

Prepared in cooperation with the City of Cedar Rapids

## Total Phosphorus Loadings for the Cedar River at Palo, Iowa, 2009–20



Scientific Investigations Report 2021–5127

**Cover:** Photograph showing Cedar River at Palo, Iowa, during low streamflow on September 19, 2017.

**Back cover:** Photographs showing (top) Cedar River at Palo, Iowa, with continuous water-quality sensors during flood on September 26, 2016, and (bottom) Cedar River at Palo, Iowa, with continuous water-quality sensors during low-flow conditions on September 19, 2017.

Photographs by Stephen J. Kalkhoff, U.S. Geological Survey.

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By Jessica D. Garrett

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

## U.S. Geological Survey, Reston, Virginia: 2021

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## Contents

Acknowledgments .....	iii
Abstract .....	1
Introduction .....	1
Purpose and Scope .....	3
Site Information .....	3
Methods for Data Collection and Computation .....	3
Continuous Water-Quality Data Collection and Computation .....	3
Water Sample Collection and Analysis .....	3
Methods for Computation of Concentrations and Loads .....	4
Water-Quality Sample and Sensor Data .....	4
Continuous Water-Quality Time-Series Data to Compute Nutrient Loadings .....	7
Total Phosphorus Models .....	7
Total Phosphorus Concentrations, Loads, and Yields .....	9
Summary .....	13
References Cited .....	14

## Figures

1. Map showing selected U.S. Geological Survey streamflow-gaging, nutrient, and turbidity monitoring station study sites in the Cedar River Basin in Iowa .....	2
2. Graphs showing duration curves with calibration samples, Cedar River at Blairs Ferry Road at Palo, Iowa .....	6
3. Graphs showing sampled and estimated total phosphorus values for four models, Cedar River at Blairs Ferry Road at Palo, Iowa .....	9
4. Graph showing annual total phosphorus loads relative to phosphorus-reduction benchmark and 45-percent reduction goal .....	12
5. Graph showing the relation between annual runoff and total phosphorus yield from the Cedar River at Blairs Ferry Road at Palo, Iowa .....	13

## Tables

1. Summary of calibration samples and time-series data, Cedar River at Blairs Ferry Road at Palo, Iowa .....	5
2. Total phosphorus concentration regression models, Cedar River at Blairs Ferry Road at Palo, Iowa .....	8
3. Summary of total phosphorus concentrations, loads, and yields for the Cedar River at Blairs Ferry Road at Palo, Iowa .....	10

## Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
Area		
square mile (mi <sup>2</sup> )	259.0	hectare (ha)
square mile (mi <sup>2</sup> )	2.590	square kilometer (km <sup>2</sup> )
Flow rate		
cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second (m <sup>3</sup> /s)
ton per day (ton/d)	0.0105	kilogram per second (kg/s)
ton per year (ton/yr)	$2.8747 \times 10^{-5}$	kilogram per second (kg/s)
Mass		
ton, short (2,000 lb)	0.9072	metric ton (t)
Yield		
pound per acre per year (lb/acre/yr)	112.1	kilogram per square kilometer per day (kg/km <sup>2</sup> /d)
pound per square mile per day (lb/mi <sup>2</sup> /d)	0.17515	kilogram per square kilometer per day (kg/km <sup>2</sup> /d)

## Supplemental Information

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

Turbidity is given in formazin nephelometric units (FNU).

## Abbreviations

LOADEST LOAD ESTimator

log logarithm

$R^2$  coefficient of determination

USGS U.S. Geological Survey

WRTDS Weighted Regressions on Time, Discharge, and Season

< less than



# Total Phosphorus Loadings for the Cedar River at Palo, Iowa, 2009–20

By Jessica D. Garrett

## Abstract

In support of nutrient reduction efforts, total phosphorus loads and yields were computed using turbidity-surrogate and LOAD ESTimator (LOADEST) models for the Cedar River at Palo, Iowa, for January 1, 2009, to December 15, 2020. Sample data were used to create a total phosphorus concentration turbidity-surrogate model. Total phosphorus loads also were computed from two streamflow-based LOADEST load models for the periods 2009–20 and 2016–20. The 2009–20 model was used for comparison with previously published loads at this site. The 2016–20 LOADEST model was used with the turbidity-surrogate model before sensor deployment and during periods of missing sensor data to obtain a more complete annual total phosphorus load. This report presents computed loads and methods needed to compute site-specific loads accurately and track annual progress toward nutrient reduction goals within the State.

A comparison of loads from Weighted Regressions on Time, Discharge, and Season; LOADEST; and surrogate models indicated substantial differences at this site among these methods. Changes in both monitoring approaches (high-frequency sensor and surrogate data) and changes in load-calculation methods present potential challenges in assessing trends, such as assessment of load reduction.

Annual total phosphorus loads for the Cedar River at Palo, Iowa, ranged from 1,370 to 2,360 U.S. short tons per year for 2018–20, based on the turbidity-surrogate model with gaps in sensor data filled with the 2016–20 LOADEST model. Annual total phosphorus yields for the Cedar River ranged from 0.67 to 1.16 pounds per acre per year for 2018–20. Although this load estimate is lower than previous estimates for the benchmark period of 2006–10, when normalized by streamflow, nearly all the apparent reduction can be attributed to differences in the load-calculation methods.

## Introduction

The U.S. Geological Survey (USGS) and the City of Cedar Rapids cooperatively studied total phosphorus loads in the Cedar River at Blairs Ferry Road at Palo, Iowa (USGS

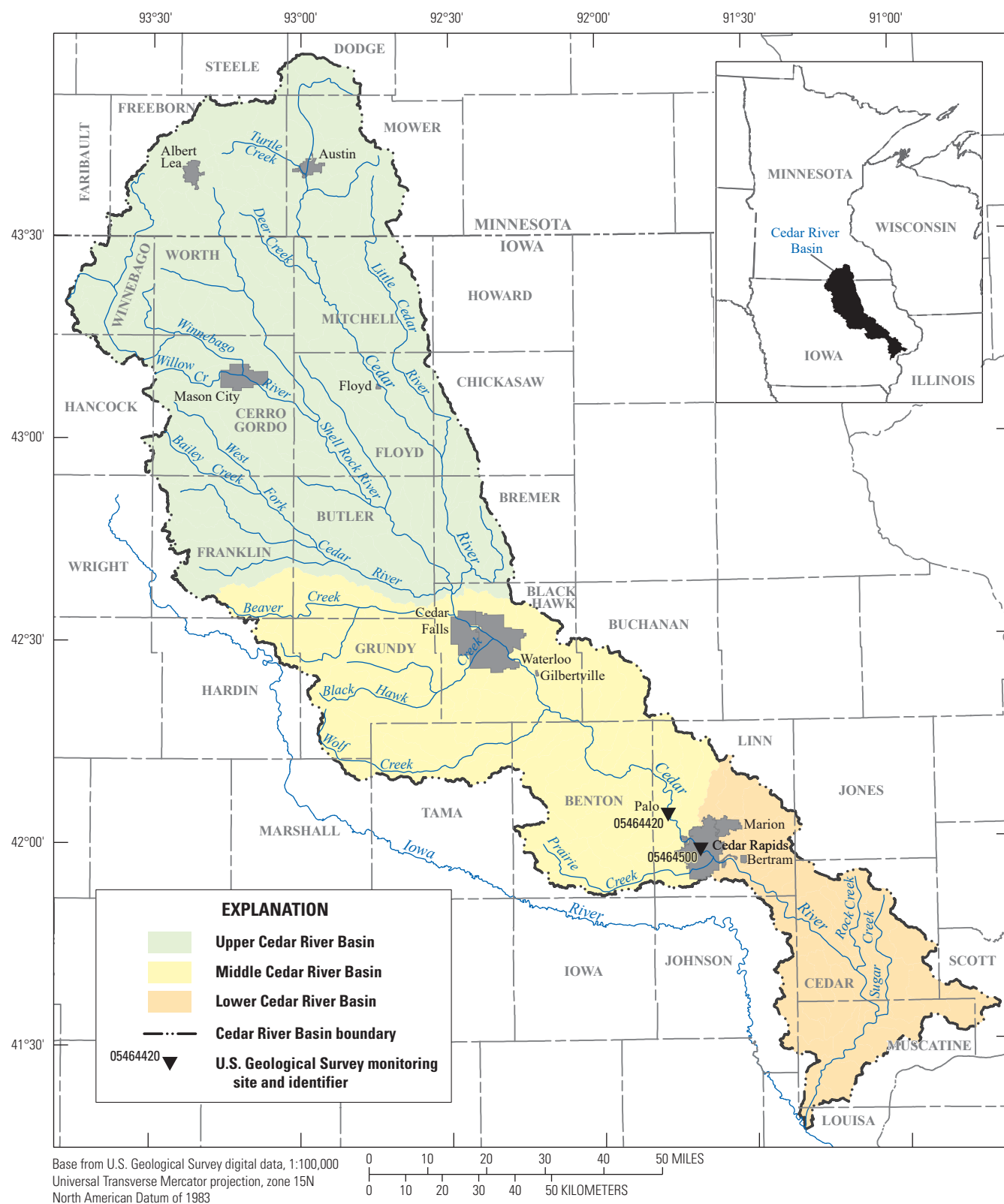
station 05464420), hereafter referred to as “Cedar River at Palo, Iowa” (fig. 1). The Cedar River is used for recreation, cooling water, as a drinking water supply, and as a receiving body for permitted discharges; however, the Cedar River and nearby rivers have been identified as large contributors of nutrient loads (nitrogen and phosphorus). These high nutrient levels cause eutrophication of local and downstream waterbodies (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, 2017; Iowa Department of Agriculture and Land Stewardship and others, 2019).

The nutrient reduction strategy in Iowa (Iowa Department of Agriculture and Land Stewardship and others, 2019), as in other Midwest States (Minnesota Pollution Control Agency, 2014; Ohio Environmental Protection Agency and others, 2016; Illinois Environmental Protection Agency and others, 2019), calls for large reductions in nutrient loads. The total phosphorus-reduction goal in Iowa is 45 percent, using the period 1980–96 as the baseline, although initial estimates for the nutrient reduction strategy in Iowa were based on a baseline period of 2000–6 because of greater data availability.

Load-calculation methods based on streamflow and periodic (weekly to monthly) samples using programs such as LOAD ESTimator (LOADEST) or Weighted Regressions on Time, Discharge, and Season (WRTDS) may be able to detect such large changes but may not be accurate enough to assess interim progress toward load reduction goals; load-calculation estimation errors can be substantial, particularly for total phosphorus and other constituents with a strongly positive or logarithmic- (log-) curvilinear relation between concentration and streamflow (Hirsch, 2014; Lee and others, 2016). LOADEST and WRTDS can be applied consistently across large scales to assess regional patterns (Aulenbach and others, 2007; Robertson and others, 2009), but more accurate methods are needed locally to compute site-specific loads and track annual progress toward nutrient reduction goals (Jones and others, 2018; Iowa Department of Agriculture and Land Stewardship and others, 2019).

Surrogates use indirect data intended to provide information about a parameter that is difficult to measure directly, but the association between the surrogate and the parameter of interest is often direct or uncomplicated. Several studies have determined that turbidity can be a good predictor for total phosphorus concentration, that additional parameters associated with dissolved constituents can improve turbidity-based

## 2 Total Phosphorus Loadings for the Cedar River at Palo, Iowa, 2009–20



**Figure 1.** Selected U.S. Geological Survey streamflow-gaging, nutrient, and turbidity monitoring station study sites in the Cedar River Basin in Iowa.

models, and that site specificity is important (Christensen and others, 2006; Rasmussen and others, 2009; Schaepe and others, 2014; Schilling and others, 2017).

## Purpose and Scope

The purpose of this report is to describe the models developed to compute a time series of concentrations and loads of total phosphorus for the Cedar River at Palo, Iowa (USGS station 05464420), for the period beginning in 2009 and to summarize resulting concentrations, loads, and yields. The models are based on empirical statistical regression between turbidity sensor measurements or streamflow and sample results (Garrett, 2019).

Continuous sensor data, streamflow, and sample results are summarized, and regression models and modeled continuous (15-minute or daily interval) data are presented for the Cedar River near Palo, Iowa, for January 1, 2009, to December 15, 2020. Also, the turbidity-surrogate model can be used to compute ongoing total phosphorus concentrations and loads. Continuous turbidity data are summarized through the deployment period beginning August 8, 2018, including a range of seasonal and streamflow event conditions. Sample concentration data for orthophosphate and total phosphorus are presented. Statistical regression models relating turbidity sensor data and sample results are described, including information on model selection and diagnostic procedures. The models and methods presented in this report can be used to compute ongoing time-series total phosphorus concentrations and loads to monitor changes in total phosphorus concentrations and loads in the Cedar River at Palo, Iowa.

## Site Information

Water-quality samples and turbidity data summarized in this report were collected from the Cedar River at Palo, Iowa (fig. 1). This site with a drainage area of 6,342 square miles is collocated with an existing streamflow-gaging station. Mean annual runoff for the selected site is 15.7 inches for the period of streamflow record, which includes water years 2009–20 (U.S. Geological Survey, 2021). A water year is defined as the 12-month period from October 1 to September 30 and is designated by the year in which it ends. Annual runoff for water years 2018–20 was higher than the mean annual runoff for 2009–20, concurrent with deployment of the turbidity sensor, with a range of 18.3–22.8 inches (U.S. Geological Survey, 2021). Water-quality sensor data available at this site include continuous temperature and nitrate concentration beginning October 2012, and specific conductance, dissolved oxygen, and turbidity beginning August 2018.

## Methods for Data Collection and Computation

Instream sensors were used to record turbidity at 15-minute intervals beginning March 2018 at the Cedar River at Palo, Iowa. Discrete water samples from August 2018 to October 2020, concurrent with sensor data, were used for calibration of the turbidity-based total phosphorus concentration model. Discrete water samples collected from April 2009 to October 2020 were used for the calibration of streamflow-based LOADEST models to calculate loads before sensor deployment and to fill periods of missing turbidity data. LOADEST models were fitted using data from two periods: 2009–20 and 2016–20.

## Continuous Water-Quality Data Collection and Computation

Turbidity was monitored using a YSI EXO turbidity sensor (YSI, 2020) in formazin nephelometric units. The EXO sonde including the turbidity sensor was installed in a protective polyethylene pipe suspended from the bridge.

Field inspections of water-quality sensors and data processing followed methods described by Anderson (2005) and Wagner and others (2006). Turbidity standards and deionized water (turbidity free) were used before and after deployment and in the field to detect calibration changes. Cross-sectional data were collected to document general mixing of the stream and to verify data collected at the sensor location represented conditions throughout the channel. Mixing was documented by measuring multiple cross-channel readings of water temperature, specific conductance, pH, dissolved oxygen, and turbidity with a multiparameter sonde. Additionally, samples collected at the deployed sensor location were compared with flow-integrated cross-channel samples.

## Water Sample Collection and Analysis

Discrete water sample data include long-term routine monitoring and targeted samples for 2009–20, the period of available streamflow data for the Cedar River at Palo, Iowa. Discrete water samples were collected monthly from September 2016 to October 2020 and during targeted conditions, such as high streamflow. Monthly samples followed USGS procedures for flow-integrated sample collection and processing described by the USGS “National Field Manual for the Collection of Water-Quality Data” (U.S. Geological Survey, variously dated). A second sample concurrent to the flow-integrated monthly sample was collected from a single cross-section location at the sensor. Targeted samples were collected from a single cross-section location. Concurrent flow-integrated samples were used to assess channel mixing, but only one sample per day was used in the model calibration sets, with preference given to the flow-integrated sample.

Samples were analyzed for total phosphorus by the USGS National Water Quality Laboratory in Lakewood, Colorado (Fishman, 1993; O'Dell, 1993; Patton and Kryskalla, 2003). Additional sample data for 2001–14 are described by Kalkhoff (2018), including data from long-term monitoring completed by the Iowa Department of Natural Resources (Iowa Department of Natural Resources, 2020) and synoptic Cedar River Basin studies completed by the USGS (U.S. Geological Survey, 2021).

## Methods for Computation of Concentrations and Loads

Linear regression models for total phosphorus concentrations or loads were fitted to explanatory variables for turbidity or streamflow. A simple regression model (turbidity-surrogate model) for the log-transformed total phosphorus concentration was fitted to the log-transformed explanatory variable turbidity (R Core Team, 2020). LOADEST was used for models of log-transformed total phosphorus loads and log-transformed streamflow (Runkel and De Cicco, 2017). The log-transformed models provide a better linear fit but were retransformed to the original units (the base of the logarithm raised to the power of each side of the equation) so that total phosphorus can be calculated directly. The retransformation can introduce a model bias in the calculated constituent, which was corrected using a nonparametric smearing bias-correction factor (Duan, 1983). Diagnostic tests and plots were considered to verify models had low residual variance, residual plots indicating normality and homoscedasticity, and a mean observed (sampled) to estimated ratio near 1.0 for values during known samples. The observed to estimated ratio was constrained to a maximum range of 0.5–2. Model residuals were inspected for extreme values, which were investigated as potential outliers.

The total phosphorus-turbidity model calibration set included sample results matched to the nearest instantaneous turbidity time-series data, and the resulting continuous total phosphorus concentrations are computed at the same interval as the turbidity time series (typically 15-minute intervals). Continuous and daily mean total phosphorus concentrations from the turbidity-surrogate model (Garrett, 2019) are computed and stored in the USGS National Water Information System (U.S. Geological Survey, 2021). Total phosphorus loads, in U.S. short tons per day, were computed as concentrations, in milligrams per liter, and multiplied by streamflow, in cubic feet per second, as well as a unit conversion factor. The turbidity-surrogate calculation for loads used continuous concentrations and continuous streamflow to compute continuous loads, which were then summarized as daily mean loads.

Streamflow-based LOADEST model calibration sets use sample results matched to daily mean streamflow for two periods, 2009–20 and 2016–20, with resulting total phosphorus loads computed at a daily time step. The 2009–20 LOADEST model was used to compute daily loads from 2009 to 2020, including during the gap in sampling from October 2014 to

September 2016. The 2016–20 LOADEST model was used to compute daily loads before sensor deployment in August 2018 and during gaps in turbidity data.

Comparisons among loads from the three models and previously published load estimates computed using WRTDS (Kalkhoff, 2018) were used to assess the effect of transitioning among the various models. A comparison also was made with a time series of daily loads obtained by combining loads from the turbidity-surrogate model and the 2016–20 LOADEST model. This comparison provides a more complete time series based primarily on the surrogate model, with gaps filled from the LOADEST results before sensor deployment and during gaps in sensor data.

## Water-Quality Sample and Sensor Data

This section presents summaries of calibration samples used for total phosphorus models and summaries of continuous turbidity sensor data used for total phosphorus load and yield calculations. Model calibration samples should represent the full range of environmental conditions, covering the range of predictor variables (turbidity and streamflow), as well as other conditions affecting the model. To evaluate how well samples represented environmental conditions, the ranges of turbidity and streamflow measurements concurrent with sample collection were compared with the ranges of turbidity and streamflow measurements during the estimation period for each model (table 1, fig. 2). The estimation period for the turbidity-surrogate model was August 8, 2018, to December 15, 2020 (fig. 2A and B). The estimation periods for the LOADEST models were January 1, 2016, to December 15, 2020 (fig. 2C), and March 26, 2009, to December 15, 2020 (fig. 2D). The range of sampled streamflow also was compared with long-term (30-year, 1990–2019) streamflow. Long-term statistics were based on streamflow from the downstream streamflow-gaging station with a longer period of record, Cedar River at Cedar Rapids, Iowa (USGS station 05464500), adjusted by a drainage area ratio equal to 0.974 (Hirsch, 1979). Sampled turbidity values did not fully cover the range of observed turbidity values; however, the percentage of time during the estimation period when conditions exceeded the sampled range (high or low) was small (table 1). The range of sampled streamflow covered most of the range of observed streamflow during the estimation period for all models.

Total phosphorus concentrations for turbidity-surrogate calibration samples ranged from 0.081 to 0.438 milligram per liter (mg/L). Although orthophosphate concentrations generally were much less than total phosphorus concentrations overall (less than  $< 0.004$  to 0.237 mg/L), orthophosphate in individual samples accounted for as much as 91 percent of total phosphorus (mean 38 percent; U.S. Geological Survey, 2021). Sampled streamflow ranged from 1,270 to 46,500 cubic feet per second (ft<sup>3</sup>/s), compared with a range of 1,170 to 63,300 ft<sup>3</sup>/s during the calibration period, or the long-term

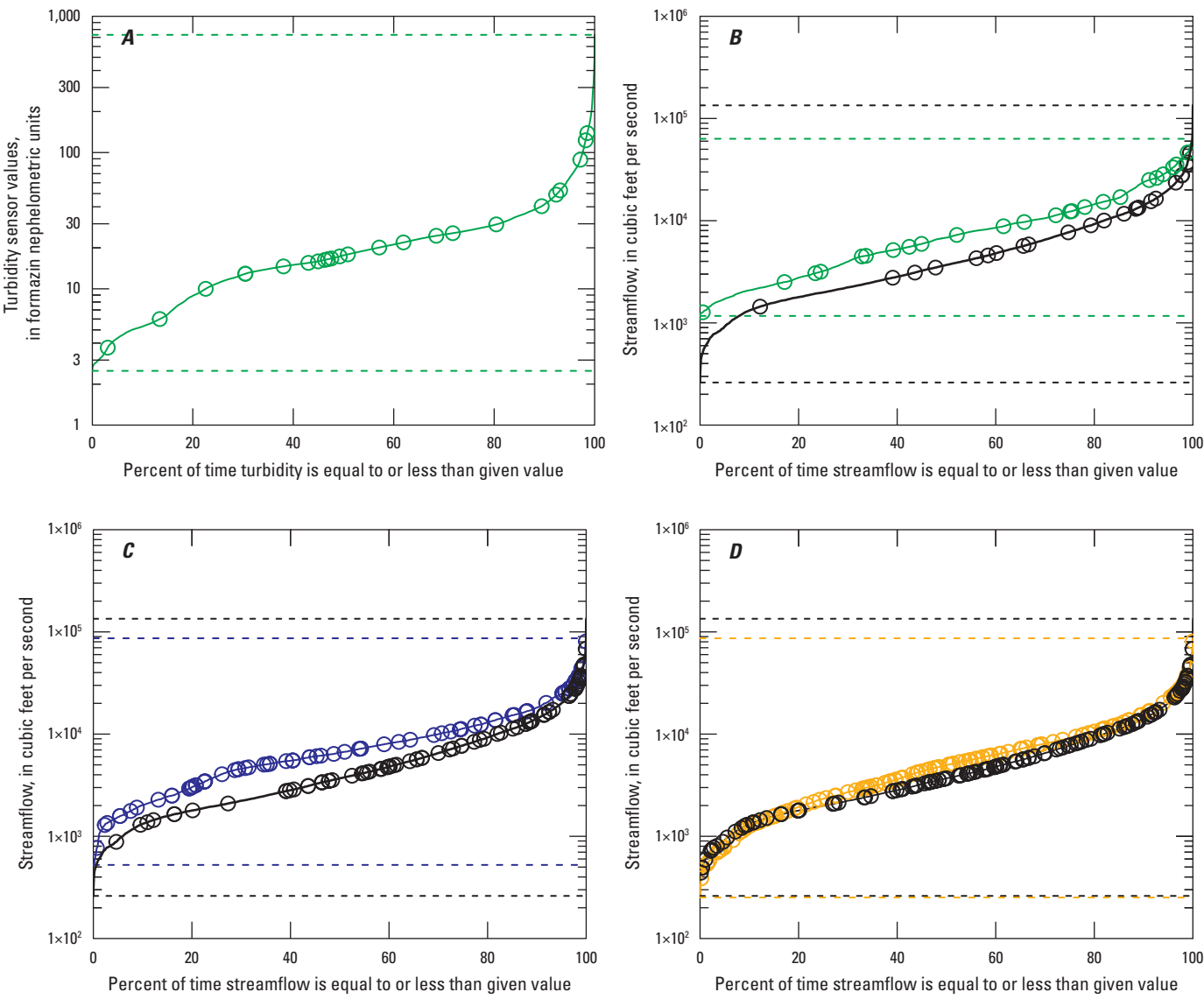


**Table 1.** Summary of calibration samples and time-series data, Cedar River at Blairs Ferry Road at Palo, Iowa (U.S. Geological Survey station 05464420).[mg/L, milligram per liter; ton/d, U.S. short ton per day; FNU, formazin nephelometric unit; ft<sup>3</sup>/s, cubic foot per second; --, not applicable; <, less than; LOADEST, LOAD ESTimator]

Statistic	Sample conditions			Time-series data matched to samples <sup>1</sup>		Overall time-series data during estimation period <sup>1</sup>		<sup>2</sup> Long-term streamflow, ft <sup>3</sup> /s
	Total phosphorus, mg/L	Orthophosphate, mg/L	Total phosphorus load (ton/d)	Turbidity, FNU	Streamflow, ft <sup>3</sup> /s	Turbidity, FNU	Streamflow, ft <sup>3</sup> /s	
Turbidity-surrogate model, calibration/estimation period August 8, 2018, to December 15, 2020								
Maximum	0.438	0.237	43.0	140	46,500	730	63,300	134,000
99th percentile	--	--	--	--	44,000	160	46,600	38,200
98th percentile	--	--	--	--	41,400	110	42,000	28,800
75th percentile	0.216	0.121	13.1	32	19,000	27	12,200	7,710
Median	0.167	0.069	4.51	18	10,500	18	6,830	3,670
25th percentile	0.140	0.009	1.45	15	5,000	12	3,220	1,970
Minimum	0.081	<0.004	0.486	3.7	1,270	2.6	1,170	261
Count	24	24	24	24	24	53,657	76,583	10,288
LOADEST model, calibration/estimation period January 1, 2016, to December 15, 2020								
Maximum	0.669	0.381	74.8	--	80,600	--	86,600	134,000
99th percentile	0.546	0.369	56.3	--	60,000	--	43,900	38,200
98th percentile	0.461	0.360	43.7	--	45,800	--	34,100	28,800
75th percentile	0.304	0.175	11.0	--	15,400	--	11,300	7,710
Median	0.194	0.095	3.66	--	6,710	--	6,600	3,670
25th percentile	0.157	0.031	1.54	--	4,050	--	3,850	1,970
Minimum	0.081	<0.004	0.372	--	770	--	525	261
Count	61	61	61	--	61	--	1,812	10,288
LOADEST model, calibration/estimation period March 26, 2009, to December 15, 2020								
Maximum	1.20	1.00	74.8	--	80,600	--	86,600	134,000
99th percentile	0.666	0.425	43.6	--	45,600	--	40,300	38,200
98th percentile	0.631	0.371	42.0	--	40,000	--	30,300	28,800
75th percentile	0.278	0.160	6.31	--	11,000	--	9,180	7,710
Median	0.200	0.812	2.52	--	5,040	--	4,980	3,670
25th percentile	0.153	<0.020	1.03	--	2,490	--	2,320	1,970
Minimum	0.081	<0.004	0.372	--	388	--	252	261
Count	130	127	130	--	130	--	4,284	10,288

<sup>1</sup>Instantaneous (15-minute interval) time-series data were used for turbidity-surrogate model summaries; daily mean data were used for LOADEST summaries.<sup>2</sup>Long-term statistics were based on streamflows from the downstream streamflow-gaging station with a longer period of record, Cedar River at Cedar Rapids, Iowa (U.S. Geological Survey station 05464500), adjusted by a drainage area ratio equal to 0.974.

6    Total Phosphorus Loadings for the Cedar River at Palo, Iowa, 2009–20



EXPLANATION

[LOADEST, LOAD ESTimator]

- Instantaneous duration curve**
  - Period of turbidity-surrogate concentration model—August 8, 2018, to December 15, 2020
- Daily duration curve**
  - Period of short LOADEST model—January 1, 2016, to December 15, 2020
  - Period of long LOADEST model—March 26, 2009, to December 15, 2020
- October 1, 1992, to December 15, 2020
- Minimum/maximum duration curve value
- Calibration samples

**Figure 2.** Duration curves with calibration samples, Cedar River at Blairs Ferry Road at Palo, Iowa (U.S. Geological Survey station 05464420; U.S. Geological Survey, 2021). *A*, turbidity sensor values for turbidity-surrogate model; *B*, streamflow for turbidity-surrogate model; *C*, streamflow for short LOADEST model; *D*, streamflow for long LOADEST model.

(30-year) range of 261 to 134,000 ft<sup>3</sup>/s (U.S. Geological Survey, 2021). The maximum sampled streamflow was greater than the 98th percentile of streamflow for the estimation period and greater than the 99th percentile of streamflow for the long-term period.

For calibration samples for the 5-year LOADEST model (January 1, 2016, to December 15, 2020), total phosphorus concentrations ranged from 0.081 to 0.669 mg/L, with orthophosphate concentrations (<0.004 to 0.381 mg/L) accounting for as much as 99 percent of total phosphorus (mean 47 percent) (U.S. Geological Survey, 2021). Daily mean streamflow on sampled days ranged from 770 to 80,600 ft<sup>3</sup>/s, ranging to greater than the 99th percentile relative to either the estimation period or the long-term period.

For the LOADEST model using the longer period (March 26, 2009, to December 15, 2020), total phosphorus concentrations ranged from 0.081 to 1.20 mg/L, with orthophosphate concentrations (<0.004 to 1.00 mg/L) accounting for as much as all the total phosphorus (mean 45 percent; Iowa Department of Natural Resources, 2020; U.S. Geological Survey, 2021) in individual samples. Daily mean streamflow on sampled days ranged from 388 to 80,600 ft<sup>3</sup>/s. The maximum sampled streamflow was greater than the 99th percentile of streamflow for either the estimation period or the long-term period.

Turbidity sensor records beginning August 2018 include data gaps because deployments are seasonal and because of sensor fouling or other problems. Turbidity sensor records include about 37 percent of days for 2018, 53 percent of days for 2019, and 79 percent of days for 2020 (U.S. Geological Survey, 2021). Sensors were not initially deployed until August 8, 2018. Sensors are removed for winter, typically from December through March. The maximum sampled turbidity was between the 98th and 99th percentile of instantaneous (15-minute interval) turbidity values in the estimation period.

## Continuous Water-Quality Time-Series Data to Compute Nutrient Loadings

This section presents models selected for total phosphorus concentrations and loads and summaries of resulting total phosphorus concentrations, loads, and yields. Factors affecting model performance are discussed, such as outliers and extrapolation, particularly relative to annual loads. Resulting total phosphorus concentrations, loads, and yields are summarized for 2018–20 from the turbidity-surrogate model, the 2009–20 LOADEST model, and the 2016–20 LOADEST model and compared with 2002–13 results based on a previously published WRTDS model (Kalkhoff, 2018).

### Total Phosphorus Models

The regression model for total phosphorus concentrations in the Cedar River near Palo, Iowa, was based on turbidity (table 2). Streamflow-based LOADEST models were applied before sensor deployment and during gaps to obtain a more complete record of loads (table 2). LOADEST models generally provide poor estimates of concentration because they are fitted to loads. The total phosphorus concentration model uses the following form:

$$\ln(TP \text{ conc.}) = b_0 + b_1 \times \ln(TURB) \text{ or} \quad (1)$$

$$TP \text{ conc.} = BCF \times \exp(b_0) \times TURB^{b_1}, \quad (2)$$

where

$\ln$	is the natural logarithm;
$TP \text{ conc.}$	is phosphorus concentration, unfiltered, in milligrams per liter;
$b_0$ and $b_1$	are fitted parameter estimates;
$TURB$	is turbidity, in units appropriate to sensor used (formazin nephelometric units);
$BCF$	is the model bias-correction factor; and
$\exp$	denotes the natural exponential function.

Similarly, the LOADEST models use the form:

$$\ln(TP \text{ load}) = b_0 + b_1 \times \ln(Q) + b_2 \times \ln(Q)^2, \quad (3)$$

where

$TP \text{ load}$	is total phosphorus load, in U.S. short tons per day;
$b_0 \dots b_2$	are fitted parameter estimates; and
$Q$	is centered daily mean streamflow, in cubic feet per second.

Streamflow terms in LOADEST models are centered, so that linear and quadratic terms are orthogonal, to eliminate problems associated with collinear explanatory variables (Runkel and De Cicco, 2017).

The turbidity-surrogate total phosphorus concentration model had a good empirical fit, with a coefficient of determination ( $R^2$ ) of 0.806, a root mean square error of 0.209, and a retransformation bias-correction factor of 1.02 (table 2, fig. 3). The 2009–20 LOADEST total phosphorus load model had a good fit, with an  $R^2$  value of 0.895, a root mean square error of 0.171, and a retransformation bias-correction factor of 1.11 (table 2, fig. 3). The 2016–20 LOADEST total phosphorus load model was similar, with an  $R^2$  value 0.889, a root mean square error of 0.186, and a retransformation bias-correction factor of 1.10 (table 2, fig. 3).

Although calibration samples did not fully cover the range of observed turbidity values, the turbidity-surrogate model was used to extrapolate beyond the sampled range (3.7–140 formazin nephelometric units [FNU], table 1) to

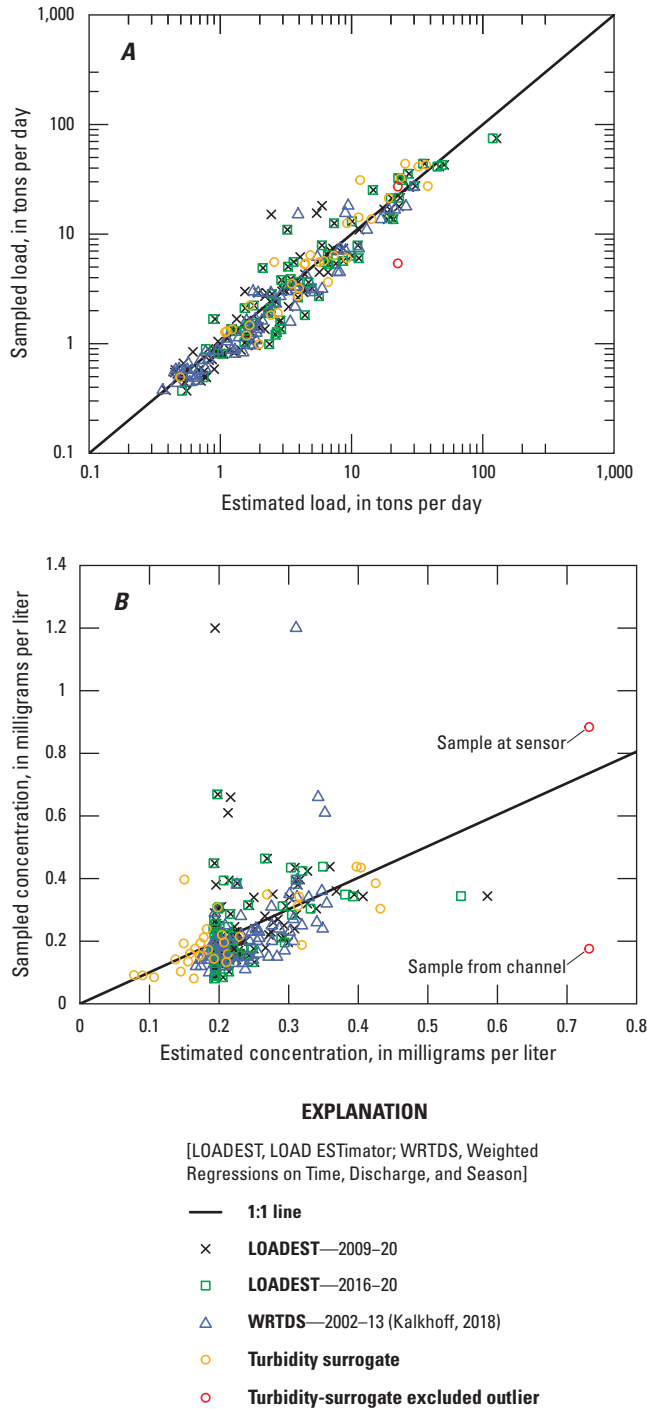
**Table 2.** Total phosphorus concentration regression models, Cedar River at Blairs Ferry Road at Palo, Iowa (U.S. Geological Survey station 05464420).

[ $R^2$ , coefficient of determination; RMSE, root mean square error; BCF, bias-correction factor;  $n$ , count;  $\ln$ , natural logarithm;  $TP\ conc.$ , total phosphorus concentration, in milligrams per liter;  $TURB$ , turbidity, in formazin backscatter ratio units; LOADEST, LOAD ESTimator;  $TP\ load$ , total phosphorus load, in U.S. short tons per day;  $Q$ , centered streamflow, in cubic feet per second.]

Model	Start date	End date	Regression Model	Model diagnostics				Summary of model input variables		
				$R^2$	RMSE	BCF	$n$	Variable and range	Mean	Median
Turbidity surrogate	8/3/2018	Current, as of publication	$\ln(TP\ conc.) = -3.26 + 0.498 \times \ln(TURB)$	0.806	0.209	1.02	24	$TURB$ 3.7–140	33	18
2009–20 LOADEST	3/26/2009	12/15/2020	$\ln(TP\ load) = 0.882 + 1.06 \times \ln(Q) + 0.123 \times \ln(Q)^2$	0.895	0.171	1.11	130	$Q$ <sup>1</sup> 388–80,600	9,080	5,040
2016–20 LOADEST	1/1/2016	12/15/2020	$\ln(TP\ load) = 1.41 + 1.18 \times \ln(Q) + 0.113 \times \ln(Q)^2$	0.889	0.186	1.10	61	$Q$ <sup>1</sup> 770–80,600	12,600	6,710

<sup>1</sup>Streamflow ranges presented as actual, uncentered values.





**Figure 3.** Sampled and estimated total phosphorus values for four models, Cedar River at Blairs Ferry Road at Palo, Iowa (U.S. Geological Survey station 05464420). *A*, total phosphorus concentrations; *B*, total phosphorus loads.

about 300 FNU. One outlier on May 19, 2019, was removed from the calibration set for the turbidity-surrogate model. The outlier had the highest sampled turbidity of 360 FNU and a total phosphorus concentration in the channel of 0.176 mg/L, but the concentration of the sample collected at the sensor was

0.884 mg/L. These samples were collected during a period when field observations indicated poor cross-section mixing, with a notable disconnect between data at the sensor location and the main channel. Although this high-turbidity outlier was excluded from the regression, the estimated concentration based on the surrogate model agreed well with the sample collected at the sensor, indicating the model may be appropriately used to extrapolate to higher turbidities (fig. 3). Nevertheless, periods with high turbidity (greater than about 300 FNU), particularly during noted disconnect between the channel and sensor location, were not used for computation with the turbidity surrogate.

Because calibration samples for the LOADEST models nearly cover the observed range of conditions for the explanatory variable (streamflow), these models were extrapolated beyond the sampled range. No outliers were excluded from the LOADEST total phosphorus load models.

## Total Phosphorus Concentrations, Loads, and Yields

Total phosphorus concentrations, loads, and yields are summarized for the Cedar River at Palo, Iowa, and compared with previously published estimates for this site (table 3; Kalkhoff, 2018). Annual summaries are based on calendar years. Concentrations, loads, and yields are presented for five models. Results from the (1) surrogate model with gaps filled with LOADEST incorporate the valuable high-frequency data from the (2) surrogate model only with the uninterrupted daily time series of the (3) 2016–20 LOADEST model. Results of the (4) 2009–20 LOADEST model provide a historical bridge for comparison with previously published (5) WRTDS results (Kalkhoff, 2018).

From the turbidity-surrogate model, daily mean total phosphorus concentrations computed at the Cedar River at Palo, Iowa, ranged from 0.066 to 0.432 mg/L (table 3). The greatest sample concentration used in the model calibration was 0.438 mg/L (table 1). The maximum sampled turbidity value in the calibration set was 140 FNU (table 1). The continuous turbidity data exceeded 140 FNU at the site on 17 days, totaling about 190 hours in the nearly 21 months of data collection. However, most of the turbidity data exceeding 140 FNU occurred during periods of disconnect between the channel and sensor location in May 2019, which were not used to compute total phosphorus concentrations. The remaining turbidity record contained fewer than 13 hours with turbidity exceeding 140 FNU. Surrogate-computed total phosphorus daily loads at the Cedar River at Palo, Iowa, site ranged from 0.273 to 38.4 U.S. short tons (tons) per day, and daily yields ranged from 0.0861 to 12.1 pounds per square mile per day (table 3). Annual total phosphorus loads from the surrogate model with gaps filled with LOADEST range from 1,370 to 2,360 tons per year for 2018–20.

**Table 3.** Summary of total phosphorus concentrations, loads, and yields for the Cedar River at Blairs Ferry Road at Palo, Iowa (U.S. Geological Survey station 05464420).

[mg/L, milligram per liter; ton/d, U.S. short ton per day; lb/mi<sup>2</sup>/d, pound per square mile per day; lb/acre/yr, pound per acre per year; max, maximum; min, minimum; LOADEST, LOAD ESTimator; WRTDS, Weighted Regressions on Time, Discharge, and Season]

Year	Daily mean concentration, mg/L				Daily load, ton/d				Daily yield, lb/mi²/d				Annual load, ton	Annual yield, lb/acre/yr
	Mean	Median	Max	Min	Mean	Median	Max	Min	Mean	Median	Max	Min		
Surrogate model with gaps filled with LOADEST														
2018	0.202	0.198	0.432	0.074	6.46	3.36	38.4	0.397	2.04	1.06	12.1	0.125	2,360	1.16
2019	0.200	0.195	0.463	0.083	6.02	3.50	77.1	0.959	1.90	1.10	24.3	0.302	2,200	1.08
¹2020	0.174	0.178	0.404	0.066	3.74	2.01	37.1	0.273	1.18	0.634	11.7	0.0861	1,370	0.674
Surrogate model only														
¹2018	0.172	0.167	0.432	0.074	8.38	4.07	38.4	1.09	2.64	1.28	12.1	0.343	3,060	1.51
¹2019	0.189	0.181	0.427	0.083	6.14	4.66	26.9	1.10	1.94	1.47	8.48	0.348	2,240	1.11
¹2020	0.169	0.166	0.404	0.066	4.06	1.88	37.1	0.273	1.28	0.591	11.7	0.0861	1,490	0.732
2016–20 LOADEST														
2016	0.219	0.205	0.574	0.192	7.34	4.41	134	1.91	2.31	1.39	42.3	0.602	2,690	1.32
2017	0.209	0.203	0.295	0.192	3.94	2.79	20.7	0.395	1.24	0.879	6.52	0.125	1,440	0.709
2018	0.229	0.207	0.439	0.192	8.07	3.84	66.8	0.397	2.54	1.21	21.1	0.125	2,950	1.45
2019	0.218	0.204	0.463	0.192	6.59	4.20	77.1	0.959	2.08	1.32	24.3	0.302	2,410	1.19
¹2020	0.212	0.199	0.392	0.192	4.62	2.27	49.0	0.725	1.46	0.715	15.4	0.229	1,690	0.832
2009–20 LOADEST														
2009	0.208	0.201	0.290	0.194	3.86	2.60	18.8	0.785	1.22	0.818	5.94	0.248	1,410	0.695
2010	0.214	0.199	0.421	0.194	5.48	3.05	55.6	1.13	1.73	0.962	17.5	0.357	2,000	0.986
2011	0.214	0.209	0.315	0.194	3.31	1.62	24.6	0.668	1.04	0.510	7.75	0.211	1,210	0.595
2012	0.244	0.229	0.477	0.194	1.03	0.747	5.53	0.324	0.324	0.236	1.74	0.102	376	0.185
2013	0.243	0.221	0.506	0.194	5.69	1.21	89.1	0.360	1.79	0.382	28.1	0.114	2,080	1.02
2014	0.224	0.204	0.467	0.194	4.29	1.58	73.0	0.419	1.35	0.500	23.0	0.132	1,570	0.771
2015	0.207	0.199	0.323	0.194	3.32	2.18	26.5	0.622	1.05	0.688	8.36	0.196	1,210	0.598
2016	0.221	0.206	0.617	0.194	7.47	4.43	144	1.93	2.36	1.40	45.4	0.608	2,740	1.35
2017	0.212	0.206	0.315	0.194	3.98	2.80	21.0	0.447	1.25	0.884	6.63	0.141	1,450	0.716
2018	0.233	0.210	0.459	0.194	8.21	3.85	69.9	0.448	2.59	1.21	22.0	0.141	3,000	1.48
2019	0.220	0.205	0.487	0.194	6.70	4.21	81.0	0.989	2.11	1.33	25.6	0.312	2,440	1.20
¹2020	0.215	0.203	0.407	0.194	4.66	2.28	50.8	0.760	1.47	0.720	16.0	0.240	1,710	0.841

**Table 3.** Summary of total phosphorus concentrations, loads, and yields for the Cedar River at Blairs Ferry Road at Palo, Iowa (U.S. Geological Survey station 05464420).—Continued

[mg/L, milligram per liter; ton/d, U.S. short ton per day; lb/mi<sup>2</sup>/d, pound per square mile per day; lb/acre/yr, pound per acre per year; max, maximum; min, minimum; LOADEST, LOAD ESTimator; WRTDS, Weighted Regressions on Time, Discharge, and Season]

Year	Daily mean concentration, mg/L				Daily load, ton/d				Daily yield, lb/mi²/d				Annual load, ton	Annual yield, lb/acre/yr
	Mean	Median	Max	Min	Mean	Median	Max	Min	Mean	Median	Max	Min		
WRTDS (Kalkhoff, 2018)														
2002	0.203	0.209	0.291	0.148	1.54	1.22	8.42	0.310	0.484	0.384	2.66	0.0977	560	0.276
2003	0.209	0.211	0.348	0.148	1.88	0.623	17.7	0.221	0.592	0.196	5.59	0.0698	686	0.338
2004	0.229	0.219	0.554	0.150	4.51	1.80	89.6	0.226	1.42	0.567	28.3	0.0713	1,650	0.813
2005	0.206	0.207	0.395	0.149	2.55	1.53	26.4	0.389	0.805	0.481	8.33	0.123	931	0.459
2006	0.199	0.199	0.334	0.147	2.22	1.28	14.7	0.554	0.700	0.405	4.63	0.175	810	0.399
2007	0.227	0.210	0.440	0.153	5.19	2.92	32.8	0.880	1.64	0.922	10.4	0.277	1,890	0.933
2008	0.237	0.204	0.744	0.157	10.2	1.76	268	0.559	3.22	0.556	84.6	0.176	3,740	1.84
2009	0.220	0.219	0.427	0.162	4.27	2.84	24.8	0.679	1.35	0.897	7.83	0.214	1,560	0.769
2010	0.237	0.220	0.626	0.164	6.68	3.19	82.7	0.941	2.11	1.01	26.1	0.297	2,440	1.20
2011	0.232	0.212	0.478	0.168	4.10	1.72	37.2	0.550	1.29	0.541	11.7	0.173	1,500	0.738
2012	0.265	0.258	0.408	0.186	1.21	0.781	6.84	0.277	0.382	0.246	2.16	0.0874	444	0.219
2013	0.264	0.252	0.515	0.177	6.65	1.30	88.3	0.330	2.10	0.409	27.9	0.104	2,430	1.20

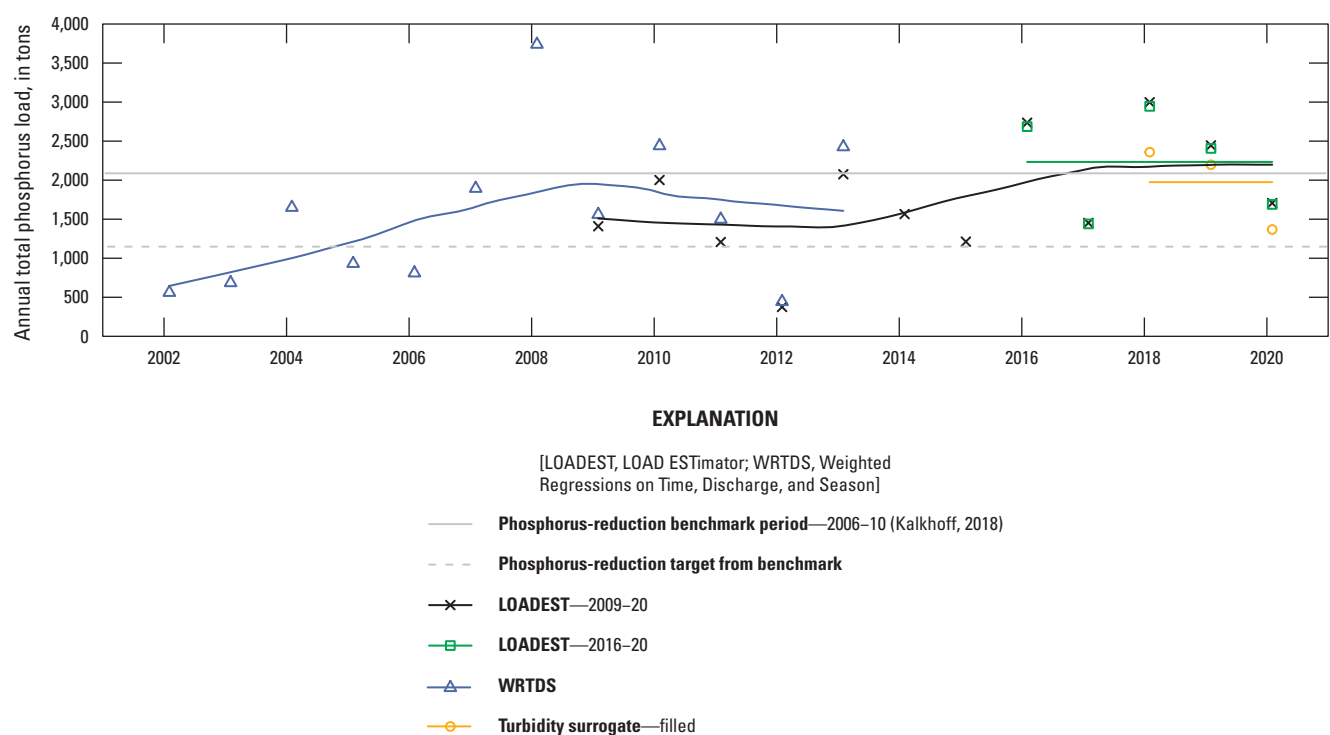
<sup>1</sup>Summaries presented include incomplete years for surrogate model without gaps filled and incomplete records for 2020 for all models.

Because LOADEST models are fitted to loads, these models provide less reliable estimates of concentration; however, the comparison of observed and estimated loads from the LOADEST models is important to assess model performance, particularly model bias and extrapolation (Hirsch, 2014). Daily loads from the 2016–20 model ranged from 0.395 to 134 tons per day, and loads from the 2009–20 model ranged from 0.324 to 144 tons per day (table 3). The range of observed loads (daily load computed from sample concentration and daily mean streamflow) was 0.372 to 74.8 tons per day for both the 2016–20 and 2009–20 models (table 1). Concentrations from the 2016–20 LOADEST model ranged from 0.192 to 0.574 mg/L, and concentrations from the 2009–20 model ranged from 0.194 to 0.617 mg/L, compared with sample ranges of 0.081 to 0.669 mg/L and 0.081 to 1.20 mg/L, respectively (table 3, table 1). The maximum sampled streamflow of 80,600 ft<sup>3</sup>/s was used in the calibration set for both LOADEST models, compared with a maximum daily mean streamflow of 86,600 ft<sup>3</sup>/s for either period. The daily mean streamflow exceeded the maximum sampled streamflow once in the period of record for the streamflow-gaging station, during the same event as the maximum sampled streamflow in September 2016.

The statewide baseline (1980–96) total phosphorus load is about 23,800 tons per year (equivalent to an annual statewide yield of 1.32 pounds per acre per year [lb/acre/yr]), and a 45-percent reduction would require an annual statewide total phosphorus yield of 0.73 lb/acre/yr to achieve this goal (Iowa

Department of Agriculture and Land Stewardship and others, 2019). A second historical period, or benchmark period, used for the statewide reduction goal is 2006–10 because sufficient monitoring data are available to calculate annual total phosphorus transport from all major rivers that drain from Iowa (Iowa Department of Agriculture and Land Stewardship and others, 2019). Mean annual statewide total phosphorus yield for the benchmark period was 1.08 lb/acre/yr. Specific to the Cedar River at Palo, mean annual loads during the 2006–10 benchmark period were 2,088 tons, or a yield of 1.03 pounds per acre (Kalkhoff, 2018; table 3; fig. 4). Similar to statewide data availability, data are not available to compute loads for the 1980–96 baseline period for the Cedar River at Palo.

The overlapping model periods provide some information about transitioning among the different models. Annual loads reported from WRTDS were a mean of 15 percent greater than annual loads computed from LOADEST for 2009–13. LOADEST results were similar (less than a 2-percent difference) for 2016–20 regardless of which calibration period was used. The 2018–20 loads from LOADEST alone were 16 percent greater than loads from the combined turbidity-surrogate and LOADEST model. Based on these comparisons, transitioning from WRTDS to LOADEST and then to the combined turbidity-surrogate LOADEST model, nearly 30 percent of an apparent reduction in load may be due to changes in sample collection through time and the mathematical load model selection. Although computation of loads using surrogates or high-frequency sampling, such as with nitrate sensors or phosphate



**Figure 4.** Annual total phosphorus loads relative to phosphorus-reduction benchmark and 45-percent reduction goal (WRTDS loads from Kalkhoff, 2018).

analyzers, is considered more accurate, the change in methods presents challenges for trends assessment (such as assessment of load reduction goals).

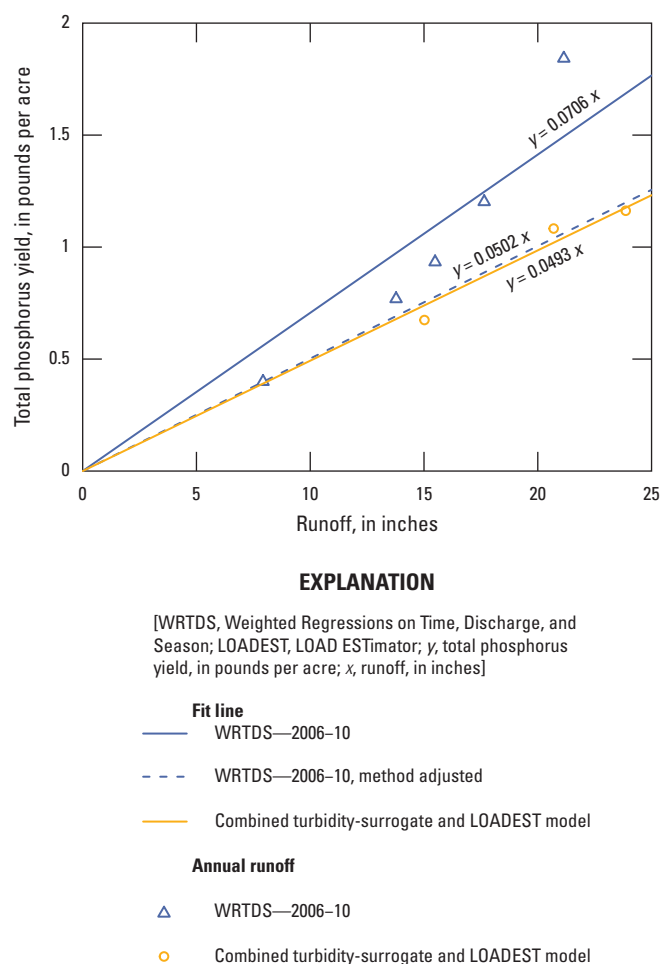
Although it is important to assess the reduction of loads overall, runoff-transport relations are an additional tool to evaluate progress of nutrient reduction while controlling for effects of interannual streamflow variability or trends (Kalkhoff, 2018). A uniform reduction in yield over a range of streamflow conditions will result in a lower slope of the runoff-transport fit line (fig. 5). Although normalizing for changes in flow (as in the runoff and yield plots) allows for assessment of progress despite changes in flow, the reductions in actual loads are needed, including effects of changes in flow. Changes in flow may mask improvement in loads for a given streamflow, but load reduction is still needed even if streamflow is increasing. Changes in data collection and load computation methods also may mask or exacerbate perceived environmental changes. A comparison of loads presented in this report indicated a nearly 30-percent adjustment is needed

for transitioning among the different models. For 2018–20, the slope was 0.0493 based on yields from the combined turbidity-surrogate and LOADEST model (fig. 5). The slope for the benchmark period 2006–10 was 0.0706 using the WRTDS model. When adjusted for changes in load computation methods, however, the slope is 0.0502, indicating little change in loads when normalized for streamflow and accounting for changes in load computation methods.

## Summary

In support of nutrient reduction strategies, total phosphorus loads and yields were computed based on continuously monitored turbidity sensor data for more accurate calculations compared with methods based on periodic sample collection and continuous streamflow. Instream sensors recorded continuous turbidity in the Cedar River at Palo, Iowa, collocated with a continuous streamflow-gaging station during 2018–20. Sensor installation, maintenance, and records processing followed U.S. Geological Survey protocols including field data collection to verify that data accurately represent stream conditions. Surrogate models at the Cedar River at Blairs Ferry Road at Palo, Iowa (U.S. Geological Survey station 05464420), described relations between total phosphorus concentrations from discrete samples and continuous sensor data to allow computation of continuous total phosphorus concentrations. Streamflow-based LOAD ESTimator (LOAD-EST) load models for the periods 2009–20 and 2016–20 were calibrated using samples within each period. The 2016–20 LOADEST results also were used with the turbidity-surrogate loads to generate a more complete annual load by using the LOADEST results before sensor deployment and during gaps in sensor data. The turbidity-based concentration model had a good empirical fit (coefficient of determination = 0.81). The LOADEST models (coefficients of determination = 0.90 and 0.89) were fitted to loads.

A comparison of the longer period LOADEST model with previously published loads using Weighted Regressions on Time, Discharge, and Season indicated the Weighted Regressions on Time, Discharge, and Season model was consistently greater by about 15 percent of annual loads for years computed for both models (2009–13). Although there was little difference (less than 2 percent) between the LOAD-EST models during comparison years (2016–20), the 2016–20 LOADEST results were about 16 percent greater than the combined turbidity-surrogate and LOADEST result (comparison years 2018–20). Accurate calculations are needed to track annual progress toward nutrient reduction goals at specific sites and across the State, but the comparison of load computation methods at this site highlights challenges in assessing environmental trends during changes in data collection (periodic samples to high-frequency sensor data) and in computational approaches (different load models).



**Figure 5.** The relation between annual runoff and total phosphorus yield from the Cedar River at Blairs Ferry Road at Palo, Iowa (U.S. Geological Survey station 05464420; WRTDS results from Kalkhoff, 2018).



Annual total phosphorus loads for the Cedar River ranged from 1,370 to 2,360 U.S. short tons (tons) per year for 2018–20, based on the turbidity-surrogate model with gaps filled with the 2016–20 LOADEST model. Annual total phosphorus yields for the Cedar River at Palo, Iowa, ranged from 0.674 to 1.16 pounds per acre per year for 2018–20. Previously published estimates for this site for the 2006–10 period, used as a benchmark for nutrient reduction efforts, indicated a mean annual load of 2,088 tons and a yield of 1.03 pounds per acre. Normalized to streamflow, total phosphorus yields in 2018–20 were lower; however, nearly all the apparent reduction can be attributed to differences in the load-calculation methods.

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