Prepared in cooperation with the Iowa Department of Natural Resources

The Use of Continuous Water-Quality Time-Series Data to Compute Nutrient Loadings for Selected Iowa Streams, 2008–17

Scientific Investigations Report 2019–5054

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

Cover. Photograph showing Turkey River in northeastern Iowa with continuous water-quality sensors during a flood in June 2014. Photograph by Lance R. Gruhn, U.S. Geological Survey.

Back cover. Center: Photograph showing water marks on the bridge that illustrate the wide range of streamflow conditions at this site on the Nodaway River in southwestern Iowa with continuous water-quality sensors. Photograph by Joseph G. Gorman, U.S. Geological Survey.
Lower left: Photograph showing turbid stream water flowing through a protective sensor pipe. Photograph by Richard L. Kopish, U.S. Geological Survey.
Lower right: Photograph showing sensor with anti-fouling wiper for extended deployment. 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

U.S. Geological Survey, Reston, Virginia: 2019

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
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 square mile per day ($lb/mi^2/d$)	0.17515	kilogram per square kilometer per day ($kg/km^2/d$)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8.$$

Datum

Horizontal coordinate information is referenced to the Universal Transverse Mercator (UTM) coordinate system, zone 15 North.

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

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

Abbreviations

dTime	centered date
FBRU	formazin backscatter ratio unit
FNU	formazin nephelometric unit
IADNR	Iowa Department of Natural Resources
IASHL	Iowa State Hygienic Laboratory
LTRM	Long Term Resource Monitoring
NO_3	nitrate
Q	streamflow
R^2	coefficient of determination
TP	phosphorus, unfiltered
TURB	turbidity
USGS	U.S. Geological Survey

The Use of Continuous Water-Quality Time-Series Data to Compute Nutrient Loadings for Selected Iowa Streams, 2008–17

By Jessica D. Garrett

Abstract

In support of nutrient reduction efforts, nitrate (as nitrate plus nitrite) and phosphorus loads and yields were computed for selected streams in Iowa based on continuously monitored sensor data for 2008–17 and 2014–17, respectively. Sample data were used to assess nitrate sensor bias and to create phosphorus-turbidity surrogate models. Where needed, nitrate loads were corrected for site-specific sensor bias, which was determined to be as high as 9.25 percent. Nitrate loads presented in this report using continuous (generally 15-minute interval) data were on average 4 percent less, but as much as 38 percent less, than annual loads computed from daily mean nitrate concentrations not corrected for sensor bias. Streamflow-based phosphorus models had poorer fit (adjusted coefficient of determination values less than 0.75) than turbidity-based models (adjusted coefficient of determination approximately 0.9). However, alternate models based on streamflow were used to obtain a more complete annual phosphorus load despite seasonal and fragmentary sensor data.

Mean annual nitrate yields for 18 selected sites (96 site-years) ranged from 1.68 to 164 pounds per square mile per day (lb/mi^2/d), compared to 19.4 lb/mi^2/d average statewide yield needed to achieve the nitrate-reduction goal. Mean annual phosphorus yields for selected sites on the Maquoketa River, South Raccoon River, and West Nishnabotna River range from 1.57 to 7.19 lb/mi^2/d, compared to 1.06 lb/mi^2/d average statewide yield needed to achieve the phosphorus-reduction goal.

Introduction

The U.S. Geological Survey (USGS) and the Iowa Department of Natural Resources (IADNR) cooperatively studied nitrate and phosphorus loads using surrogate relations in several streams. Eutrophication of local and downstream waters, specifically an abundance of the nutrients nitrogen and phosphorus, is a high-priority issue in the Mississippi River Basin (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, 2017) and local Iowa waters (Iowa Department of Agriculture and Land Stewardship and others, 2017a). Nutrient reduction goals in Iowa focus on nitrate loads as the dominant form of nitrogen, particularly for agricultural nonpoint sources from a landscape with pervasive subsurface drainage. Though laboratory and sensor measurements for nitrate include nitrite, nitrite is negligible in Iowa surface waters (Garrett, 2012), and the term “nitrate” is used for nitrate plus nitrite throughout this report.

Using consistent methods applied across large scales, Iowa streams rank among the largest contributors to total Mississippi River Basin nutrient loads (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, 2017b; Jones and others, 2018). The nutrient reduction strategy in Iowa (Iowa Department of Agriculture and Land Stewardship and others, 2017a), as in other Midwest States (Anderson and others, 2016; Illinois Environmental Protection Agency and others, 2015; Ohio Environmental Protection Agency and others, 2016), calls for large reductions in nutrient delivery to the Gulf of Mexico; the reduction goal for Iowa is 45 percent. Several traditional monitoring and load-computation approaches may be able to detect such large changes, but there also is a need to detect lesser interim changes.

Load-calculation methods based on infrequent (weekly to monthly) samples may not be accurate enough to assess interim progress toward load reduction goals because load-calculation estimation errors can be quite large. Aulenback and others (2007, updates through 2016) reported load estimates for the Iowa River at Wapello, Iowa (05465500), for 1978–2016 with mean annual 95-percent confidence intervals for predicted fluxes of 42 percent for phosphorus and 76 percent for nitrate (Aulenbach and others, 2007); Garrett (2012) reported confidence intervals of 41 percent for phosphorus flux and 31 percent for nitrate flux for 10 streams in Iowa during 2004–08.

Many factors affect load-calculation errors. For example, Johnes (2007) highlights basin characteristics, such as low base-flow index and high population densities, that make load estimates more sensitive to errors. Lee and others (2016) describe greater sensitivity to errors for constituents with strongly positive or log-curvilinear relation between concentration and streamflow. Although greater sensitivity to errors was common for some constituents (total phosphorus and suspended sediment), the relation was ultimately site-specific. Several researchers concluded no single model performed well across multiple sites or years (Schilling and others, 2017a; Preston and others, 1989; Lee and others, 2016), and that any of these models can be grossly inaccurate or biased when model assumptions are not met (Stenback and others, 2011; Preston and others, 1989; Hirsch, 2014).

In contrast, monitoring with continuous data improves accuracy of load calculation (Cassidy and Jordan, 2011; Duan and others, 2014; Jones and others, 2012; Jones and others, 2018; Pellerin and others, 2014; Reynolds and others, 2016; Rozemeijer and others, 2010; Terrio and others, 2015). Jones and others (2012) demonstrated about a 10-fold improvement in the accuracy of assessing phosphorus regulatory compliance, as percent of time exceeding a concentration-based criterion, based on daily versus monthly data. Reynolds and others (2016) showed precision improved 9–12 percent for multiple metrics—mean concentration, exceedance of concentration-based criterion, peak concentrations, and total loads—with nitrate sampling frequency increased from monthly to daily. However, Cassidy and Jordan (2011) determined none of the typical sampling regimes (weekly, daily, event-triggered, or random) allowed load calculations accurate enough to assess interannual changes in phosphorus loads for very small (3–5 square kilometers) basins.

Though current phosphorus sensor technologies (Warwick and others, 2013) are not as field robust or accurate as ultraviolet nitrate sensors, many of the benefits of continuous data can be obtained with surrogate-derived concentration data (Baldwin and others, 2012; Jones and others, 2012; Rasmussen and others, 2009; Stubblefield and others, 2007). Surrogates, by definition, use indirect data intended to provide information about something 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 phosphorus, turbidity makes sense physically because, in many Iowa streams, total phosphorus loads are dominated by particulate-bound phosphorus (Garrett, 2012). Turbidity is a measure of the scatter of light from particles in the water, particularly fine-grained sediment. Several studies have determined turbidity to be a good predictor for total phosphorus, that additional parameters associated with dissolved constituents or biological processes can improve turbidity-based models, and that site specificity is important (Christensen and others, 2006; Rasmussen and others, 2005; Schaepe and others, 2014; Schilling and others, 2017b).

Purpose and Scope

The purpose of this report is to describe procedures for computing a time series of concentrations and loads of nitrate and total phosphorus based on data from water-quality sensors in selected Iowa streams collected during 2008–17. Techniques and guidelines are discussed to develop and evaluate an unbiased nitrate load time series based on continuous sensor measurements verified with sampled data, and total phosphorus loads primarily based on empirical statistical regression between sensor measurements and sample results, with alternate models and filling procedures for periods with gaps in sensor data.

Continuous sensor data, sample results, regression models, and modeled continuous data are presented for selected sites. Continuous nitrate, turbidity, and water temperature data are summarized through time and through a range of seasonal and streamflow event conditions. Sample concentration data for nitrate, nitrogen, orthophosphate, phosphorus, and suspended solids are presented. Statistical regression models relating sensor data and sample results are described, with detail on model selection and diagnostics. Time-series nutrient (nitrate and phosphorus) concentrations and loads presented in this report and computed moving forward using the methods presented can be used to monitor changes in stream nutrients.

Sites

Water-quality samples and sensor data summarized in this report were collected in selected Iowa stream sites collocated with existing streamflow-gaging stations (fig. 1, table 1). The drainage area of nitrate and turbidity monitoring sites across the State vary from 3 to 12,500 square miles (mi^2). Of these, three sites with turbidity monitoring were selected for development of phosphorus surrogate relations—Maquoketa River near Green Island, Iowa; South Raccoon River at Redfield, Iowa; and West Nishnabotna River at Randolph, Iowa (USGS stations 05418720, 05484000, and 06808500, respectively).

Methods for Data Collection and Computation

In-stream sensors were used to record nitrate, turbidity, and temperature at 15-minute intervals during 2008–17. At selected sites with turbidity sensors, discrete water samples were collected during 2014–17 for calibration of phosphorus models. Quality-control samples were collected at all sites to assess sensor performance and consistency in data collection.

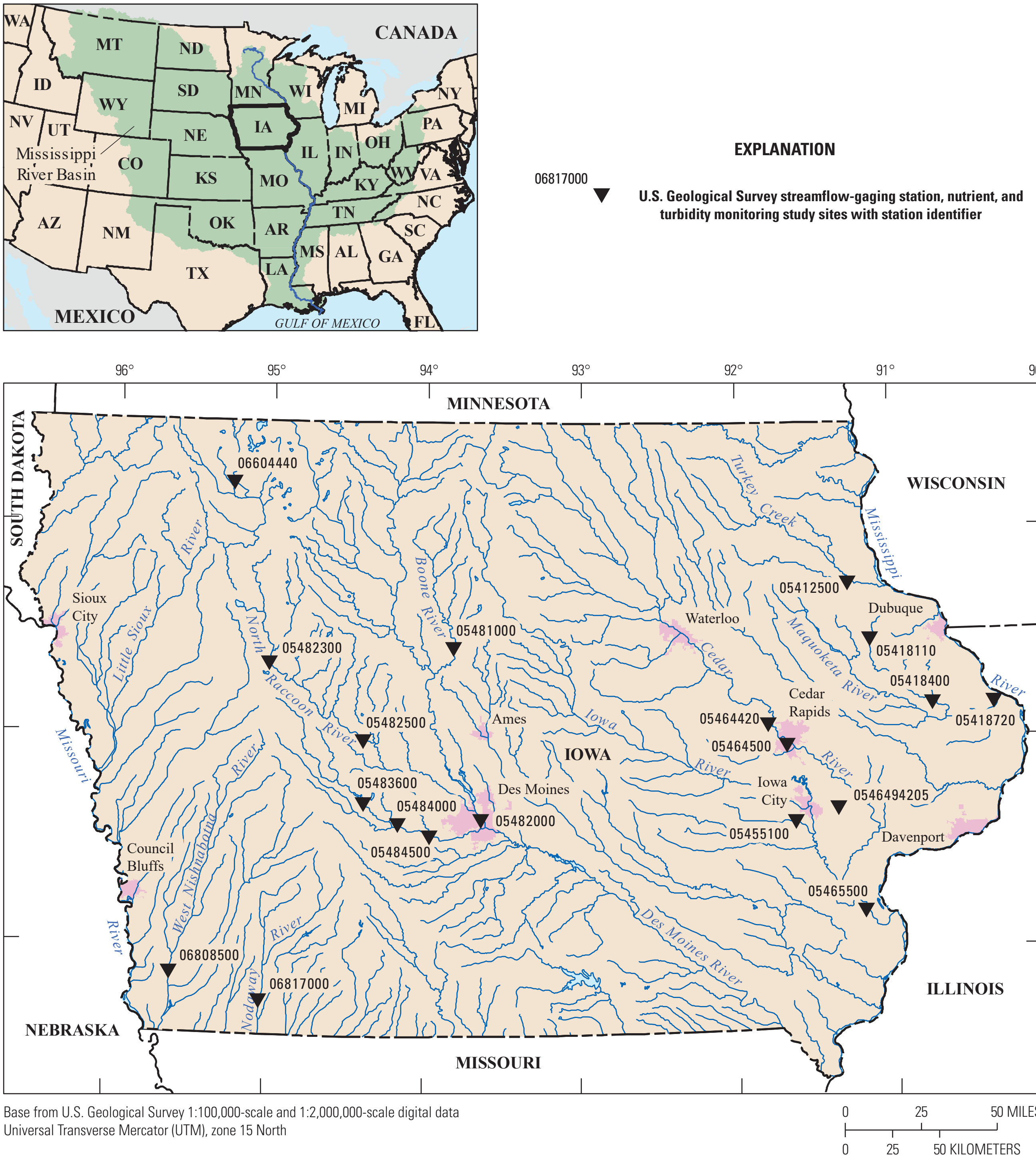

Figure 1. U.S. Geological Survey streamflow-gaging, nutrient, and turbidity monitoring station study sites in Iowa.

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

[USGS, U.S. Geological Survey; mi^2, square miles; nitrate, nitrate plus nitrite]

Site location	USGS site number	Drainage area, mi^2	Sensors	Start	End
Turkey River at Garber, Iowa	05412500	1,545	Nitrate	5/9/2012	Ongoing.
North Fork Maquoketa River below Bear Creek at Dyersville, Iowa	05418110	122	Nitrate, turbidity	4/12/2012	11/13/2014
North Fork Maquoketa River near Fulton, Iowa	05418400	505	Nitrate, turbidity	5/12/2012	11/12/2014
Maquoketa River near Green Island, Iowa	05418720	1,869	Nitrate, turbidity	5/23/2014	10/23/2018
Old Mans Creek near Iowa City, Iowa	05455100	201	Nitrate	5/18/2012	10/30/2015
Cedar River at Blairs Ferry Road at Palo, Iowa	05464420	6,342	Nitrate	10/14/2012	Ongoing.
Cedar River at Cedar Rapids, Iowa	05464500	6,510	Nitrate	4/14/2009	9/30/2012
Hoover Creek near 2nd Street at West Branch, Iowa	0546494205	2.76	Nitrate, turbidity[1]	3/7/2016	8/21/2017
Iowa River at Wapello, Iowa	05465500	12,500	Nitrate, turbidity	6/3/2009	Ongoing.
Boone River near Webster City, Iowa	05481000	844	Nitrate	3/15/2012	[2]10/2/2017
Des Moines River at 2nd Avenue at Des Moines, Iowa	05482000	6,245	Nitrate	9/24/2013	Ongoing.
North Raccoon near Sac City, Iowa	05482300	700	Nitrate	3/27/2008	Ongoing.
North Raccoon near Jefferson City, Iowa	05482500	1,619	Nitrate	4/3/2008	Ongoing.
Middle Raccoon River at Panora, Iowa	05483600	440	Nitrate	5/18/2010	[2]11/10/2015
South Raccoon River at Redfield, Iowa	05484000	994	Nitrate, turbidity[1]	3/3/2016	Ongoing.
Raccoon River at Van Meter, Iowa	05484500	3,441	Nitrate	3/2/2012	Ongoing.
Little Sioux River at 300th Street near Spencer, Iowa	06604440	523	Nitrate[3]	6/1/2012	10/1/2015
West Nishnabotna River at Randolph, Iowa	06808500	1,326	Nitrate, turbidity	3/2/2016	Ongoing.
Nodaway River at Clarinda, Iowa	06817000	762	Nitrate	5/30/2012	Ongoing.

[1]Sites with different period of record for nitrate or turbidity: nitrate at site 0546494205 ends 11/30/2016; turbidity at site 05484000 ends 11/13/2017.

[2]Additional data available from University of Iowa, 2019.

[3]Sites except 06604440 include water temperature monitoring.

Continuous Water-Quality Data Collection and Computation

Nitrate was monitored using Hach Nitratax plus sc probes (Hach Company, 2014). Turbidity was monitored using Hach Solitax plus sc probes (Hach Company, 2009) in formazin backscatter ratio units (FBRUs) or using FTS DTS-12 turbidity sensors (Forest Technology Systems, Inc., 2015a) in formazin nephelometric units (FNUs). Although FBRUs and FNUs measure infrared light, turbidity in FBRUs is a ratiometric measure of light backscatter at two detector angles, whereas FNU measurements use a single backscatter detection angle. 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. Temperature was monitored using a WATERLOG® H-377 temperature probe (Design Analysis Associates, Inc., 2007) or FTS DigiTemp submersible water temperature sensor (Forest Technology Systems, Inc., 2015b).

Field inspections of sensors and data processing followed methods described by Anderson (2005) and Wagner and others (2006), with several adaptations. Sensor servicing was avoided during streamflow events 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. The “bucket method” was employed in the field, using a sample of stream water taken before sensor cleaning for post-cleaning checks when a comparison meter was not available to document possible changing stream conditions. 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 with a multiparameter sonde, with multiple point grab samples analyzed with sensors from the site, or by comparison to flow-integrated samples.

The calibration threshold criteria for nitrate sensors was within 0.3 milligram per liter (mg/L) or 5 percent, and sensors were recalibrated when the calibration criteria were not met following verification during at least two consecutive visits using fresh standard solutions. 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.

Steps to process continuous water-quality records are described by Wagner and others (2006), with several adaptations. Data corrections were applied to nitrate data if the fouling and calibration errors exceeded the data correction criteria, typically the greater of 0.3 mg/L or 5 percent, though correction criteria for specific sites and periods varied somewhat, from 0.1 mg/L or 3 percent to 0.5 mg/L or 10 percent. The quality of the data was rated based on the severity of corrections applied: good within 0.5 mg/L or 10 percent, fair within 0.8 mg/L or 15 percent, and poor within 2.0 mg/L or 20 percent, which is the maximum allowable correction. The data-quality rating was downgraded one category for days with fragmentary data or other noted problems.

Water Sample Collection and Analysis

Discrete water samples for surrogate development at two sites were collected monthly by IADNR and Iowa State Hygienic Laboratory (IASHL) staff and during targeted events by USGS staff. The USGS sample collection protocol for the South Raccoon River at Redfield, Iowa (05484000), and the West Nishnabotna River at Randolph, Iowa (06808500), was consistent with IADNR and IASHL protocol (Mary Skopec, IADNR,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 acidified if needed, chilled, and transported to the laboratory and analyzed within 24 hours. Samples for surrogate development were analyzed by the IASHL facility in Ankeny, Iowa, for phosphorus, Kjeldahl nitrogen, ammonia, orthophosphate, and nitrate by colorimetric methods (U.S. Environmental Protection Agency methods 365.4, 351.2, 350.1, 365.1, and 353.2, respectively), and for suspended solids by gravimetric method (Fishman and Friedman, 1989; Iowa Department of Natural Resources, 2019; U.S. Environmental Protection Agency, 1983).

Discrete water samples for the surrogate model development at one site were obtained from another program. Approximately monthly water-sample data for the Maquoketa River near Green Island, Iowa (05418720), were accessed from the Upper Mississippi River Restoration Long Term Resource Monitoring (LTRM) program (Soballe and Fischer, 2004; U.S. Geological Survey, 2018a), with occasional additional sample data available in the National Water Information System (U.S. Geological Survey, 2018b).

Quality-Control Samples

Quality-control samples were used to describe variability in the data. Concurrent replicates were collected at sites with sample collection by the IADNR, IASHL, and USGS to describe comparability of data collected by the different agencies and verify that consistent procedures were maintained. Nitrate sensor check samples were collected every 4 to 6 weeks to describe nitrate sensor performance in the stream relative to laboratory data. Optical nitrate sensors are theoretically susceptible to matrix interference, such as from certain organic compounds that absorb light near the wavelengths used by the sensor (Pellerin and others, 2013). Nitrate sensor check samples collected in addition to model calibration samples were analyzed by the USGS National Water Quality Laboratory in Lakewood, Colorado (Patton and Kryskalla, 2011).

Methods for Continuous Concentration Models

Candidate multiple linear regression models for phosphorus concentration included explanatory variables for turbidity, nitrate, temperature, and streamflow with transformed and untransformed variables prepared in R (R Core Team, 2017), including natural logarithm and time-series transforms. Change in streamflow, a time-series transform, was computed as difference between streamflow at each step (instantaneous value or daily mean) and the moving mean of the preceding 30 days, similar to streamflow variability terms described by Garrett (2012). The model was fitted to log-transformed phosphorus to provide a better linear fit. The log-transformed model was retransformed to the original units so that phosphorus can be calculated directly. The retransformation introduces a model bias in the calculated constituent. This model bias was corrected using a nonparametric smearing model bias correction factor (Duan, 1983).

Explanatory time-series variables for primary models used a 15-minute time step, with small gaps filled by linear interpolation. Small gaps are typically up to a few hours for turbidity, or several days for nitrate. Models presented in this report apply linear interpolation for nitrate across 10-day gaps, which is slightly more conservative than other load estimates for Iowa streams (Jones and others, 2018). However, a 10-day gap is consistent with findings of several researchers that linear interpolation for nitrate load calculation is fairly robust (Hirsch, 2014; Lee and others, 2016; Schilling and others, 2017a). The lengths of small gaps are site-specific and much shorter for turbidity than gaps for nitrate to avoid misrepresenting typical event behavior for each site and parameter. Data filled across small gaps were used only for load computations and were not used for published sensor data records or for matched sample-sensor data for model calibration.

Concentrations and loads were evaluated with an alternate model, such as one based on streamflow, to fill longer periods with missing sensor surrogate data, such as through the winter, when operation of sensors is sometimes impractical. Variables for alternate models use a daily time step, using daily mean data, because streamflows in periods with gaps in sensor data, such as ice periods, often are estimated at a time step longer than typical 15-minute data interval.

Diagnostic tests and plots were considered in selection of the candidate models. Preferred models had low residual variance, residual plots indicating normality and homoscedasticity, low correlation among multiple explanatory variables indicated by low pairwise correlation and a low multicollinearity statistic (variance inflation factor), and mean observed (sampled) to estimated ratio near 1.0 (maximum range allowed 0.5 to 2) for values during known samples.

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. Though a complete time series of 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. If appropriate, the applied range of a model was restricted. For example, if samples with the lowest turbidity values were excluded as outliers, the resulting model was not used during periods of low turbidity, and an alternate model was used, if available.

Methods for Generation of Time-Series Concentrations and Loads

Continuous (typically 15-minute interval) and daily mean nitrate and phosphorus concentrations are published in the National Water Information System (U.S. Geological Survey, 2018b). Nitrate concentration data were collected following methods described by Wagner and others (2006) and Pellerin and others (2013), with specific adaptations described previously in the Methods for Data Collection and Computation section. Other substances absorbing ultraviolet light at the wavelengths measured to compute nitrate concentration can affect nitrate sensor readings, resulting in a sensor bias. Sensor bias, assessed as the difference between nitrate sensor values and laboratory results, was highly variable through time and among sites, so individual time-series concentration data were not corrected for sensor bias (fig. 2*A*). Phosphorus concentration data were computed first from the primary surrogate model, based on turbidity, with alternate models applied at a daily time step to fill gaps in the primary model (fig. 2*B*).

Nitrate and phosphorus loads, in U.S. short tons 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 used continuous concentrations and continuous streamflow to compute continuous loads, which were then summarized as daily mean loads.

Though sensor-bias corrections were not applied to published concentration data, site-specific sensor bias correction was applied to the computation of nitrate loads to obtain more

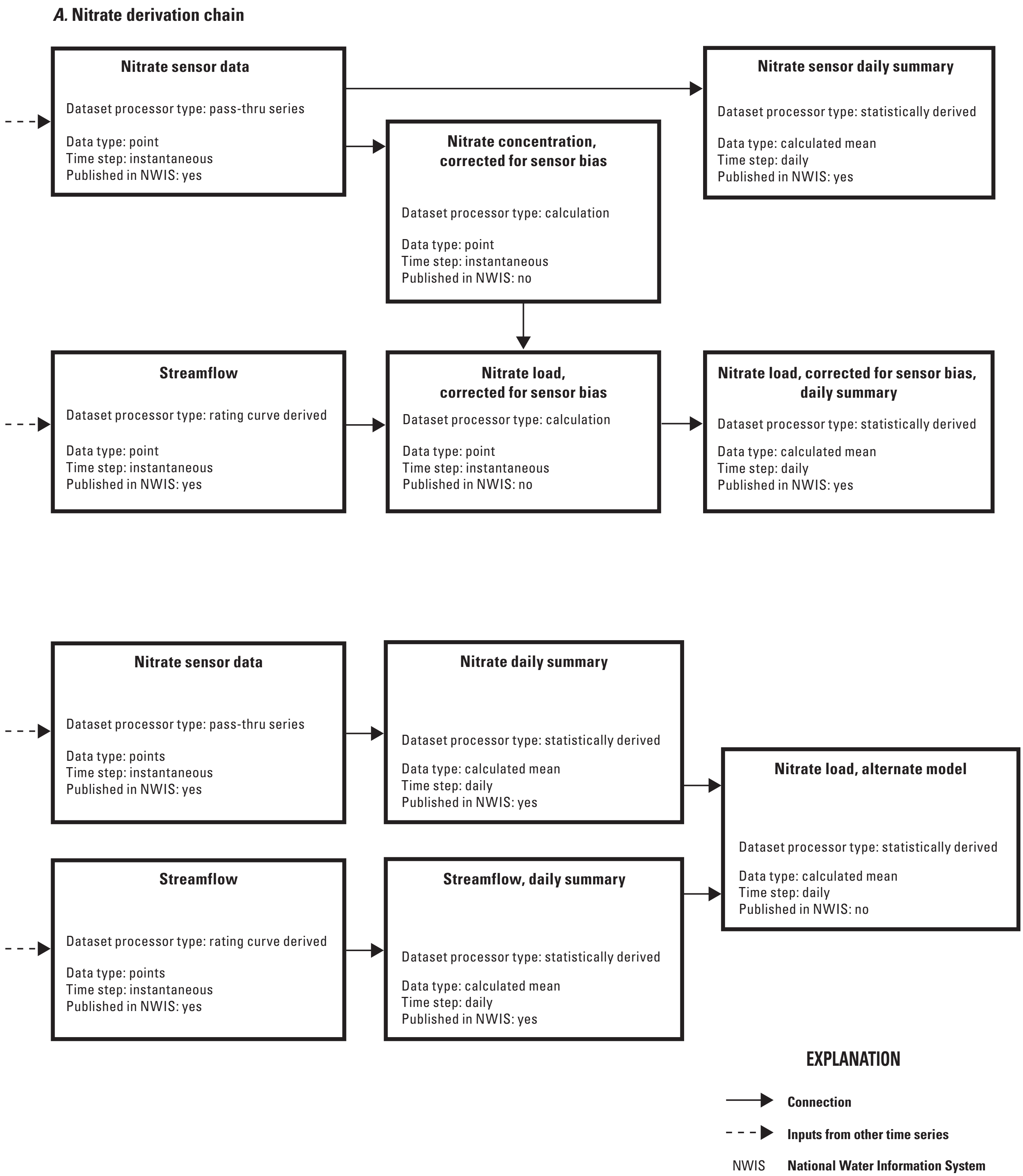

Figure 2. Derivation chains for nitrate and phosphorus concentration and load time series published to National Water Information System and unpublished intermediaries. *A*, Nitrate derivation chain. *B*, Phosphorus derivation chain.

B. **Phosphorus derivation chain**

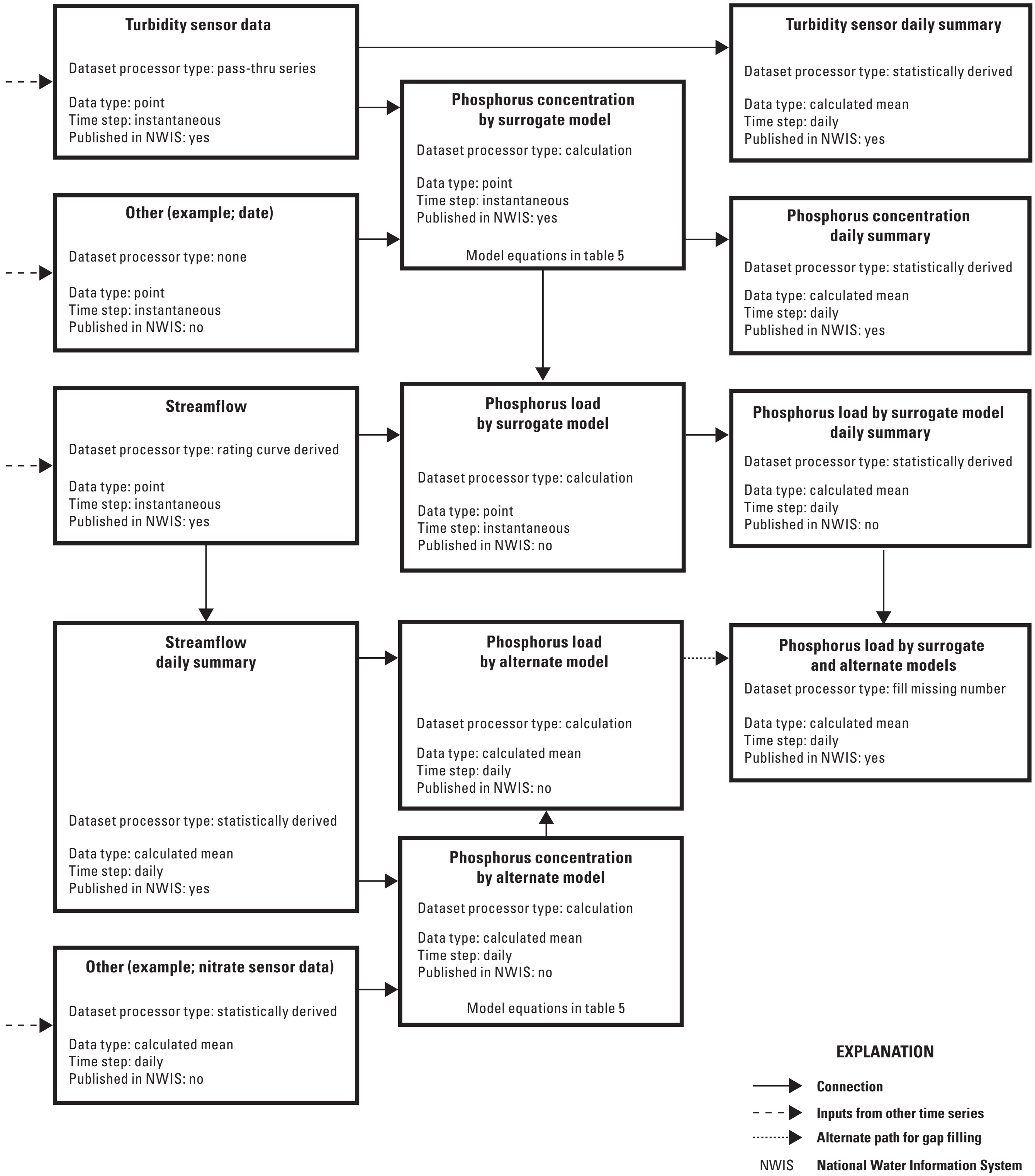

Figure 2. Derivation chains for nitrate and phosphorus concentration and load time series published to National Water Information System and unpublished intermediaries. *A*, Nitrate derivation chain. *B*, Phosphorus derivation chain.—Continued

accurate and unbiased loads (fig. 2*A*). This correction was applied to the concentration data used for load computation if the mean sensor bias was (1) statistically significant (based on 95-percent confidence interval), and (2) outside sensor specifications (greater of plus or minus 0.5 mg/L or 3 percent).

An alternate computation method was used to fill gaps in phosphorus estimates for a daily time step based on daily mean concentrations and daily mean streamflow (fig. 2*B*). The alternate computation made use of the phosphorus concentrations from alternate surrogate models, which were computed only at a daily step.

Sample Water-Quality and Sensor Data

The following section presents summaries of calibration samples used for phosphorus models and summaries of continuous sensor data used for nitrate and phosphorus load and yield calculations. Surrogate model calibration samples should represent the full range of environmental conditions, covering the range of predictor variables (turbidity), as well as other conditions affecting the model, such as seasonality or hydrologic conditions.

Calibration Samples

To evaluate how well samples represented environmental conditions, the ranges of sensor readings during sample collection were compared with the ranges of sensor conditions during the study (table 2, fig. 3). The range of sampled streamflow also was compared with the long-term (30-year) streamflows. Individual sample results are presented in appendix 1.

Sample collection methods at Maquoketa River near Green Island, Iowa (05418720; Soballe and Fischer, 2004) did not specify event targeting for high-streamflow samples; therefore, such targeted samples were not collected during the 3.5-year period of sensor operation. Nevertheless, ranges of sensor values during sample collection cover the range of conditions for the period. Nitrate sample concentrations ranged from 2.66 to 12.7 mg/L, compared to daily mean sensor readings, which ranged from 3.0 to 15.6 mg/L during the calibration period (table 2). Two samples with nitrate concentrations lower than the minimum range of nitrate time-series data were collected during winter seasonal gaps in the nitrate time-series data. Phosphorus sample concentrations ranged from 0.082 to 2.16 mg/L. Orthophosphate samples ranged from 0.004 to 0.727 mg/L but accounted for as much as 50 percent of phosphorus (mean 19 percent) in each sample. Daily mean streamflow on sampled days ranged from 702 to 18,900 ft^3/s, compared to a range of 570 to 28,000 ft^3/s during the calibration period (U.S. Geological Survey, 2018b). Because the streamflow period of record at Maquoketa River near Green Island, Iowa (05418720) was too short, long-term (30-year) streamflow data were based on the next upstream site, Maquoketa River near Maquoketa, Iowa (05418500). The drainage area of this site is 1,553 mi^2, 17 percent smaller than Maquoketa River near Green Island, Iowa (05418720). The long-term streamflow at 05418500 ranged from 110 to 45,900 ft^3/s and the highest sampled daily mean streamflow was greater than the 99th percentile for streamflow at the Maquoketa River near Green Island, Iowa (05418720), during the study (U.S. Geological Survey, 2018b).

Samples collected at the South Raccoon River at Redfield, Iowa (05484000), covered the range of nitrate concentrations, turbidity, and streamflow during the study period (table 2, fig. 3). Nitrate sample concentrations ranged from 1.4 to 11.0 mg/L, whereas daily mean sensor readings ranged from 0.6 to 13.0 mg/L during the calibration period. Phosphorus sample concentrations ranged from 0.08 to 2.6 mg/L. Although orthophosphate concentrations were much less than phosphorus concentrations overall (0.02 to 0.70 mg/L), orthophosphate in individual samples accounted for as much as 63 percent of phosphorus (mean 34 percent). Streamflows during the approximately 20-month period of sample collection were similar to or greater than the long-term average, though peak flows during the study were not historic peaks (fig. 3). Daily mean streamflow on sampled days ranged from 144 to 3,900 ft^3/s, compared to a range of 137 to 7,200 ft^3/s during the calibration period, or the long-term (30-year) range of 30 to 33,600 ft^3/s (U.S. Geological Survey, 2018b). The greatest sampled daily mean streamflow coincided with the 99th percentile for the study period, and 98th percentile relative to long-term streamflow.

Similarly, samples collected at the West Nishnabotna River at Randolph, Iowa (068088500), covered the range of nitrate concentrations, turbidity, and streamflow conditions during the 20-month study period. Nitrate sample concentrations ranged from 3.6 to 9.6 mg/L, compared to daily mean sensor readings, which ranged from 3.8 to 11.6 mg/L during the calibration period. Phosphorus sample concentrations ranged from 0.22 to 6.5 mg/L. Orthophosphate samples ranged from 0.11 to 0.74 mg/L but accounted for as much as 74 percent of phosphorus (mean 34 percent). Streamflows during the study period were similar to or greater than the long-term average through most of the range of streamflows (table 2). Daily mean streamflow on sampled days ranged from 400 to 6,500 ft^3/s, compared to a range of 370 to 6,500 ft^3/s during the calibration period, and the long-term (30-year) range of 46 to 25,800 ft^3/s (U.S. Geological Survey, 2018b). The greatest sampled daily mean streamflow coincided with the greatest measured daily mean streamflow for the study period, and the 99th percentile daily mean streamflow relative to long-term streamflows.

Continuous Sensor Data Summary

Nitrate and turbidity sensor records are fragmentary for all sites because deployments are seasonal and sensor fouling or other problems can result in data gaps. Nitrate sensor records typically include 51 to 71 percent of days for each

Table 2. Summary of calibration samples and time series data.

[mg/L, milligram per liter; FNU, formazin nephelometric unit; FBRU, formazin backscatter ratio unit; ft³/s, cubic feet per second; USGS, U.S. Geological Survey; >, greater than; --, not applicable]

Statistic	Sample concentrations, mg/L			Time series data matched to samples			Time series data during study period			30-year daily mean
				Instantaneous	Daily mean		Instantaneous	Daily mean		
	Nitrate	Phosphorus	Orthophosphate	Turbidity, FNU or FBRU	Discharge, ft³/s	Nitrate, mg/L	Turbidity, FNU or FBRU	Discharge, ft³/s	Nitrate, mg/L	Discharge, ft³/s
Maquoketa River near Green Island, Iowa (USGS station number 05418720)[1]										
Maximum	12.7	2.16	0.727	1,590	18,900	12.3	>1,600	28,000	15.6	45,900
99th percentile	--	--	--	--	--	--	1,280	8,950	13.6	8,020
75th percentile	8.83	0.299	0.058	150	2,330	8.7	92	2,130	8.5	1,520
25th percentile	4.92	0.154	0.020	41	1360	4.8	23	1,070	5.4	581
Minimum	2.66	0.082	0.004	14	702	3.5	1.8	570	3.0	110
Count	46	46	46	26	46	35	66,804	1,314	865	11,025
South Raccoon River at Redfield, Iowa (USGS station number 05484000)										
Maximum	11.0	2.6	0.70	2,150	3,900	11.6	9,250	7,200	13.0	33,600
99th percentile	--	--	--	--	--	--	1,770	4,810	12.7	6,170
75th percentile	8.4	0.58	0.10	343	1,170	9.2	99	977	9.6	714
25th percentile	4.8	0.19	0.07	44	442	5.6	39	339	5.7	148
Minimum	1.4	0.08	0.02	[2]6.8	144	1.2	6.5	137	0.6	30
Count	26	26	26	20	26	26	44,751	652	619	11,030
West Nishnabotna River at Randolph, Iowa (USGS station number 06808500)										
Maximum	9.6	6.5	0.74	6,200	6,500	10.6	8,160	6,500	11.6	25,800
99th percentile	--	--	--	--	--	--	2,300	5,370	11.2	5,500
75th percentile	7.7	1.2	0.18	731	2,300	8.6	144	1,690	9.4	1,070
25th percentile	6.3	0.38	0.14	107	953	7.0	73	785	7.0	277
Minimum	3.6	0.22	0.11	20	400	3.8	17	370	3.8	46
Count	29	29	28	26	29	26	51,323	663	531	11,042

[1]The upper range of turbidity sensor at station 05418720 was 1,600 units. The 30-year streamflow statistics for Maquoketa River were based on upstream site Maquoketa River near Maquoketa, Iowa (05418500).

[2]The minimum instantaneous turbidity at station 05484000 was excluded from models as an overly influential outlier. The next least value was 29 units.

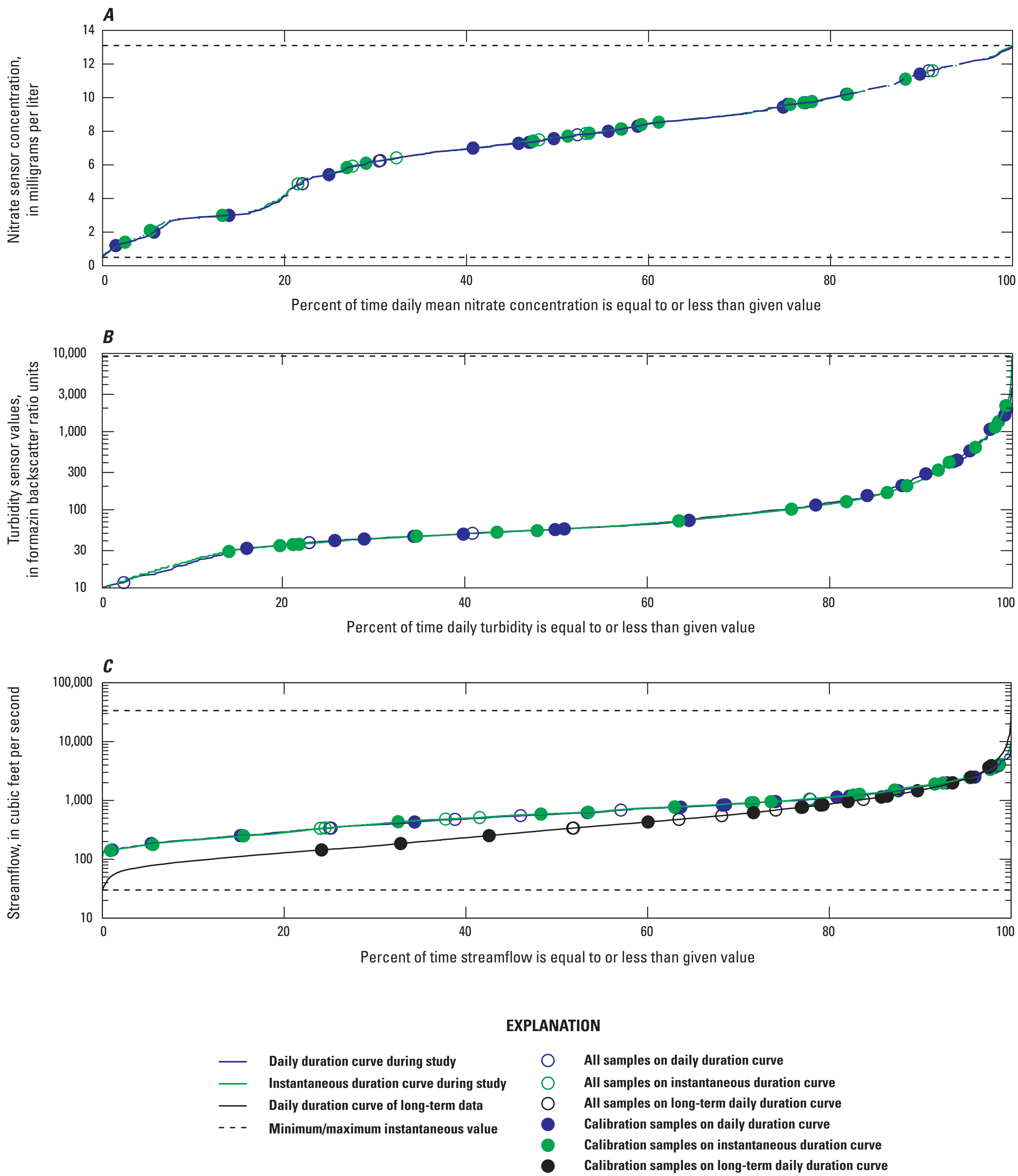

Figure 3. Nitrate, turbidity, and streamflow duration curves with sampled conditions, South Raccoon River at Redfield, Iowa (U.S. Geological Survey station 05484000; U.S. Geological Survey, 2018b).

year (interquartile range of annual percentage of days monitored, table 3), with the largest gaps from November through March. For phosphorus surrogate sites, turbidity records include 57, 74, and 84 percent of days from the beginning of the periods of record through 2017 for the sites Maquoketa River near Green Island, Iowa (05418720); South Raccoon River at Redfield, Iowa (05484000); and West Nishnabotna River at Randolph, Iowa (06808500), respectively.

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

In this section, results of site-specific nitrate sensor bias relative to laboratory samples and models selected for calculating phosphorus concentrations are described. Resulting nitrate and phosphorus concentrations, loads, and yields are summarized.

Nitrate

The following section presents results of site-specific nitrate sensor bias relative to laboratory samples and summarizes resulting nitrate concentrations, loads, and yields. Presented loads based on continuous data (typically 15-minute interval) also are compared with loads computed from daily mean data without sensor bias correction.

Nitrate Sensor Bias

Nitrate sensor bias, the difference between sensor data and laboratory results, generally was within sensor and laboratory accuracy and performance standards but demonstrated a slight positive sensor bias, typically within 5 percent, based on data from 36 sites in Iowa and Illinois from March 2008 through October 2017 (appendix 2). The sensor bias is described for three ranges of data to allow a uniform mean difference or percent difference (slope) for each range of data and to minimize the step in the calculated sensor bias correction between adjacent ranges (fig. 4, table 4). For example, the small step in figure 4 is evident between the mean percent difference and the mean difference for samples greater than 15 mg/L, though this break point was chosen to minimize this step. The mean difference (and 95-percent confidence limits) between sensor data and laboratory results among all 36 Iowa and Illinois sites was 0.14 (0.09 to 0.19) mg/L for sensor data less than or equal to 3 mg/L, 4.64 (3.90 to 5.42) percent for sensor data greater than 3 mg/L and less than or equal to 15 mg/L, and 0.70 (0.35 to 1.05) mg/L for sensor data greater than 15 up to the greatest sampled concentration, 40.3 mg/L (fig. 4; table 4). The greatest mean difference between sensor and laboratory results (9.25 percent) occurred at in the West Nishnabotna River at Randolph, Iowa, station. The computed mean sensor bias was applied for all ranges of data if sensor bias was significant in at least one range, to prevent discontinuities in the data from one range of data to another.

Nitrate Concentrations, Loads, and Yields

Nitrate sensor concentrations are summarized for selected sites, with loads and yields presented for sites with collocated nitrate sensor and streamflow data (table 3, fig. 5). Nitrate sensor values ranged from below detection to 30.9 mg/L (sensor operating range 0.1 to 45 mg/L). Annual mean nitrate loads ranged from 0.3 to 367 U.S. short tons per day (ton/d) for sites with a 100-fold range in drainage area. Loads were computed using sensor values below detection rather than computing censored (less than) loads, though this had a negligible effect on annual loads because low sensor values generally were concurrent with low streamflow. The site most affected by sensor values below detection was the North Raccoon River near Jefferson, Iowa (05482500), particularly in 2012 and 2017. In 2012, 31 percent of days used for annual load computation included sensor values below detection, but loads on these days accounted for only 0.16 percent of the annual total. In 2017, days with sensor readings below detection occurred on 14 percent of days and accounted for less than 0.01 percent of the total load.

Overall, mean yields (load per drainage area) for complete deployment seasons (excludes 3 site-years with less than 30 percent of days, occurring at the beginning of the site period of record in 2014 for Maquoketa River near Green Island, Iowa, station 05418720; in 2012 for Cedar River at Blairs Ferry Road at Palo, Iowa, station 05464420; and in 2013 for Des Moines River at 2nd Avenue at Des Moines, Iowa, station 05482000) ranged from 1.68 to 164 pounds per square miles per day ($lb/mi^2/d$). The lowest mean yield for many sites occurred in 2012, which was a notable drought year (National Oceanic and Atmospheric Administration National Centers for Environmental Information, 2013). Mean yields (per site) for 13 monitored sites in 2012 (excluding incomplete deployment seasons) ranged from 1.68 to 11.6 $lb/mi^2/d$. In 2013, by comparison, mean yields per site ranged from 14 to 164 $lb/mi^2/d$ (excluding incomplete deployment seasons). The statewide nitrate-reduction baseline is 307,000 tons per year (Iowa Department of Agriculture and Land Stewardship and others, 2017a), equivalent to mean statewide nitrate yield of 35.3 $lb/mi^2/d$. The 45-percent reduction goal would require a mean statewide nitrate yield of 19.4 $lb/mi^2/d$ to achieve this goal (fig. 5).

For comparison, table 3 also presents summaries of an alternate nitrate load computed at a daily time step without correction for sensor bias, which previously was used at several sites. The differences between mean annual loads from the two methods were within 10 percent for 83 of the 93 complete-season site-years. The mean annual loads, however, were higher (table 3) by the alternate computation for most site-years, relative to the more accurate loads based on a 15-minute time step that were corrected for sensor bias when appropriate (table 4), overall by a mean of 3.8 percent. The greatest

Table 3. Summary of nitrate sensor concentrations and loads.

[Concentrations in milligrams per liter, loads in U.S. short tons per day, and yields in pounds per square mile per day; Max, maximum; Min, minimum; USGS, U.S. Geological Survey; shaded sites include a correction for sensor bias; --, loads not computed at Hoover Creek near 2nd Street at West Branch, Iowa; <, less than]

Year	Nitrate concentration			Days		Loads			Yield			Alternate loads, from computation on daily mean data without sensor bias correction				Comparison of load statistic, as percent difference (ratio of [load minus alternate load] and load)	
	Mean	Max	Min	Count	Percent	Mean	Max	Min	Mean	Max	Min	Days	Mean	Max	Min	Mean	Max
Turkey River at Garber, Iowa (USGS station number 05412500)																	
2012	4.0	14.4	1.8	151	41.4	8.11	103	0.793	10.5	133	1.03	151	8.33	93.1	0.943	−2.63	9.29
2013	7.8	15.6	2.2	158	43.3	45.1	263	3.74	58.4	341	4.84	158	47.5	249	4.10	−5.26	5.63
2014	7.4	14.9	3.8	204	55.9	43.2	518	5.24	55.9	670	6.78	204	44.3	349	5.60	−2.62	32.5
2015	6.4	15.3	2.5	229	62.7	19.3	123	2.14	25.0	160	2.77	229	20.4	119	2.33	−5.61	3.48
2016	9.1	15.3	3.4	274	75.1	60.3	279	18.9	78.0	361	24.4	274	65.3	523	20.6	−8.39	−87.7
2017	7.4	11.5	2.9	283	77.5	43.2	194	5.82	54.6	252	7.54	269	48.4	348	6.29	−12.1	−79.0
North Fork Maquoketa River below Bear Creek at Dyersville, Iowa (USGS station number 05418110)																	
2012	6.3	9.9	3.9	135	37.0	0.706	2.34	0.341	11.6	38.3	5.59	135	0.708	2.17	0.337	−0.272	7.06
2013	10.5	23.4	3.5	212	58.1	4.54	60.9	0.628	74.5	998	10.3	212	4.44	58.5	0.600	2.29	3.83
2014	9.0	19.9	5.5	206	56.4	2.73	31.7	0.610	44.7	519	10.0	206	2.59	16.1	0.613	4.92	49.3
North Fork Maquoketa River near Fulton, Iowa (USGS station number 05418400)																	
2012	4.9	7.8	3.6	148	40.5	2.81	8.05	1.90	11.1	31.9	7.54	148	2.95	7.66	1.98	−5.27	4.86
2013	7.5	17.1	3.7	216	59.2	9.42	106	2.63	37.3	420	10.4	216	9.95	157	2.78	−5.68	−48.2
2014	7.2	15.6	4.4	215	58.9	10.0	104	2.56	39.6	413	10.1	215	10.9	155	2.79	−8.96	−48.8
Maquoketa River near Green Island, Iowa (USGS station number 05418720)																	
2014	5.1	10.8	3.9	92	25.2	22.8	546	9.17	24.4	584	9.81	92	21.7	436	9.11	4.92	20.1
2015	6.1	15.0	3.0	193	52.9	31.1	221	6.85	33.3	236	7.33	193	30.7	297	6.86	1.33	−34.6
2016	7.4	9.0	4.6	129	35.3	41.1	67.3	21.7	43.9	72.0	23.3	129	42.8	217	22.8	−4.37	−223
2017	7.9	12.6	5.0	244	66.8	42.2	226	14.9	45.1	242	16.0	239	42.4	196	14.9	−0.484	13.6
Old Mans Creek near Iowa City, Iowa (USGS station number 05455100)																	
2012	1.9	8.8	0.1	158	43.3	0.279	2.65	0.00	2.77	26.3	0.00	158	0.292	2.69	0.00	−4.95	−1.49
2013	4.8	12.2	0.1	198	54.2	3.74	53.6	0.00	37.3	534	0.00	198	4.70	151	0.00	−25.6	−181
2014	7.1	15.2	2.8	195	53.4	3.94	64.6	0.168	39.2	643	1.67	195	5.09	189	0.188	−28.9	−193
2015	6.4	11.5	1.8	165	45.2	3.06	25.8	0.127	30.5	257	1.26	165	3.44	27.2	0.208	−12.2	−5.07

Table 3. Summary of nitrate sensor concentrations and loads.—Continued

[Concentrations in milligrams per liter, loads in U.S. short tons per day, and yields in pounds per square mile per day; Max, maximum; Min, minimum; USGS, U.S. Geological Survey; shaded sites include a correction for sensor bias; --, loads not computed at Hoover Creek near 2nd Street at West Branch, Iowa; <, less than]

Year	Nitrate concentration			Days		Loads			Yield			Alternate loads, from computation on daily mean data without sensor bias correction				Comparison of load statistic, as percent difference (ratio of [load minus alternate load] and load)	
	Mean	Max	Min	Count	Percent	Mean	Max	Min	Mean	Max	Min	Days	Mean	Max	Min	Mean	Max
Cedar River at Blairs Ferry Road at Palo, Iowa (USGS station number 05464420)																	
2012	1.6	2.1	1.3	6	1.6	3.29	6.08	2.48	1.04	1.92	0.781	6	3.82	5.56	2.95	−16.0	8.54
2013	8.9	18.5	2.4	138	37.8	367	1,770	7.28	116	557	2.30	138	380	1,910	7.47	−3.60	−7.91
2014	6.3	13.3	0.4	223	61.1	166	1,530	2.23	52.3	483	0.705	223	173	1,580	4.85	−4.30	−3.27
2015	8.1	14.6	3.2	254	69.6	148	876	23.8	46.7	276	7.50	254	157	845	24.4	−5.87	3.49
2016	8.7	14.2	2.9	256	70.1	252	794	75.5	79.4	250	23.8	256	264	745	84.4	−4.99	6.18
2017	6.1	11.4	0.6	293	80.3	129	539	1.57	40.6	170	0.496	290	135	548	2.50	−5.23	−1.60
Cedar River at Cedar Rapids, Iowa (USGS station number 05464500)																	
2009	6.5	10.4	1.3	187	51.2	152	486	14.4	46.8	149	4.42	187	152	452	17.1	0.624	6.85
2010	5.7	9.7	2.1	201	55.1	164	608	17.0	50.3	187	5.24	201	162	570	18.4	0.920	6.36
2011	7.8	12.2	1.9	131	35.9	237	693	14.3	73.0	213	4.41	131	234	676	13.6	1.51	2.46
2012	2.6	13.6	0.1	121	33.2	33.5	329	0.194	10.3	101	0.0595	121	32.0	304	0.193	4.45	7.63
Hoover Creek near 2nd Street at West Branch, Iowa (USGS station number 0546494205)																	
2016	6.0	9.6	2.8	258	70.7	--	--	--	--	--	--	--	--	--	--	--	--
Iowa River at Wapello, Iowa (USGS station number 05465500)																	
2009	4.5	9.1	1.2	119	32.6	221	568	17.6	35.4	90.9	2.82	119	221	655	17.4	0.261	−15.3
2010	4.7	8.1	2.4	142	38.9	259	698	51.3	41.5	112	8.21	142	257	695	50.4	1.01	0.453
2011	4.5	10.8	0.1	139	38.1	232	778	0.734	37.1	125	0.117	139	230	748	0.725	0.948	3.90
2012	2.5	12.1	0.1	227	62.2	56.2	449	0.505	8.99	71.9	0.0808	227	55.7	451	0.526	0.907	−0.360
2013	5.2	14.1	0.2	183	50.1	338	2,160	1.03	54.1	346	0.164	183	343	2,300	1.05	−1.31	−6.48
2014	5.5	12.0	1.0	258	70.7	199	1,330	13.5	31.8	213	2.17	258	201	1,570	14.3	−1.14	−18.0
2015	5.1	21.6	2.9	239	65.5	174	1,330	38.0	27.9	213	6.08	239	177	1,840	38.2	−1.63	−38.3
2016	7.0	13.4	3.1	239	65.5	318	850	114	50.9	136	18.2	239	319	862	118	−0.399	−1.43
2017	5.1	11.0	<0.1	309	84.7	199	768	0.175	31.9	123	0.0280	294	207	769	0.169	−3.92	−0.194

Table 3. Summary of nitrate sensor concentrations and loads.—Continued

[Concentrations in milligrams per liter, loads in U.S. short tons per day, and yields in pounds per square mile per day; Max, maximum; Min, minimum; USGS, U.S. Geological Survey; shaded sites include a correction for sensor bias; --, loads not computed at Hoover Creek near 2nd Street at West Branch, Iowa; <, less than]

Year	Nitrate concentration			Days		Loads			Yield			Alternate loads, from computation on daily mean data without sensor bias correction				Comparison of load statistic, as percent difference (ratio of [load minus alternate load] and load)	
	Mean	Max	Min	Count	Percent	Mean	Max	Min	Mean	Max	Min	Days	Mean	Max	Min	Mean	Max
Boone River near Webster City, Iowa (USGS station number 05481000)																	
2012	3.0	21.0	0.1	220	60.3	2.19	95.3	0.00188	5.20	226	0.00445	220	2.03	65.5	0.00187	7.51	31.3
2013	14.9	30.9	0.3	150	41.1	69.4	534	0.0140	164	1,270	0.0331	150	70.3	543	0.0142	−1.31	−1.71
2014	12.7	20.7	0.4	186	51.0	22.3	245	0.0853	52.8	580	0.202	186	23.6	377	0.134	−5.96	−53.8
2015	11.8	21.5	1.8	204	55.9	26.5	170	0.275	62.9	403	0.652	204	26.1	174	0.307	1.57	−2.06
2016	13.0	20.7	2.8	236	64.7	47.7	211	0.913	113	499	2.16	236	47.5	240	1.06	0.334	−14.0
2017	7.8	16.4	<0.1	205	56.2	25.5	151	0.00329	60.4	357	0.00781	205	25.4	137	0.00344	0.277	9.04
Des Moines River at 2nd Avenue at Des Moines, Iowa (USGS station number 05482000)																	
2013	1.5	1.9	0.4	58	15.9	0.700	1.14	0.140	0.224	0.366	0.0450	58	0.830	2.21	0.272	−18.5	−93.5
2014	8.0	13.7	1.6	263	72.1	98.8	480	1.71	31.6	154	0.548	263	104	516	1.88	−5.11	−7.53
2015	10.6	18.4	3.1	324	88.8	171	596	12.8	54.8	191	4.10	324	180	728	13.4	−5.03	−22.1
2016	9.9	14.9	2.2	336	92.1	199	597	16.7	63.6	191	5.35	336	206	620	18.8	−3.77	−3.85
2017	6.6	14.0	0.8	353	96.7	107	564	0.856	34.4	180	0.274	353	112	589	1.08	−4.31	−4.59
North Raccoon River near Sac City, Iowa (USGS station number 05482300)																	
2008	10.6	16.0	3.3	224	61.4	26.7	178	0.478	76.4	510	1.37	224	26.8	220	0.482	−0.204	−23.1
2009	8.6	15.7	1.6	264	72.3	8.35	62.7	0.126	23.9	179	0.360	264	8.18	58.4	0.125	2.03	6.79
2010	9.1	13.5	3.8	193	52.9	20.7	115	4.74	59.3	329	13.5	193	20.9	136	4.79	−0.542	−18.0
2011	8.3	15.5	1.1	227	62.2	16.2	135	0.111	46.3	385	0.317	227	17.0	193	0.105	−4.88	−43.1
2012	6.5	16.1	0.1	226	61.9	3.04	56.8	0.00432	8.68	162	0.0123	226	2.90	40.2	0.00460	4.69	29.2
2013	11.6	24.1	0.2	216	59.2	22.6	266	0.0108	64.6	760	0.0309	216	22.9	292	0.0105	−1.17	−9.92
2014	11.7	19.3	1.6	239	65.5	18.0	174	0.183	51.3	497	0.522	239	17.9	194	0.172	0.410	−11.5
2015	16.0	23.6	1.6	289	79.2	40.8	173	0.180	117	496	0.514	289	40.3	251	0.215	1.14	−44.8
2016	11.3	17.1	1.9	306	83.8	30.7	210	0.492	87.8	599	1.41	306	30.2	219	0.601	1.61	−4.60
2017	8.8	17.8	2.3	321	87.9	14.2	241	0.232	40.5	688	0.662	321	13.9	210	0.219	2.20	12.8

Table 3. Summary of nitrate sensor concentrations and loads.—Continued

[Concentrations in milligrams per liter, loads in U.S. short tons per day, and yields in pounds per square mile per day; Max, maximum; Min, minimum; USGS, U.S. Geological Survey; shaded sites include a correction for sensor bias; --, loads not computed at Hoover Creek near 2nd Street at West Branch, Iowa; <, less than]

Year	Nitrate concentration			Days		Loads			Yield			Alternate loads, from computation on daily mean data without sensor bias correction				Comparison of load statistic, as percent difference (ratio of [load minus alternate load] and load)	
	Mean	Max	Min	Count	Percent	Mean	Max	Min	Mean	Max	Min	Days	Mean	Max	Min	Mean	Max
North Raccoon River near Jefferson City, Iowa (USGS station number 05482500)																	
2008	8.0	11.5	0.4	224	61.4	57.4	394	0.195	70.9	487	0.241	224	57.7	453	0.190	−0.520	−14.9
2009	7.8	16.4	0.3	212	58.1	28.4	156	0.0862	35.1	193	0.106	212	28.1	138	0.0945	1.32	11.7
2010	8.4	11.1	3.6	239	65.5	59.2	296	9.36	73.2	366	11.6	239	59.0	267	9.67	0.335	9.75
2011	5.5	13.0	0.1	237	64.9	29.8	190	0.0324	36.8	235	0.0400	237	29.1	200	0.0323	2.14	−4.93
2012	3.0	13.3	0.1	210	57.5	4.15	59.0	0.00515	5.13	72.9	0.00636	210	3.95	47.1	0.00534	5.02	20.2
2013	14.6	30.5	0.5	139	38.1	68.8	498	0.0859	85.0	616	0.106	139	70.4	484	0.0870	−2.34	2.79
2014	10.4	20.3	0.3	210	57.5	35.8	303	0.0717	44.2	374	0.0886	210	35.0	190	0.0705	2.24	37.2
2015	15.8	23.4	3.7	251	68.8	75.2	433	3.66	92.9	535	4.52	251	74.4	542	4.40	1.11	−25.3
2016	10.8	17.0	2.8	267	73.2	62.6	450	1.67	77.4	556	2.07	267	62.0	438	1.87	0.935	2.58
2017	7.2	15.4	<0.1	271	74.2	38.5	384	0.00143	47.6	475	0.00177	271	38.0	372	0.00131	1.32	3.15
Middle Raccoon River at Panora, Iowa (USGS station number 05483600)																	
2010	7.3	10.2	4.7	227	62.2	12.2	130	0.405	55.3	593	1.84	227	13.0	164	0.452	−6.87	−26.0
2011	5.5	10.0	0.5	327	89.6	4.35	36.9	0.0839	19.8	168	0.381	327	4.53	36.7	0.0687	−4.10	0.611
2012	1.3	2.7	0.5	199	54.5	0.370	2.97	0.0397	1.68	13.5	0.180	199	0.334	2.13	0.0253	9.82	28.1
2013	9.9	22.6	0.5	279	76.4	10.9	271	0.0697	49.6	1,230	0.317	279	12.5	338	0.0482	−14.6	−24.9
2014	5.1	16.8	1.0	220	60.3	4.41	62.5	0.0912	20.0	284	0.415	220	4.51	65.0	0.0869	−2.28	−3.99
2015	12.8	18.1	5.4	152	41.6	26.0	202	3.45	118	919	15.7	152	28.1	257	3.66	−8.00	−27.3
South Raccoon River at Redfield, Iowa (USGS station number 05484000)																	
2016	8.5	12.7	3.5	258	70.7	19.2	108	3.23	38.7	217	6.49	258	21.3	154	3.56	−11.0	-42.7
2017	6.2	13.0	0.6	331	90.7	14.7	142	0.340	29.6	286	0.684	331	15.9	148	0.346	−7.82	−3.84

Table 3. Summary of nitrate sensor concentrations and loads.—Continued

[Concentrations in milligrams per liter, loads in U.S. short tons per day, and yields in pounds per square mile per day; Max, maximum; Min, minimum; USGS, U.S. Geological Survey; shaded sites include a correction for sensor bias; --, loads not computed at Hoover Creek near 2nd Street at West Branch, Iowa; <, less than]

Year	Nitrate concentration			Days		Loads			Yield			Alternate loads, from computation on daily mean data without sensor bias correction				Comparison of load statistic, as percent difference (ratio of [load minus alternate load] and load)	
	Mean	Max	Min	Count	Percent	Mean	Max	Min	Mean	Max	Min	Days	Mean	Max	Min	Mean	Max
Raccoon River at Van Meter, Iowa (USGS station number 05484500)																	
2012	3.5	10.0	0.1	200	54.8	10.1	83.5	0.0563	5.85	48.5	0.0327	200	10.2	98.1	0.0339	−1.49	−17.6
2013	8.3	20.5	1.3	232	63.6	105	976	0.496	60.9	567	0.288	232	107	1,030	0.489	−2.55	−5.51
2014	8.2	15.9	0.2	250	68.5	79.9	443	0.208	46.5	257	0.121	250	84.9	483	0.210	−6.24	−9.17
2015	11.6	18.7	5.0	279	76.4	149	585	10.7	86.6	340	6.22	279	159	1,760	11.5	−6.58	−201
2016	9.3	13.9	3.2	301	82.5	97.9	498	4.28	56.9	290	2.49	301	101	499	4.54	−3.35	−0.107
2017	6.2	14.6	0.6	325	89.0	57.8	516	0.540	33.6	300	0.314	325	59.7	520	0.532	−3.32	−0.702
Little Sioux River at 300th Street near Spencer, Iowa (USGS station number 06604440)																	
2012	4.1	9.1	1.4	166	45.5	2.14	33.8	0.0505	8.17	129	0.193	166	2.10	34.4	0.0593	1.79	−1.93
2013	5.2	14.9	0.8	223	61.1	3.61	31.4	0.0194	13.8	120	0.0741	223	3.84	31.9	0.0275	−6.40	−1.79
2014	2.8	7.9	0.4	219	60.0	2.29	59.1	0.0103	8.75	226	0.0395	219	2.56	69.8	0.0305	−11.8	−18.0
2015	3.0	9.3	0.3	176	48.2	0.625	5.75	0.00247	2.39	22.0	0.00946	176	0.666	5.52	0.0108	−6.47	3.94
West Nishnabotna River at Randolph, Iowa (USGS station number 06808500)																	
2016	8.5	11.4	3.8	241	66.0	37.3	129	12.6	56.2	194	19.0	241	41.6	174	14.1	−11.7	−35.4
2017	7.8	11.6	4.2	283	77.5	24.6	143	4.42	37.1	215	6.67	283	27.3	172	5.07	−11.2	−20.6
Nodaway River at Clarinda, Iowa (USGS station number 06817000)																	
2012	1.6	6.6	0.1	173	47.4	1.22	20.7	0.0128	3.19	54.4	0.0337	173	1.22	17.5	0.0177	−0.655	15.8
2013	5.0	14.1	0.4	256	70.1	11.4	136	0.0356	29.9	358	0.0934	256	12.2	184	0.0432	−6.97	−35.1
2014	5.1	11.0	0.3	176	48.2	14.8	249	0.0411	38.9	654	0.108	176	20.5	379	0.0538	−38.2	−52.1
2015	4.1	7.9	2.0	187	51.2	9.98	118	0.899	26.2	309	2.36	187	11.8	184	0.980	−18.0	−55.7
2016	4.0	8.0	1.8	222	60.8	8.77	74.7	0.927	23.0	196	2.43	222	9.45	101	0.932	−7.79	−34.9
2017	3.8	9.0	<0.1	295	80.8	8.91	145	0.00734	23.4	380	0.0193	295	9.46	170	0.0154	−6.09	−17.8

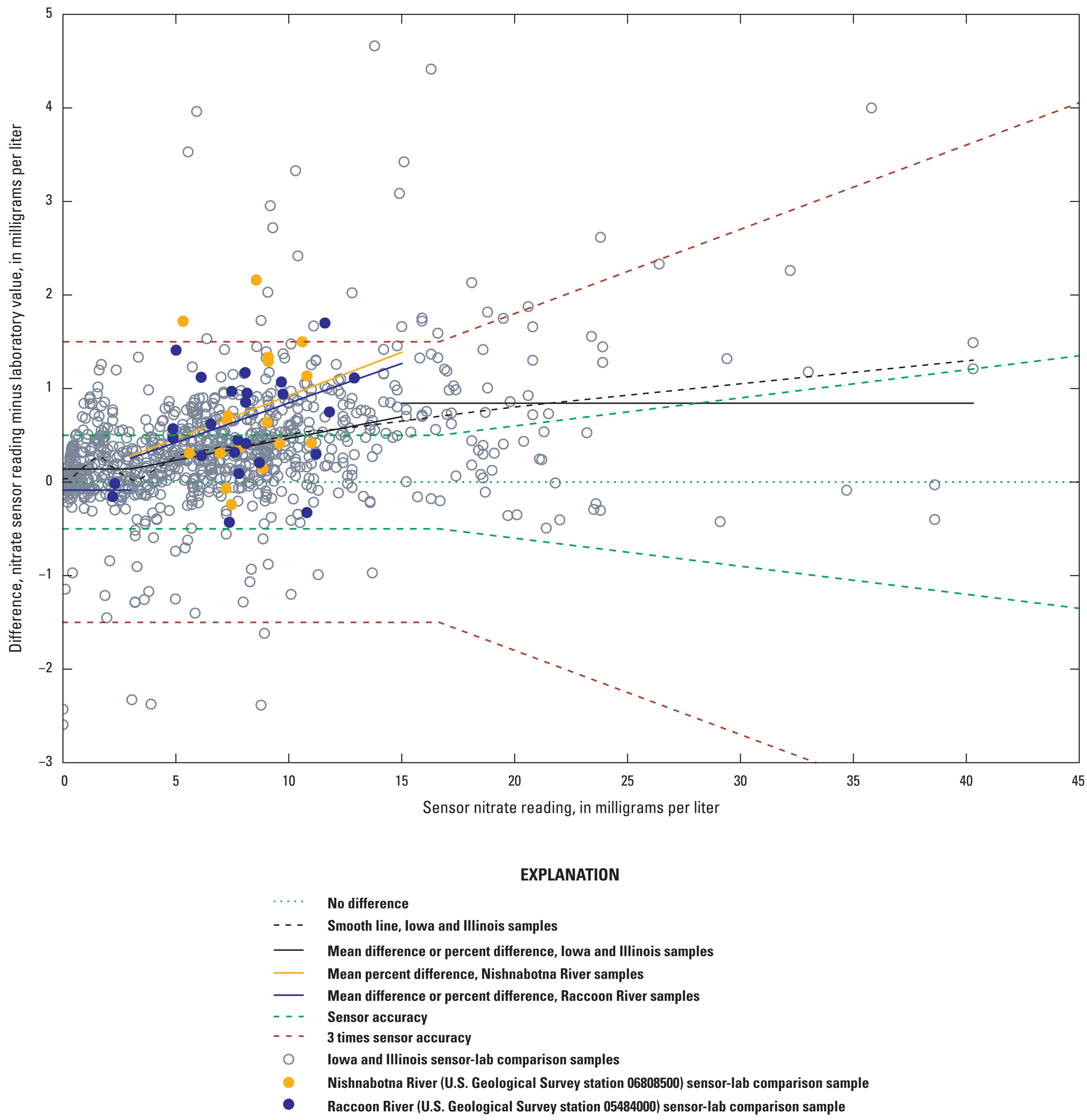

Figure 4. Nitrate sample results and sensor data for selected sites in Iowa and Illinois.

Table 4. Comparison between sensor values and laboratory results for selected streams in Iowa. Sensor bias correction is applied to load computation if mean sensor bias is statistically significant and outside of sensor accuracy.

[Nitrate, nitrate plus nitrite; mg/L, milligram per liter; L95, lower 95-percent confidence limit; U95, upper 95-percent confidence limit; --, not applicable; ND, not determined because fewer than two samples in range]

Site location	Nitrate less than or equal to 3 mg/L			Nitrate greater than 3 and less than or equal to 15 mg/L			Nitrate greater than 15 mg/L			Sample count	Sensor bias applied?
	Mean difference	L95	U95	Mean percent difference	L95	U95	Mean difference	L95	U95		
Stream sites in Iowa and Illinois, 36 sites	0.14	0.09	0.19	4.64	3.90	5.42	0.70	0.35	1.05	1,021	--
Turkey River at Garber, Iowa	0.32	0.13	0.50	6.32	4.14	8.49	ND	--	--	40	Yes.
North Fork Maquoketa River below Bear Creek at Dyersville, Iowa	ND	--	--	3.25	0.16	6.35	ND	--	--	11	No.
North Fork Maquoketa River near Fulton, Iowa	ND	--	--	5.35	3.66	7.04	ND	--	--	26	Yes.
Maquoketa River near Green Island, Iowa	ND	--	--	4.16	−0.51	8.82	ND	--	--	9	No.
Old Mans Creek near Iowa City, Iowa	0.45	−0.38	1.27	6.26	2.91	9.61	ND	--	--	17	Yes.
Cedar River at Blairs Ferry Road at Palo, Iowa	0.21	−0.14	0.56	5.56	3.84	7.28	ND	--	--	27	Yes.
Cedar River at Cedar Rapids, Iowa	ND	--	--	2.19	−4.15	8.53	ND	--	--	6	No.
Hoover Creek near 2nd Street at West Branch, Iowa	ND	--	--	2.62	−1.96	7.20	ND	--	--	5	No.
Iowa River at Wapello, Iowa	0.09	0.01	0.16	1.18	−0.47	2.84	ND	--	--	140	No.
Boone River near Webster City, Iowa	−0.02	−0.19	0.15	3.67	0.9	6.45	0.73	−0.08	1.54	18	No.
Des Moines River at 2nd Avenue at Des Moines, Iowa	0.21	−0.03	0.46	4.76	3.32	6.19	ND	--	--	30	Yes.
North Raccoon River near Sac City, Iowa	−0.20	−0.31	−0.10	2.03	0.47	3.59	0.24	−0.13	0.62	67	No.
North Raccoon River near Jefferson, Iowa	−0.03	−0.23	0.18	3.77	1.50	6.04	1.35	0.35	2.35	59	No.
Middle Raccoon River at Panora, Iowa	−0.12	−0.18	−0.05	4.27	1.65	6.88	0.60	−0.60	1.80	25	Yes.
South Raccoon River at Redfield, Iowa	−0.09	−0.97	0.80	8.45	5.35	11.55	ND	--	--	25	Yes.
Raccoon River at Van Meter, Iowa	−0.05	−0.13	0.04	4.55	3.05	6.06	0.89	−0.35	2.14	33	Yes.
Little Sioux River at 300th St near Spencer, Iowa	0.23	0.16	0.29	6.89	2.65	11.13	ND	--	--	34	Yes.
West Nishnabotna River at Randolph, Iowa	ND	--	--	9.25	4.61	13.89	ND	--	--	17	Yes.
Nodaway River at Clarinda, Iowa	0.04	−0.17	0.24	6.09	3.71	8.48	ND	--	--	28	Yes.

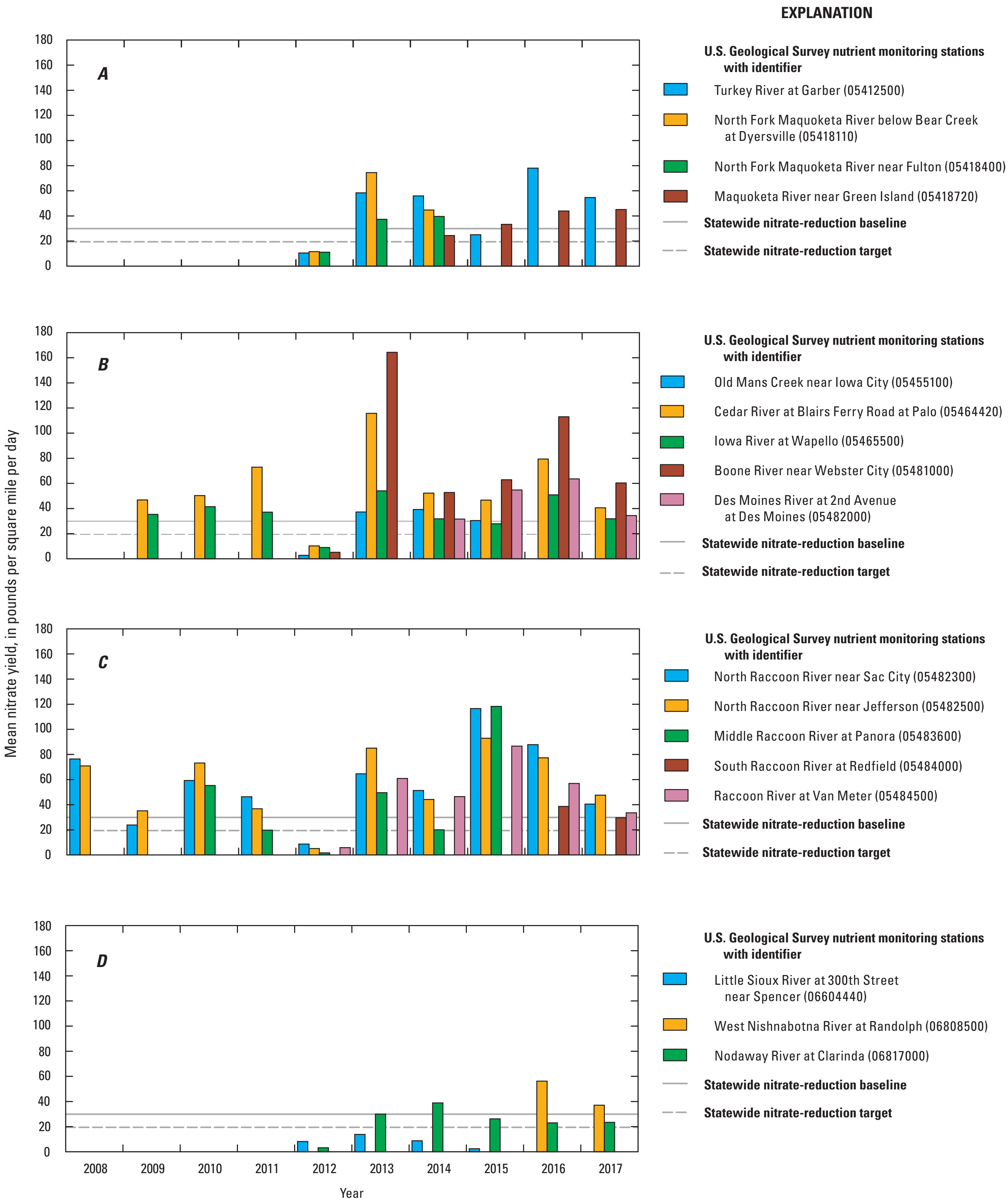

Figure 5. Mean nitrate yield based on period of available sensor data relative to Iowa nitrate-reduction baseline and goal for statewide load (Iowa Department of Agriculture and Land Stewardship and others, 2017a).

difference in mean annual loads (38.2 percent) occurred in 2014 at the Nodaway River at Clarinda, Iowa (06817000), though the difference was within 10 percent for 4 of the other 5 years monitored. Though small basins generally are considered more sensitive to flashy events, thus requiring increased frequency of data for accurate load computation (for example, Johnes, 2007; Cassidy and Jordan, 2011), the difference between the two methods was greater than 10 percent for river drainages as large as 1,545 mi^2. The change in maximum daily load for the year was within 10 percent for only 47 of 93 complete-season site-years. The greatest difference in maximum daily load for the year was 223 percent, though there were 4 site-years with a difference greater than 100 percent.

Phosphorus

The following section presents models selected for phosphorus concentrations and summaries of resulting phosphorus concentrations, loads, and yields. Factors affecting model performance are discussed, such as outliers and extrapolation, particularly relative to annual loads.

Phosphorus Models

The final surrogate regression models for phosphorus concentrations at the selected sites were based on turbidity, streamflow, nitrate, and date (table 5). Though primary models were based on turbidity, alternate models were applied during gaps to obtain a more complete record of concentration despite periods of fragmentary sensor data (table 5). Phosphorus models use the general form:

$$\ln(TP) = b_0 + b_1 \times \ln(TURB) + b_2 \times \ln(Q) + b_3 \times \mathrm{NO_3} + b_4 \times dTime, \text{ or} \quad (1)$$

$$TP = BCF \times \exp(b_0) \times TURB^{b_1} \times Q^{b_2} \times \exp(b_3 \times \mathrm{NO_3}) \times \exp(b_4 \times dTime) \quad (2)$$

where

$b_0 \ldots b_4$ are fitted parameter estimates;
TP is phosphorus concentration, unfiltered, in milligrams per liter;
TURB is turbidity, in units appropriate to sensor used;
Q is streamflow, in cubic feet per second;
NO_3 is nitrate concentration, in milligrams per liter;
dTime is centered date, in decimal days (per Cohn and others, 1992); and
BCF is model bias correction factor.

Turbidity-surrogate phosphorus models at selected sites had good empirical fit, with an adjusted coefficient of determination (R^2) of approximately 0.9 and a root mean square error of approximately 0.29 mg/L. Turbidity-surrogate phosphorus models included calibration samples collected through the range of observed conditions during the study period. Alternate phosphorus models using streamflow at selected sites had marginal fit, with adjusted R^2 values less than 0.75 and root mean square error values 0.5 mg/L or greater. Models were extrapolated beyond the sampled range except where outliers were excluded or models were segmented by flow, in which case models were applied only to the reduced range of data.

For the Maquoketa River near Green Island, Iowa (05418720), one sample was excluded that was collected at the greatest sampled streamflow of 18,900 ft^3/s (table 5, model 1b), so the resulting model may not be appropriate for streamflow values near or exceeding 18,900 ft^3/s. Because the primary turbidity-based model was applied during most ice-free periods, high-streamflow events during winter ice-affected conditions were more likely to result in gaps in daily phosphorus loads, specifically in December 2015 and outside the study period in February 2018.

For the turbidity model for the South Raccoon River at Redfield, Iowa (05484000, table 5, model 1a), the lowest sampled turbidity of 6.8 FBRUs was excluded and the next lowest sampled value was 29.3 FBRUs. Therefore, the resulting model may overestimate phosphorus concentrations at very low turbidity values. Turbidity at or below the value of the excluded outlier was rare, occurring on 3 consecutive days for a total of less than 5 hours.

For the West Nishnabotna River at Randolph, Iowa (06808500), samples with turbidities less than 100 FBRUs were excluded from the primary turbidity-based model 1a because the slope between log-phosphorus and log-turbidity is not significantly different than zero in this range. Therefore, resulting predictions from model 1a were not applied on days when a large portion of turbidity values were less than 100 FBRUs. Alternate streamflow-based models 1b and 1c use only samples collected at streamflow less than or greater than 1,000 ft3/s, respectively, and are appropriate for their respective streamflow ranges. A single sample excluded from model 1c was a winter (ice-affected) event sample where the estimated daily mean may not have accurately represented the conditions at the time of sample collection. The resulting estimates during similar events may underestimate phosphorus concentrations for those days.

Phosphorus Concentrations, Loads, and Yields

Phosphorus concentrations, loads, and yields are summarized for three selected sites with surrogate models using collocated sensor and streamflow data (table 6). Mean annual phosphorus yields for the three sites ranged from 1.57 to 7.19 $lb/mi^2/d$ (table 6). The statewide phosphorus-reduction baseline is 16,800 tons per year (equivalent to a mean statewide yield of 1.93 $lb/mi^2/d$) and a 45-percent reduction goal would require a mean statewide phosphorus yield of 1.06 $lb/mi^2/d$ to achieve this goal (Iowa Department of Agriculture and Land Stewardship and others, 2017a; fig. 6).

Table 5. Total phosphorus concentration regression models.

[Adj. R^2, adjusted coefficient of determination; RMSE, root mean square error; *n*, count; USGS, U.S. Geological Survey; *TP*, total phosphorus concentration in milligrams per liter; *TURB*, turbidity in formazin nephelometric units or formazin backscatter ratio units; *dTime*, centered date in decimal days; *Q*, streamflow in cubic feet per second; NO_3, nitrate plus nitrate concentration in milligrams per liter; --, not applicable]

Model	Period of input data		Regression model	Model diagnostics			Summary of model input variables		
	Start date	End date		Adj. R^2	RMSE	*n*	Variable and range	Mean	Median
Maquoketa River near Green Island, Iowa (USGS station number 05418720)									
1a	8/19/2014	12/31/2017	$TP = 0.01608 \times TURB^{0.631} \div \exp(0.000443 \times dTime)$	0.907	0.215	26	*TURB* 13.8–1,590 *dTime*−528–466	158 2.89	69.2 66.6
1b	4/13/2014	12/31/2017	$TP = 0.000355 \times Q^{0.894}$	0.460	0.499	45	*Q* 702–6,660	1,980	1,720
South Raccoon River at Redfield, Iowa (USGS station number 05484000)									
1a	3/1/2016	11/13/2017	$TP = 0.01591 \times TURB^{0.636}$	0.897	0.293	19	*TURB* 29.3–2,150	369	102
1b	3/1/2016	12/31/2017	$TP = 0.00136 \times Q^{1.05} \div \exp(0.183 \times NO_3)$	0.651	0.539	24	*Q* 144–3,900 NO_3 1.20–11.6	1,080 7.25	800 7.46
West Nishnabotna River at Randolph, Iowa (USGS station number 06808500)									
1a	3/1/2016	12/31/2017	$TP = 0.0111 \times TURB^{0.728}$	0.907	0.291	21	*TURB* 102–6,200	295	961
1b	3/1/2016	12/31/2017	for low *Q*; $TP = 0.346$[1]	--	0.357	9	*Q* 400–962	742	754
1c	3/1/2016	12/31/2017	for high *Q*; $TP = 9.31 \times 10^{-7} \times Q^{1.82}$	0.748	0.511	19	*Q* 1,050–6,500	2,400	2,020

[1]Streamflow parameter is not significant, and resulting best model is the mean with 95-percent confidence interval = 0.274 – 0.417 milligram per liter.

Table 6. Summary of phosphorus concentrations, loads, and yields.

[mg/L, milligram per liter; Max, maximum; Min, minimum; ton/d, U.S. short ton per day; USGS, U.S. Geological Survey]

Year	Phosphorus, mean daily concentration						Phosphorus loads, daily values							Yield, pounds per square mile per day			
	Mean, mg/L	Median, mg/L	Max, mg/L	Min, mg/L	Days, count	Days, percent	Mean, ton/d	Median, ton/d	Max, ton/d	Min, ton/d	Days, count	Days, percent	Total	Mean	Median	Max	Min
Maquoketa River near Green Island, Iowa (USGS station number 05418720)																	
2014	0.195	0.160	0.462	0.094	76	20.8	2.00	0.693	37.0	0.159	262	71.8	523	2.14	0.741	39.6	0.170
2015	0.272	0.199	1.53	0.084	193	52.9	2.00	0.516	31.4	0.143	364	99.7	730	2.14	0.552	33.6	0.154
2016	0.291	0.207	1.66	0.075	219	59.8	2.19	1.33	36.0	0.409	364	99.5	796	2.34	1.43	38.5	0.438
2017	0.190	0.143	1.35	0.026	230	63.0	1.47	0.797	23.7	0.0662	361	98.9	529	1.57	0.853	25.3	0.0708
South Raccoon River at Redfield, Iowa (USGS station number 05484000)																	
2016	0.287	0.195	2.65	0.069	235	64.2	1.36	0.347	42.1	0.0607	297	81.1	405	2.74	0.699	84.7	0.122
2017	0.306	0.220	1.94	0.072	247	67.7	0.938	0.219	32.5	0.0440	364	99.7	341	1.89	0.440	65.3	0.0885
West Nishnabotna River at Randolph, Iowa (USGS station number 06808500)																	
2016	0.787	0.525	5.35	0.297	194	53.0	4.77	2.16	95.4	0.603	365	99.7	1,740	7.19	3.26	144	0.909
2017	0.776	0.551	5.41	0.313	175	47.9	2.55	0.780	82.8	0.345	365	100	930	3.84	1.18	125	0.521

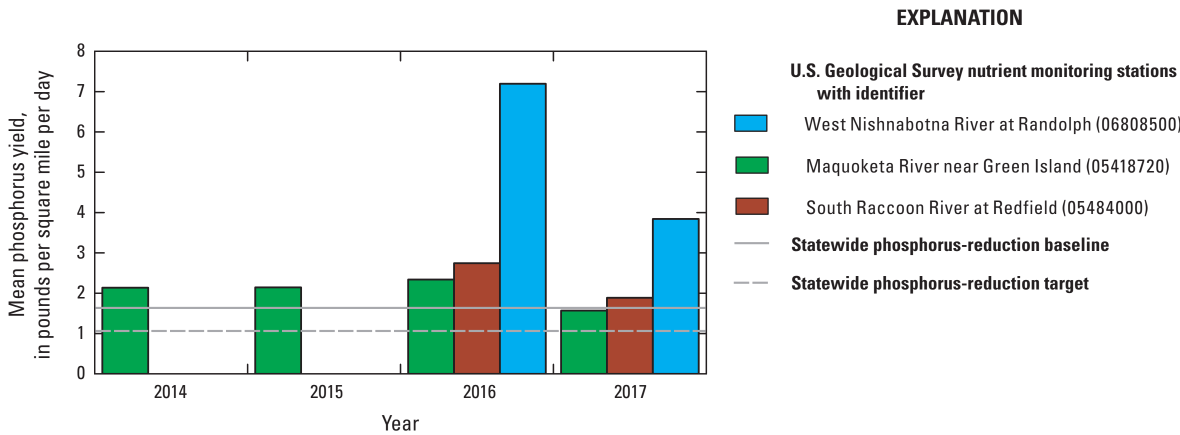

Figure 6. Mean phosphorus yield relative to Iowa phosphorus-reduction baseline and goal for statewide load (Iowa Department of Agriculture and Land Stewardship and others, 2017a).

Mean daily phosphorus concentrations computed at the Maquoketa River near Green Island, Iowa (05418720), by regression model ranged from 0.026 to 1.66 mg/L (table 6). The greatest sample concentration at this site was 2.16 mg/L (table 2). The maximum sampled turbidity value was 1,590 FNUs (table 2), very near the 1,600 FNUs maximum operating limit of the sensor. The 15-minute turbidity data exceeded 1,590 FNUs at the site on 10 days, totaling less than 99 hours in the approximately 3.5 years of data collection. The maximum daily mean phosphorus load was 37.0 ton/d, and maximum daily yield was 39.6 lb/mi^2/d.

Mean daily phosphorus concentrations at the South Raccoon River at Redfield, Iowa (05484000), computed using the regression model ranged from 0.072 to 2.65 mg/L (table 6). The greatest sample concentration at this site was 2.60 mg/L (table 2). The maximum sampled turbidity value of 2,150 FBRUs, was lower than the maximum recorded turbidity of 9,250 FBRUs (table 2), but peak turbidity readings rarely exceeded the range of sampled values. Turbidity 15-minute data exceeded 2,150 FBRUs 10 times, totaling only 78 hours in the 21 months of data collection. Because high-turbidity values were concurrent with high streamflow, phosphorus loads on days with turbidity greater than 2,150 FBRUs (1.5 percent of days) accounted for 12 percent of the annual load. The maximum daily mean phosphorus load was 42.1 ton/d and maximum daily yield was 84.7 lb/mi^2/d.

Mean daily phosphorus concentrations at the West Nishnabotna River at Randolph, Iowa (06808500), computed using the regression model ranged from 0.297 to 5.41 mg/L (table 6). The greatest sample concentration was 6.50 mg/L (table 2). The maximum sampled turbidity value at this site was 6,200 FBRUs, compared with a maximum recorded turbidity of 8,160 FBRUs (table 2). Turbidity data exceeded the sampled range on 2 days, totaling less than 17 hours in the 21 months of the study period. The maximum daily mean phosphorus load was 95.4 ton/d and maximum daily yield was 144 lb/mi^2/d.

Summary

In support of nutrient reduction strategies, nitrate plus nitrite and phosphorus loads and yields were computed based on continuously monitored sensor data for more accurate calculations compared to methods based on infrequent sample collection and continuous streamflow. In-stream sensors recorded continuous nitrate, turbidity, and temperature at selected sites collocated with continuous streamflow-gaging stations during 2008–17. Sensor installation, maintenance, and records processing followed U.S. Geological Survey (USGS) protocols including field data collection to verify that data accurately represent stream conditions. Surrogate models at three sites described relations between phosphorus samples and sensor data to allow computation of continuous phosphorus concentrations.

Nitrate loads computed in this report were on average 3.8 percent less, but as much as 38 percent less, than annual loads computed from daily mean nitrate concentration not corrected for sensor bias. Sensor bias, calculated by comparison of sensor data and laboratory samples, ranged from not significantly different from zero to 9.25 percent. Because sensor bias was variable, individual time-series concentration data were not corrected for sensor bias, but the sensor bias correction was applied to load computation. The large difference in some cases between daily and subhourly load-computation highlights the importance of continuous data. Load computation in small drainages can be particularly sensitive to time step of data computations, but subdaily computation and correction for sensor bias improved annual loads by greater than 10 percent even in river drainages larger than 1,500 square miles. Mean annual nitrate yields for 18 selected sites ranged from 1.68 to 164 pounds per square mile per day (lb/mi^2/d), compared to 19.4 lb/mi^2/d average statewide yield needed to achieve the nitrate-reduction goal.

Phosphorus loads computed in this report were based on surrogate regression models with turbidity and other continuous sensor data, with alternate models based on streamflow applied at a daily time step to fill gaps in sensor data. Turbidity-based models at three selected sites were much better at predicting phosphorus concentrations (adjusted coefficient of determination [R^2] approximately 0.9) than alternate streamflow-based models (R^2 values less than 0.75). Alternate models are valuable, nonetheless, to obtain a more complete record of concentrations and loads despite fragmentary sensor data. Mean annual phosphorus yields for selected sites on the Maquoketa River, South Raccoon River, and West Nishnabotna River ranged from 1.57 to 7.19 lb/mi^2/d, compared to 1.06 lb/mi^2/d average statewide yield needed to achieve phosphorus-reduction goal.

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Appendixes 1–2

Appendix tables are available for downloading at https://doi.org/10.3133/sir20195054.

Appendix 1. Model Calibration Samples

(Appendix tables are available for downloading at https://doi.org/10.3133/sir20195054.)

Sample data used for phosphorus surrogate model calibrations are presented in tables in this appendix. Sample data for the Maquoketa River near Green Island, Iowa (05418720), were accessed from the Upper Mississippi River Restoration Long Term Resource Monitoring (LTRM) program (Soballe and Fischer, 2004; U.S. Geological Survey, 2018) (table 1.1). Samples for the South Raccoon River at Redfield, Iowa (05484000, table 1.2) and the West Nishnabotna River at Randolph, Iowa (06808500, table 1.3) were analyzed by the Iowa State Hygienic Laboratory in Ankeny, Iowa, for phosphorus, Kjeldahl nitrogen, ammonia, orthophosphate, nitrate, and suspended solids.

Table 1.1. Phosphorus model calibration samples collected from Maquoketa River near Green Island, Iowa, U.S. Geological Survey station number 05418720.

Table 1.2. Phosphorus model calibration samples collected from South Raccoon River at Redfield, Iowa, U.S. Geological Survey station number 05484000.

Table 1.3. Phosphorus model calibration samples collected from West Nishnabotna River near Randolph, Iowa, U.S. Geological Survey station number 06808500.

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Appendix 2. Nitrate Check Samples

(Appendix tables are available for downloading at https://doi.org/10.3133/sir20195054.)

Nitrate plus nitrate samples routinely collected at Iowa and Illinois sites with in-stream data from Hach NITRATAX sensors were analyzed by the U.S. Geological Survey National Water Quality Laboratory in Lakewood, Colorado (U.S. Geological Survey, 2018). Samples collected for phosphorus surrogate model calibration in two Iowa streams also were analyzed for nitrate plus nitrite by the Iowa State Hygienic Laboratory in Ankeny, Iowa. Laboratory results in table 2.1 were compared to sensor data to assess sensor bias. Data from two sites with other sensor types were excluded.

Table 2.1. Nitrate plus nitrate samples collected from selected Iowa streams with nitrate sensor data.

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