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The Use of Continuous Water-Quality Time-Series Data to Compute Total Phosphorus Loadings for the Turkey River at Garber, Iowa, 2018–20

Scientific Investigations Report 2020–5131

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

Cover photos: (Front) Photograph showing Turkey River upstream from gage during a high-streamflow event on May 20, 2019, after a rainstorm. Highly turbid waters at this site are correlated with high phosphorus concentrations and loads. Photograph by Jessica D. Garrett, U.S. Geological Survey.

(Back) Photograph showing Turkey River downstream from gage on October 20, 2020, during low streamflow condition. Clear water with low turbidity at this site is correlated with low phosphorus concentrations and loads. Photograph by Jessica D. Garrett, U.S. Geological Survey.

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DAVID BERNHARDT, Secretary

U.S. Geological Survey
James F. Reilly II, Director

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square mile (mi^2)	259.0	hectare (ha)
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		
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 ($kg/km^2/d$)
pound per square mile per day ($lb/mi^2/d$)	0.17515	kilogram per square kilometer per day ($kg/km^2/d$)

Supplemental Information

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

Water year is defined as the 12-month period from October 1 through September 30 and designated by the calendar year in which it ends (water year 2019 is the period beginning October 1, 2018, and ending September 30, 2019).

Abbreviations

FBRU	formazin backscatter ratio unit
IASHL	Iowa State Hygienic Laboratory
R^2	coefficient of determination
USGS	U.S. Geological Survey

The Use of Continuous Water-Quality Time-Series Data to Compute Total Phosphorus Loadings for the Turkey River at Garber, Iowa, 2018–20

By Jessica D. Garrett

Abstract

In support of nutrient reduction efforts, total phosphorus loads and yields were computed for the Turkey River at Garber, Iowa (U.S. Geological Survey station 05412500), for January 1, 2018, to April 30, 2020, based on continuously monitored turbidity sensor data. Sample data were used to create a total phosphorus turbidity-surrogate model. Streamflow-based total phosphorus models were used during periods of missing sensor data to obtain a more complete annual total phosphorus load. This report presents methods needed to accurately compute site-specific loads and track annual progress toward nutrient reduction goals within the State.

Annual total phosphorus loads for the Turkey River at Garber, Iowa, were 1,740 and 1,490 U.S. short tons for 2018 and 2019, respectively, with annual yields ranging from 3.01 to 3.53 pounds per acre per year, compared to a mean statewide yield of 0.73 pound per acre per year needed to achieve the total phosphorus-reduction goal.

Introduction

The U.S. Geological Survey (USGS) and the Iowa Department of Natural Resources cooperatively studied total phosphorus loads using surrogate relations in the Turkey River at Garber, Iowa (USGS station 05412500). Eutrophication of local and downstream waterbodies, specifically an abundance of nitrogen and phosphorus, is a high-priority issue in the Mississippi River Basin (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, 2017) and in local Iowa waterbodies (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; Illinois Environmental Protection Agency and others, 2019; Ohio Environmental Protection Agency and others, 2016), calls for large reductions in nutrient delivery to the Gulf of Mexico. Iowa streams rank among the largest contributors to total Mississippi River Basin total phosphorus loads using consistent methods applied across large scales (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 within the State (Iowa Department of Agriculture and Land Stewardship and others, 2019; Jones and others, 2018). The total phosphorus-reduction goal in Iowa is 45 percent, using the period 1980–96 as the baseline, though initial estimates for the nutrient reduction strategy in Iowa were based on a baseline period of 2000–06 owing to greater data availability.

Load-calculation methods based on streamflow and infrequent (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 large changes but may not be accurate enough to assess interim progress toward load reduction goals because load-calculation estimation errors can be quite large, particularly for total phosphorus and other constituents with a strongly positive or log-curvilinear relation between concentration and streamflow (Hirsch, 2014; Hirsch and De Cicco, 2015; Lee and others, 2016; Runkel and others, 2004). Garrett (2012) reported confidence intervals ranging from 56 to 142 percent of annual total phosphorus flux for the Turkey River at Garber, Iowa (USGS station 05412500) during 2004–08, and confidence intervals from 12 to 102 percent of annual load for 9 other streams in Iowa during the same period. For the Iowa River at Wapello, Iowa, (USGS station 05465500) for 1978–2015, Aulenbach and others (2007; this U.S. Geological Survey Open File Report includes updates through 2016) reported confidence intervals from 16 to 141 percent of annual total phosphorus loads.

Surrogates, by definition, use indirect data intended to provide information about a parameter that is difficult to measure directly, but often with a direct or uncomplicated association between the surrogate and the parameter of interest. However, the relation between a surrogate and parameter of interest should be more than statistical correlation and have some physical basis. For total phosphorus, turbidity makes sense physically because, in many Iowa streams, total phosphorus loads are dominated by particulate-bound phosphorus (Garrett, 2012, 2019). Turbidity is a measure of the scatter of light from particles in the water, particularly fine-grained sediment (Anderson, 2005). Several studies have determined turbidity to be a good predictor for total phosphorus concentration, that additional parameters associated with dissolved constituents or biological processes can improve total phosphorus turbidity-surrogate 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 model developed to compute a time series of concentrations and loads of total phosphorus for the Turkey River at Garber, Iowa (USGS station 054122500) for the period beginning January 1, 2018, through April 30, 2020. The model is primarily based on empirical statistical regression between turbidity sensor measurements and sample results, with a more complete record of loads despite gaps in surrogate data owing to application of an alternate streamflow-based model during periods of missing surrogate data (Garrett, 2019).

Continuous sensor data and sample results are summarized, and regression models and computed continuous data are presented for the selected site for January 1, 2018, to April 30, 2020, though the model can be used to compute ongoing total phosphorus concentrations and loads. Continuous turbidity data are summarized through time and through 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, with detail on model selection and diagnostics. Time-series total phosphorus concentrations and loads presented in this report and computed moving forward using the methods presented can be used to monitor changes in total phosphorus concentrations and loads at the selected site.

Site Information

Water-quality samples and turbidity data summarized in this report were collected from the Tukey River at Garber, Iowa (USGS station 05412500; fig. 1). This site has a drainage area of 1,545 square miles (mi^2) and is collocated with an existing streamflow-gaging station (fig. 1). Annual runoff for the selected site was 20.0 and 25.1 inches during water years 2018 and 2019, respectively (U.S. Geological Survey, 2020). Water year is defined as the 12-month period beginning October 1 through September 30 and designated by the calendar year in which it ends. Continuous nitrate monitor data are also available at this site beginning May 2012 (U.S. Geological Survey, 2020).

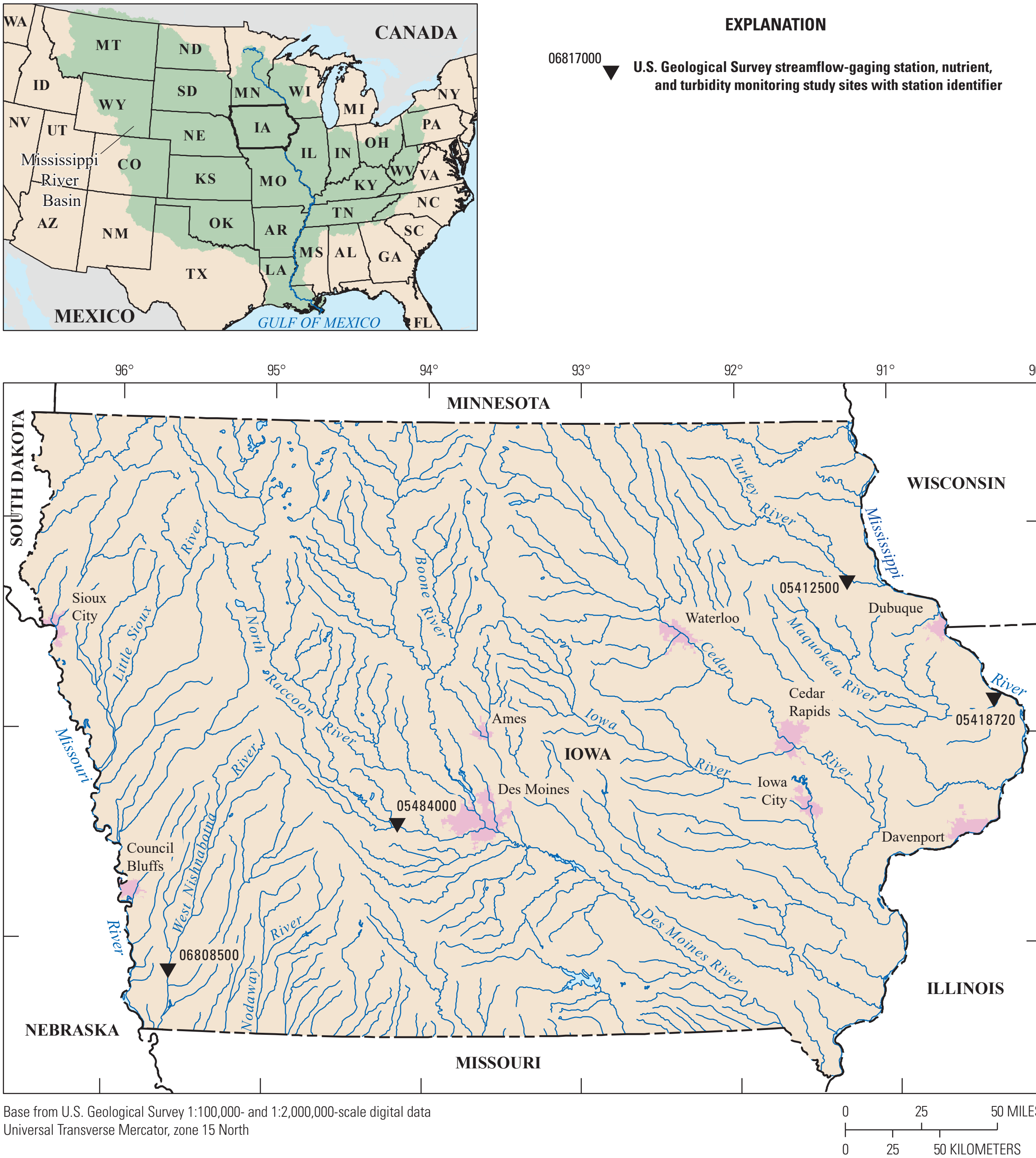

Figure 1. Selected U.S. Geological Survey streamflow-gaging, nutrient, and turbidity monitoring station study sites in Iowa.

Methods for Data Collection and Computation

In-stream sensors were used to record turbidity at 15-minute intervals beginning March 2018 at the Turkey River at Garber, Iowa (USGS station 05412500). Discrete water samples were collected from April 2018 to November 2019 for calibration of the total phosphorus turbidity-surrogate model. Discrete water samples collected from October 2013 to March 2020 were used for calibration of the streamflow-based total phosphorus model used to fill periods of missing turbidity data.

Continuous Water-Quality Data Collection and Computation

Turbidity was monitored using a Hach Solitax sc probe (Hach Company, 2009) in formazin backscatter ratio units (FBRUs) (U.S. Geological Survey, 2020). Turbidity in FBRUs is a ratiometric measure of light backscatter at two detector angles. Turbidity data are not interchangeable among sensor types or measurement units and cannot be converted to other units (Anderson, 2005); therefore, to maintain consistency in turbidity measurements at a site, the type of sensor was not changed for a site during the study. The turbidity sensor was installed in a protective polyethylene pipe secured to the bank and extending into the flowing part of the stream.

Field inspections of turbidity sensors and data processing followed methods described by Anderson (2005), Wagner and others (2006), and adaptations described by Garrett (2019). Sensor servicing was avoided during streamflow events such as flooding unless sensors were not working because (1) a field comparison meter was not always available to document potentially changing stream conditions, and (2) data during rapidly changing conditions were valuable to the study. Fouling corrections generally were not applied when time-series data indicated rapidly changing streamflow or sensor readings for several hours before and after service visits, but data-quality ratings were downgraded. Cross-sectional data were collected to show general mixing of the stream and to verify data collected at the sensor location represented conditions throughout the entire channel. Mixing was documented by measuring water temperature, specific conductance, pH, and dissolved oxygen with a multiparameter sonde that also included a turbidity sensor. Turbidity sensors were calibrated by the manufacturer at least every 2 years. Turbidity standards and deionized water (turbidity-free) were used in the field and the office to detect calibration changes between manufacturer servicing.

Water Sample Collection and Analysis

Discrete water samples were collected by Iowa State Hygienic Laboratory (IASHL) staff and by USGS staff. Event-targeted USGS sample collection from April 2018 to April 2020 was consistent with IASHL protocol (Mary Skopec, Iowa Department of Natural Resources, written commun., 2016). Water was collected midstream from the bridge using a weighted bottle or by wading and using either pre-cleaned high-density polyethylene (plastic) or pre-fired glass bottles to collect a grab sample. Sample collection bottles were rinsed twice with native river water prior to sample collection. The unfiltered sample was shaken or churned to make sure sediment did not settle and was split into individual sample bottles for the laboratory. Samples were chilled and transported to the laboratory and analyzed within 24 hours. Samples for surrogate development were analyzed by the IASHL in Ankeny, Iowa, for total phosphorus and orthophosphate by colorimetric methods (U.S. Environmental Protection Agency methods 365.4 and 365.1, respectively) (U.S. Environmental Protection Agency, 1983). IASHL sample results are available from the Iowa Department of Natural Resources database for water-quality monitoring data (Iowa Department of Natural Resources, 2020). USGS sample collection for October 2013 to September 2014 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) and analyzed by the USGS National Water Quality Laboratory in Lakewood, Colorado (Fishman, 1993; O’Dell, 1993; Patton and Kryskalla, 2003).

Methods for Continuous Concentration Models

A simple regression model (turbidity-surrogate model) for log-transformed total phosphorus concentration was fitted to the explanatory variable turbidity using R software (R version 3.6.3) (R Core Team, 2020). The log-transformed model provides a better linear fit but was 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). The total phosphorus-turbidity model uses sample results matched to the nearest instantaneous turbidity time-series data, and the resulting total phosphorus concentrations are computed at the same interval as the turbidity time series, typically 15-minute intervals.

An alternate regression model (streamflow-based model) for log-transformed total phosphorus concentration was fitted to streamflow variables to fill periods with missing turbidity sensor data, such as through the winter, when operation of sensors is sometimes impractical. Variables for the streamflow-based model use a daily time step (using daily mean streamflow data, U.S. Geological Survey, 2020) because streamflows in periods with gaps in sensor data, such as periods when the streamflow computation is affected by ice, often are computed at a time step longer than the typical 15-minute data interval.

Diagnostic tests and plots were considered to verify models had low residual variance, residual plots indicating normality and homoscedasticity, and mean observed (sampled) to computed ratio near 1.0 for values during known samples, with the maximum range allowed for observed to computed ratio of 0.5 to 2. Model residuals were inspected for extreme values, which were investigated as potential outliers. If individual data points exhibited undue influence on model parameter estimates, alternate models were considered that included all data points but an alternate selection of variables, or outliers were removed from the calibration dataset. The undue influence of outliers can "pull" the model in one area of the data, resulting in poor model fit in other areas of data. For example, low-streamflow influential outliers can result in models with greater residual errors at high streamflows, which are particularly critical for computing annual loads. Though a complete time series of total phosphorus concentration was computed from the model, the primary purpose of the resulting time series is annual load calculation, and this objective is considered when determining if an outlier should be excluded. Excluded outliers are described for each model in the "Continuous Water-Quality Time-Series Data to Compute Nutrient Loadings" section.

Methods for Generation of Time-Series Concentrations and Loads

Instantaneous (typically 15-minute interval) and daily mean total phosphorus concentrations are stored in the National Water Information System (U.S. Geological Survey, 2020). Total phosphorus concentration data were computed first from the turbidity-surrogate model, with the alternate streamflow-based model applied at a daily time step when gaps were present in the turbidity data (Garrett, 2019). Total phosphorus loads, in U.S. short tons (hereafter referred to as "ton") per day, were computed as concentrations, in milligrams per liter, multiplied by streamflow, in cubic feet per second, and a unit conversion factor. The preferred calculation chain for loads used continuous concentrations and continuous streamflow to compute continuous loads, which were then summarized as daily mean loads.

Sample Water-Quality and Sensor Data

The following 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. To be most effective, surrogate model calibration samples need to 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 concurrent with sample collection were compared with the ranges of turbidity and streamflow during the estimation period from January 2018 to December 2019 (table 1, fig. 2). The range of sampled streamflow also was compared with long-term (30-year, 1990–2019) streamflows. Overall, streamflows during the estimation period were greater than streamflows during 1990–2019, though peak flows during the estimation period (streamflow maximum duration curve values, corresponds with value at 100 percent of time streamflow is less than or equal to given value) were not historical peaks (fig. 2*B* and *C*). The calibration samples for the total phosphorus turbidity-surrogate model used samples from April 2018 to November 2019, whereas the calibration samples for the streamflow-based model used samples from October 2013 to March 2020, resulting in calibration samples for the streamflow-based model with values outside the observed streamflow range during the estimation period (table 1, fig. 2).

In figure 2*B* and *C*, greater streamflow for the 2018–19 duration curves than streamflows for 1990–2019 (for the same percentage of time streamflow is less than or equal to the given value) indicate streamflows in the more recent period were generally greater for the entire range of streamflows, with the only exception for extreme high streamflows. Though the range of sampled values did not fully cover the range of observed turbidity and streamflow values, particularly the range of long-term streamflow values for the turbidity-surrogate model, the percentage of time during the estimation period when conditions exceeded the sampled range (high or low) was small.

Total phosphorus concentrations for turbidity-surrogate calibration samples ranged from 0.06 to 2.5 milligrams per liter (mg/L). Though orthophosphate concentrations were much less than total phosphorus concentrations overall (<0.02 to 0.27 mg/L), orthophosphate in individual samples accounted for as much as 57 percent of total phosphorus (mean 25 percent). Daily mean streamflow on sampled days ranged from 727 to 19,900 cubic feet per second (ft^3/s), compared to a range of 397 to 29,200 ft^3/s during the calibration period, or the long-term (30-year) range of 82 to 52,200 ft^3/s (table 1; U.S. Geological Survey, 2020). The maximum sampled streamflow was greater than the 99th percentile of streamflow for either the calibration period or the long-term period.

Table 1. Summary of calibration samples and time series data, Turkey River at Garber, Iowa (U.S. Geological Survey station 05412500).

[mg/L, milligram per liter; FBRU, formazin backscatter ratio unit; ft³/s, cubic foot per second; --, statistic not available for percentiles requiring interpolation spacing much less than sample frequency; <, less than]

Statistic	Turbidity-surrogate model					Streamflow-based model				Long-term (1990–2019) streamflow, daily mean, ft³/s
	Sample concentrations, mg/L		Time-series data matched to samples		Overall time-series data during estimation period, 2018–19	Sample concentrations, mg/L		Time-series data matched to samples	Overall time-series data during estimation period, 2018–19	
	Total phosphorus	Orthophosphate	Turbidity, instantaneous, FBRU	Streamflow, instantaneous, ft³/s	Turbidity, instantaneous, FBRU	Total phosphorus	Orthophosphate	Streamflow, daily mean, ft³/s	Streamflow, daily mean, ft³/s	
Maximum	2.5	0.27	1,520	19,900	9,210	2.5	0.54	24,300	29,200	52,200
99th percentile	--	--	--	--	1,940	2.4	0.53	19,300	17,200	10,100
98th percentile	--	--	--	--	1,340	1.8	0.41	17,100	12,900	7,280
75th percentile	1.2	0.15	637	6,560	150	0.22	0.10	2,760	3,110	1,710
Median	0.49	0.10	284	3,670	53	0.13	0.05	1,530	1,940	813
25th percentile	0.15	0.06	31	1,820	23	0.07	0.03	529	1,180	476
Minimum	0.06	<0.02	5.2	727	4.4	0.03	<0.02	231	397	82
Count	24	24	24	24	64,416	93	83	93	730	10,957

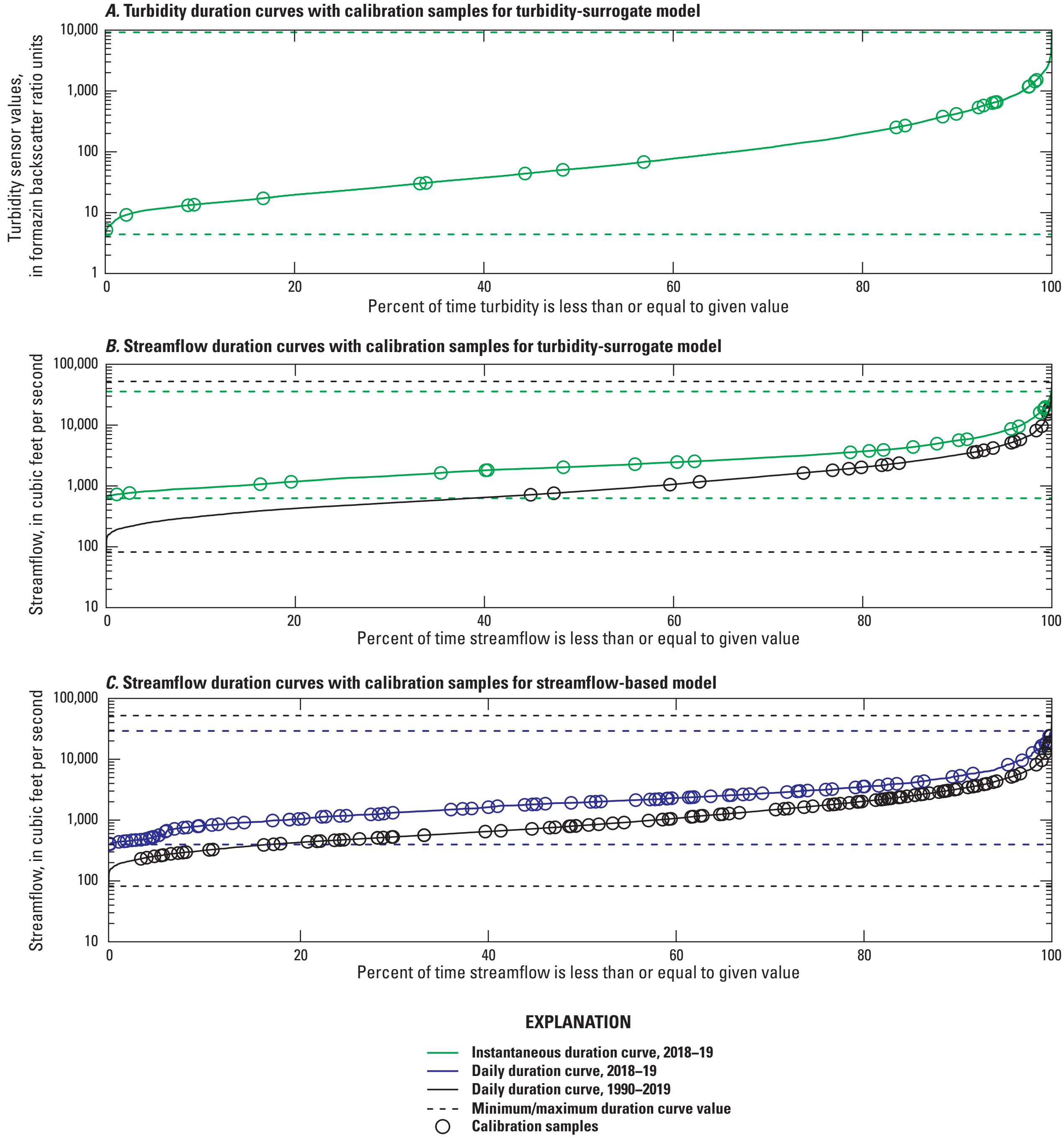

Figure 2. Duration curves with calibration samples for Turkey River at Garber, Iowa (U.S. Geological Survey station 05412500; U.S. Geological Survey, 2020). *A–B*, total phosphorus turbidity-surrogate model. *C*, streamflow-based model.

For streamflow-surrogate calibration samples, total phosphorus concentrations ranged from 0.03 to 2.5 mg/L, with orthophosphate concentrations (<0.02 to 0.54 mg/L) accounting for as much as 78 percent of total phosphorus (mean 38 percent). Daily mean streamflow on sampled days ranged from 231 to 24,300 ft^3/s, coinciding with less than the minimum for the study period to greater than the 99th percentile relative to either the estimation period or the long-term period (table 1).

Turbidity sensor records beginning March 2018 include data gaps because deployments are seasonal and because of sensor fouling or other problems. Turbidity sensor records include approximately 65 percent of days for 2018 and 63 percent for 2019, with the largest gaps from December through March when sensors are removed for the winter. The maximum sampled turbidity coincided with 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

The following section presents models selected for total phosphorus concentrations 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 2018–19.

Total Phosphorus Models

The regression models for total phosphorus concentrations at the selected site were based on turbidity and streamflow (table 2). Though the primary model was based on turbidity, an alternate streamflow-based model was applied during gaps to obtain a more complete record of concentration despite periods of missing sensor data (table 2).

The turbidity-surrogate total phosphorus model had good empirical fit, with an adjusted coefficient of determination (R^2) of approximately 0.97, a root mean square error of approximately 0.191, and a retransformation bias-correction factor of 1.02 (table 2, fig. 3). The turbidity-surrogate total phosphorus model included calibration samples collected through the range of observed conditions during the study period. The alternate streamflow-based total phosphorus model had marginal fit, with adjusted R^2 value approximately 0.74, root mean square error of 0.550, and a retransformation bias-correction factor of 1.16 (table 2, fig. 3). Because calibrations nearly cover the observed range of conditions for explanatory variables, models were extrapolated beyond the sampled range. No outliers were excluded from the turbidity-surrogate total phosphorus model. From the streamflow-based model, the three excluded outliers did not represent extremes in streamflow and therefore the model range was not constrained. Samples excluded from the streamflow-based model were collected on December 14, 2017; February 5, 2018; and August 6, 2018.

Total Phosphorus Concentrations, Loads, and Yields

Total phosphorus concentrations, loads, and yields are summarized for the Turkey River at Garber, Iowa (USGS station 05412500), and compared with sites with previously published total phosphorus surrogate models (table 3; fig. 1; Garrett, 2019; U.S. Geological Survey, 2020). Previous surrogate sites included Maquoketa River near Green Island, Iowa (USGS station 05418720); South Raccoon River at Redfield, Iowa (USGS station 05484000); and West Nishnabotna River at Randolph, Iowa (USGS station 06808500). Annual summaries are based on calendar years.

Table 2. Total phosphorus concentration regression models, Turkey River at Garber, Iowa (U.S. Geological Survey station 05412500).

[Adj. R^2, Adjusted coefficient of determination; RMSE, root mean square error; BCF, bias-correction factor; *n*, count; TP, total phosphorus concentration in milligrams per liter; TURB, turbidity in formazin backscatter ratio units; Q, streamflow in cubic feet per second]

Model	Start date	End date	Regression model	Model diagnostics				Summary of model input variables		
				Adj. R^2	RMSE	BCF	*n*	Variable and range	Mean	Median
Turbidity surrogate	3/27/2018	Current, as of publication	$TP = 0.017353 \times TURB^{0.63529}$	0.9733	0.191	1.02	24	*TURB* 5.2–1,520	428	284
Streamflow based	1/1/2018	Current, as of publication	$TP = 0.0003891366 \times Q^{0.851}$	0.738	0.550	1.16	93	*Q* 231–24,300	2,650	1,530

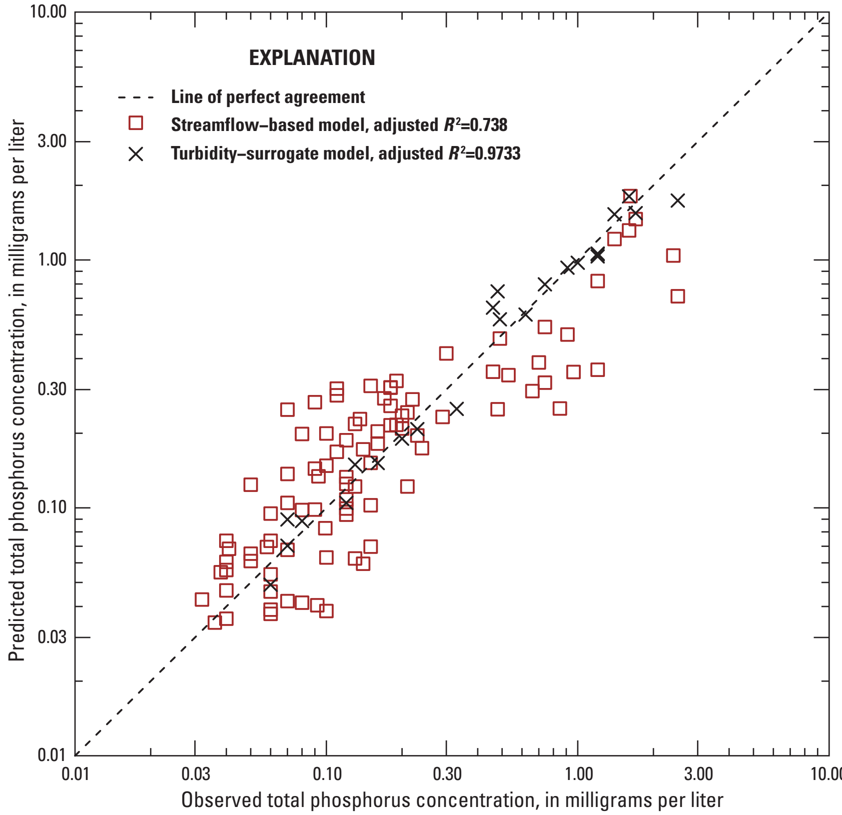

Figure 3. Observed and computed total phosphorus concentration.

Daily mean total phosphorus concentrations computed at the Turkey River at Garber, Iowa (USGS station 05412500), ranged from 0.051 to 2.30 mg/L (table 3). The greatest sample concentration at this site was 2.5 mg/L (table 1). The maximum sampled turbidity value was 1,520 FBRUs (table 1). The 15-minute turbidity data exceeded 1,520 FBRUs at the site on 25 days, totaling less than 176 hours in the approximately 22 months of data collection. Among the four sites, computed daily mean concentrations ranged from 0.026 to 5.41 mg/L. Computed total phosphorus daily loads at the Turkey River at Garber, Iowa, ranged from 0.0678 to 181 tons/day, and daily yields ranged from 0.0878 to 234 pounds per square mile per day. Annual total phosphorus loads for the Turkey River at Garber, Iowa, were fairly consistent for 2018 and 2019—1,740 and 1,490 tons per year, respectively. Yields provide a better comparison among sites than loads, and annual total phosphorus yields for the four sites ranged from 0.885 to 4.11 pounds per acre per year (lb/acre/yr) (table 3).

The statewide baseline (1980–96) total phosphorus load is approximately 23,800 tons per year (equivalent to an annual statewide yield of 1.32 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; fig. 4). 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 watersheds that drain Iowa (Iowa Department of Agriculture and Land Stewardship and others, 2019). Mean statewide annual total phosphorus yield for the benchmark period was 1.08 lb/acre/yr.

Table 3. Summary of total phosphorus concentrations, loads, and yields.

[mg/L, milligram per liter; Max, maximum; Min, minimum; %, percent; ton/d, U.S. short ton per day; lb/mi^2/d, pound per square mile per day; ton/yr, U.S. short ton per year; lb/acre/yr, pound per acre per year; USGS, U.S. Geological Survey; mi^2, square mile]

Year	Daily mean concentration, mg/L				Concentration computed days		Daily load, ton/d				Daily yield, lb/mi^2/d				Load and yield computed days		Annual load, ton/yr	Annual yield, lb/acre/yr
	Mean	Median	Max	Min	Count	%	Mean	Median	Max	Min	Mean	Median	Max	Min	Count	%		
Turkey River at Garber, Iowa (USGS station 05412500, drainage area 1,545 mi^2)																		
2018	0.373	0.239	2.30	0.051	236	64.7	4.78	0.806	144	0.0678	6.19	1.04	186	0.0878	364	99.7	1,740	3.53
2019	0.353	0.205	1.95	0.076	229	62.7	4.07	1.07	181	0.169	5.27	1.39	234	0.219	365	100	1,490	3.01
Maquoketa River near Green Island, Iowa (USGS station 05418720, drainage area 1,869 mi^2)																		
2014	0.195	0.160	0.462	0.094	76	20.8	2.00	0.693	37.0	0.159	2.14	0.741	39.6	0.170	262	71.8	729	1.22
2015	0.272	0.199	1.53	0.084	193	52.9	2.00	0.516	31.4	0.143	2.14	0.552	33.6	0.154	364	99.7	732	1.22
2016	0.291	0.207	1.66	0.075	219	59.8	2.19	1.33	36.0	0.409	2.34	1.43	38.5	0.438	364	99.5	800	1.34
2017	0.190	0.143	1.35	0.026	230	63.0	1.45	0.782	23.7	0.0662	1.55	0.837	25.3	0.0708	365	100.0	529	0.885
2018	0.082	0.070	0.142	0.046	24	6.6	6.04	1.12	110	0.143	6.46	1.20	117	0.153	279	76.4	2,198	3.68
South Raccoon River at Redfield, Iowa (USGS station 05484000, drainage area 994 mi^2)																		
2016	0.287	0.195	2.65	0.069	235	64.2	1.36	0.347	42.1	0.0607	2.74	0.699	84.7	0.122	297	81.1	499	1.57
2017	0.306	0.220	1.94	0.072	247	67.7	0.938	0.219	32.5	0.0440	1.89	0.440	65.3	0.0885	364	99.7	342	1.08
West Nishnabotna River at Randolph, Iowa (USGS station 06808500, drainage area 1,326 mi^2)																		
2016	0.787	0.525	5.35	0.297	194	53.0	4.77	2.16	95.4	0.603	7.19	3.26	144	0.909	365	99.7	1,740	4.11
2017	0.776	0.551	5.41	0.313	175	47.9	2.55	0.780	82.8	0.345	3.84	1.18	125	0.521	365	100	930	2.19
2018	0.622	0.433	3.79	0.163	247	67.7	2.71	1.01	56.5	0.275	4.08	1.53	85.2	0.414	365	100	988	2.33
2019	0.520	0.363	3.73	0.078	233	63.8	2.82	1.06	62.7	0.200	4.26	1.60	94.5	0.301	361	98.9	1,031	2.43

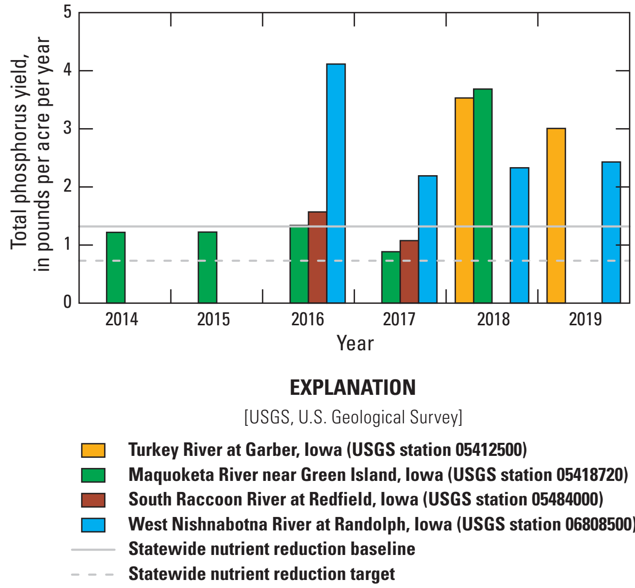

Figure 4. Mean total phosphorus yield relative to Iowa phosphorus-reduction baseline and goal for statewide load (Iowa Department of Agriculture and Land Stewardship and others, 2019).

Summary

In support of nutrient reduction strategies, total phosphorus loads and yields were computed based on continuously monitored turbidity sensor data for more accurate computations compared to methods based on infrequent sample collection and continuous streamflow. These more accurate computations are needed to track annual progress toward nutrient reduction goals at specific sites and across Iowa. In-stream sensors recorded continuous turbidity in the Turkey River at Garber, Iowa (U.S. Geological Survey station 05412500), 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 Turkey River at Garber, Iowa, described relations among total phosphorus concentrations from discrete samples and continuous sensor data to allow computation of continuous total phosphorus concentrations.

Total phosphorus loads computed for the Turkey River at Garber, Iowa, were based on a surrogate regression model with turbidity, with an alternate model based on streamflow applied at a daily time step to fill gaps in sensor data. The total phosphorus turbidity-surrogate model at the selected site was much better at predicting total phosphorus concentrations (adjusted coefficient of determination=0.97) than the alternate streamflow-based model (adjusted coefficient of determination=0.74). The alternate model was valuable to obtaining a more complete record of concentrations and loads despite gaps in sensor data. Annual total phosphorus loads for the Turkey River at Garber, Iowa, were 1,740 and 1,490 tons per year for 2018 and 2019, respectively. Annual total phosphorus yields for the Turkey River at Garber, Iowa, were 3.53 and 3.01 pounds per acre per year (lb/acre/yr) for 2018 and 2019, respectively. Mean annual total phosphorus yield at sites with previously published surrogate models for the Maquoketa River, the South Raccoon River, and the West Nishnabotna River ranged from 0.89 to 4.11 lb/acre/yr. For comparison, a mean statewide yield of 0.73 lb/acre/yr would be needed to achieve the total phosphorus-reduction goal.

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