey Scientific Investigations Report 2011–5111, 28 p. [Also available at https://pubs.usgs.gov/sir/2011/5111/.]

Hirsch, R.M., and De Cicco, L.A., 2015, User guide to Exploration and Graphics for RivEr Trends (EGRET) and dataRetrieval—R packages for hydrologic data (version 2.0, February 2015): U.S. Geological Survey Techniques and Methods, book 4, chap. A10, 93 p. [Also available at https://doi.org/10.3133/tm4A10.]

Hirsch, R.M., Moyer, D.L., and Archfield, S.A., 2010, Weighted Regressions on Time, Discharge, and Season (WRTDS), with an application to Chesapeake Bay River inputs: Journal of the American Water Resources Association, v. 46, no. 5, p. 857–880. [Also available at https://doi.org/10.1111/j.1752-1688.2010.00482.x.]

Jacobson, M.D., 2012, Phosphorus and sediment runoff loss—Management challenges and implications in a northeast Wisconsin agricultural watershed: University of Wisconsin–Green Bay. M.S. thesis 107 p., accessed April 12, 2023, at https://www.uwgb.edu/UWGBCMS/media/Watershed-Monitoring-Program/reports/thesis/Jacobson-Marty_UWGB-Thesis_August2012.pdf.

Koltun, G.F., Eberle, C.M., Gray, J.R., and Glysson, G.D., 2006, User's manual for the Graphical Constituent Loading Analysis System (GCLAS): U.S. Geological Survey Techniques and Methods, book 4, chap. C1, 51 p., accessed November 11, 2011, at https://github.com/USGS-R/USGSHydroTools.

Laboski, C.A.M., and Peters, J.B., 2012, Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin: University of Wisconsin-Extension Publication A2809, 88 p.

Lee, C.J., Hirsch, R.M., Schwarz, G.E., Holtschlag, D.J., Preston, S.D., Crawford, C.G., and Vecchia, A.V., 2016, An evaluation of methods for estimating decadal stream loads: Journal of Hydrology, v. 542, p. 185–203. [Also available at https://doi.org/10.1016/j.jhydrol.2016.08.059.]

McGregor, K.C., Binger, R.L., Bowie, A.J., and Foster, G.R., 1995, Erosivity index values for northern Mississippi: Transactions of the ASAE. American Society of Agricultural Engineers, v. 38, p. 1039–1047. [Also available at https://www.researchgate.net/profile/Ron-Bingner/publication/279892111_Erosivity_Index_Values_for_Northern_Mississippi/links/5970ab430f7e9bb1f4b92a06/Erosivity-Index-Values-for-Northern-Mississippi.pdf.]

Nathan, R.J., and McMahon, T.A., 1990, Evaluation of automated techniques for base flow and recession analysis: Water Resources Research, v. 26, no. 7, p. 1465–1473. [Also available at https://doi.org/10.1029/WR026i007p01465.]

National Centers for Environmental Information, 2020, Climate Data Online search [Normals annual/seasonal dataset, 2011–2020, Appleton, Wis., station]: National Oceanic and Atmospheric Administration, National Centers for Environmental Information database, accessed September 12, 2020, at https://www.ncdc.noaa.gov/cdo-web/search.

National Oceanic and Atmospheric Administration, 2020, Climate Data Online: National Oceanic and Atmospheric Administration, National Centers for Environmental Information database, accessed October 2010 at http://www.ncdc.noaa.gov/oa/ncdc.html. [Database moved by time of publication; accessed April 14, 2023, at https://www.ncdc.noaa.gov/cdo-web/.]

Outagamie County Land Conservation Department, 2015, Nonpoint source implementation plan for the Plum and Kankapot Creek watersheds: Outagamie County Land Conservation Department, digital data. [Also available at https://dnr.wisconsin.gov/topic/Nonpoint/9keyElement/planMap.html.]

Pronschinske, M.A., Horwatich, J.A., Loken, L.C., and Komiskey, M.J., 2023, Water quality and estimated changes in the Plum Creek watershed 2010–2020 (data release and model archive): U.S. Geological Survey data release, https://doi.org/10.5066/P92A0H98.

Sharpley, A.N., McDowell, R.W., and Kleinman, J.A., 2001, Phosphorus loss from land to water—Integrating agricultural and environmental management: Plant and Soil, v. 237, p. 287–307.

U.S. Department of Agriculture Natural Resources Conservation Service Soil Survey Staff, 2020a, Soil Survey Geographic (SSURGO) database for [Outagamie, Brown, and Calumet Counties, Wisconsin]: Natural Resources Conservation Service database, accessed August 17, 2021, at https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm.

U.S. Department of Agriculture Natural Resources Conservation Service Soil Survey Staff, 2020b, Web Soil Survey: Natural Resources Conservation Service database, accessed August 17, 2021, at https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm.

U.S. Department of Agriculture Natural Resources Conservation Service Soil Survey Staff, 2020c, Gridded National Soil Survey Geographic (gNATSGO) database for conterminous United States: Natural Resources Conservation Service database, accessed April 29, 2021, at https://nrcs.app.box.com/v/soils.

U.S. Department of Agriculture, 2021, CropScape—Cropland data layer: National Agricultural Statistics Service database, accessed April 20, 2021, at https://nassgeodata.gmu.edu/CropScape/. [Cropland data layers from 2011 to 2020 were accessed.]

U.S. Environmental Protection Agency [EPA], 1991, Guidance for water quality-based decisions—The TMDL process: Washington, D.C., U.S. Environmental Protection Agency, Office of Water, accessed April 22, 2021 at https://www.epa.gov/sites/default/files/2018-10/documents/guidance-water-tmdl-process.pdf.

Wisconsin Department of Natural Resources, 2001, Lower Fox River Basin integrated management plan: Wisconsin Department of Natural Resources, Publication Wt–666–2001, [variously paged]. [Also available at https://dnr.wi.gov/water/basin/lowerfox/lowerfox.pdf.]

Wischmeier, W.H., and Smith, D.D., 1978, Predicting rainfall erosion losses—A guide to conservation planning: U.S. Department of Agriculture, Agriculture Handbook 537, 58 p. [Also available at https://naldc.nal.usda.gov/download/CAT79706928/PDF.]

Wisconsin Department of Natural Resources, 2012, Total maximum daily load and watershed management plan for total phosphorus and total suspended solids in the lower Fox River Basin and lower Green Bay: Wisconsin Department of Natural Resources, [variously paged].

Wisconsin Department of Natural Resources, 2021, Wisconsin's Nonpoint Source Program management plan FY 2021–2025: Wisconsin Department of Natural Resources, 110 p. [Also available at https://dnr.wisconsin.gov/sites/default/files/topic/Nonpoint/NPSProgramManagementPlan20212025.pdf.]

Wisconsin Department of Natural Resources, 2022, Celebrating the 50th anniversary of the Clean Water Act: Wisconsin Department of Natural Resources web page, accessed November 2022 at https://dnr.wisconsin.gov/topic/SurfaceWater/CWA50th.

Zheng, B., Campbell, J.B., and de Beurs, K.M., 2012, Remote sensing of crop residue cover using multi-temporal Landsat imagery: Remote Sensing of Environment, v. 117, p. 177–183. [Also available at https://doi.org/10.1016/j.rse.2011.09.016.]

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