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Open-File Report 2022–1010

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

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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)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
ounce, fluid (fl. oz)	29.57	milliliter (mL)
ounce, fluid (fl. oz)	0.02957	liter (L)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ounce, avoirdupois (oz)	28,350,000	microgram (µg)
ounce, avoirdupois (oz)	28,349.5	milligram (mg)

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

°C = (°F – 32) / 1.8.

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
milliliter (mL)	0.0338	ounce, fluid (fl. oz)
liter (L)	33.81402	ounce, fluid (fl. oz)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
	Mass	
milligram (mg)	0.00003527	ounce, avoirdupois (oz)
microgram (µg)	0.00000003527	ounce, avoirdupois (oz)

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

$$°F = (1.8 \times °C) + 32.$$

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).

Turbidity is given in formazin nephelometric units (FNU).

Abbreviations

<	less than
AMLE	absolute maximum likelihood estimation
E. coli	*Escherichia coli*
fDOM	fluorescent dissolved organic matter
n	number of samples
OLS	ordinary least squares
R^2	coefficient of determination
RPD	relative percentage difference
TKN	total Kjeldahl nitrogen
USGS	U.S. Geological Survey
VIF	variance inflation factor

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Abstract

Data were collected at two monitoring sites along the Little Arkansas River in south-central Kansas that bracket most of the easternmost part of the *Equus* Beds aquifer. The data were used as part of the city of Wichita's aquifer storage and recovery project to evaluate source water quality. The U.S. Geological Survey, in cooperation with the City of Wichita, has continued to monitor the water quality of these sites through 2019 to update previously published regression-based models using continuously measured physicochemical properties and discretely sampled water-quality constituents of interest. The purpose of this report is to provide an update of the previously published linear regression models that have been used to continuously compute estimates of water-quality constituent concentrations or densities at these two sites. Water-quality constituent model updates include those for dissolved and suspended solids, suspended-sediment concentration, hardness, alkalinity, primary ions (bicarbonate, calcium, sodium, chloride, and sulfate), nutrients (total Kjeldahl nitrogen and total phosphorus), total organic carbon, indicator bacteria (*Escherichia coli* and fecal coliform bacteria), a trace element (arsenic), and a pesticide (atrazine).

Regression analyses were used to develop surrogate models that related continuously measured physicochemical properties, streamflow, and seasonal components to discretely sampled water-quality constituent concentrations or densities. Specific conductance was an explanatory variable for dissolved solids, primary ions, and atrazine. Turbidity was an explanatory variable for total suspended solids and sediment, nutrients, total organic carbon, and indicator bacteria. Streamflow and water temperature were explanatory variables for dissolved arsenic. Seasonal components were included as explanatory variables for atrazine models. The amount of variance explained by most of the updated models was within 5 percent of previously published models.

Introduction

The water supply of the city of Wichita in south-central Kansas comes from two primary sources—the *Equus* Beds aquifer and Cheney Reservoir (fig. 1). Historically, the volume of water pumped out of parts of the *Equus* Beds aquifer exceeded the natural recharge rate and aquifer water levels have decreased (Hansen and others, 2014; Whisnant and others, 2015; Klager, 2016). The easternmost area of the aquifer that includes the Wichita well field (fig. 1) is susceptible to saltwater contamination from the Arkansas River (fig. 1) and saltwater intrusion from the oil field evaporation pit contamination plumes created in the 1930s (Whittemore, 2007; Klager and others, 2014). The *Equus* Beds aquifer storage and recovery project was created to help Wichita meet increasing water demands and, as an added benefit, inhibit saltwater encroachment (Ziegler and others, 2010; Klager and others, 2014). Source water for artificial recharge is obtained from the Little Arkansas River (fig. 1) and is injected into the *Equus* Beds aquifer for later use.

The sites Little Arkansas River at Highway 50 near Halstead, Kansas (hereafter referred to as the "Halstead site," U.S. Geological Survey [USGS] station 07143672, fig. 1) and Little Arkansas River near Sedgwick, Kansas (hereafter referred to as the "Sedgwick site," USGS station 07144100, fig. 1) bracket most of the easternmost part of the *Equus* Beds aquifer. Data were collected for these two sites as part of the aquifer storage and recovery project to evaluate source water quality. Real-time water-quality monitors were installed to provide continuous measures of water temperature, specific conductance, pH, dissolved oxygen, turbidity, nitrate plus nitrite, and colored dissolved organic matter fluorescence (fDOM). Continuous measurement of water-quality physicochemical properties in near real time allowed characterization of surface water during conditions in the Little Arkansas River at time scales that would not have been possible otherwise and serves as a complement to discrete water-quality sampling. Regression models based on surrogate water-quality measurements in real time are useful to compute estimates

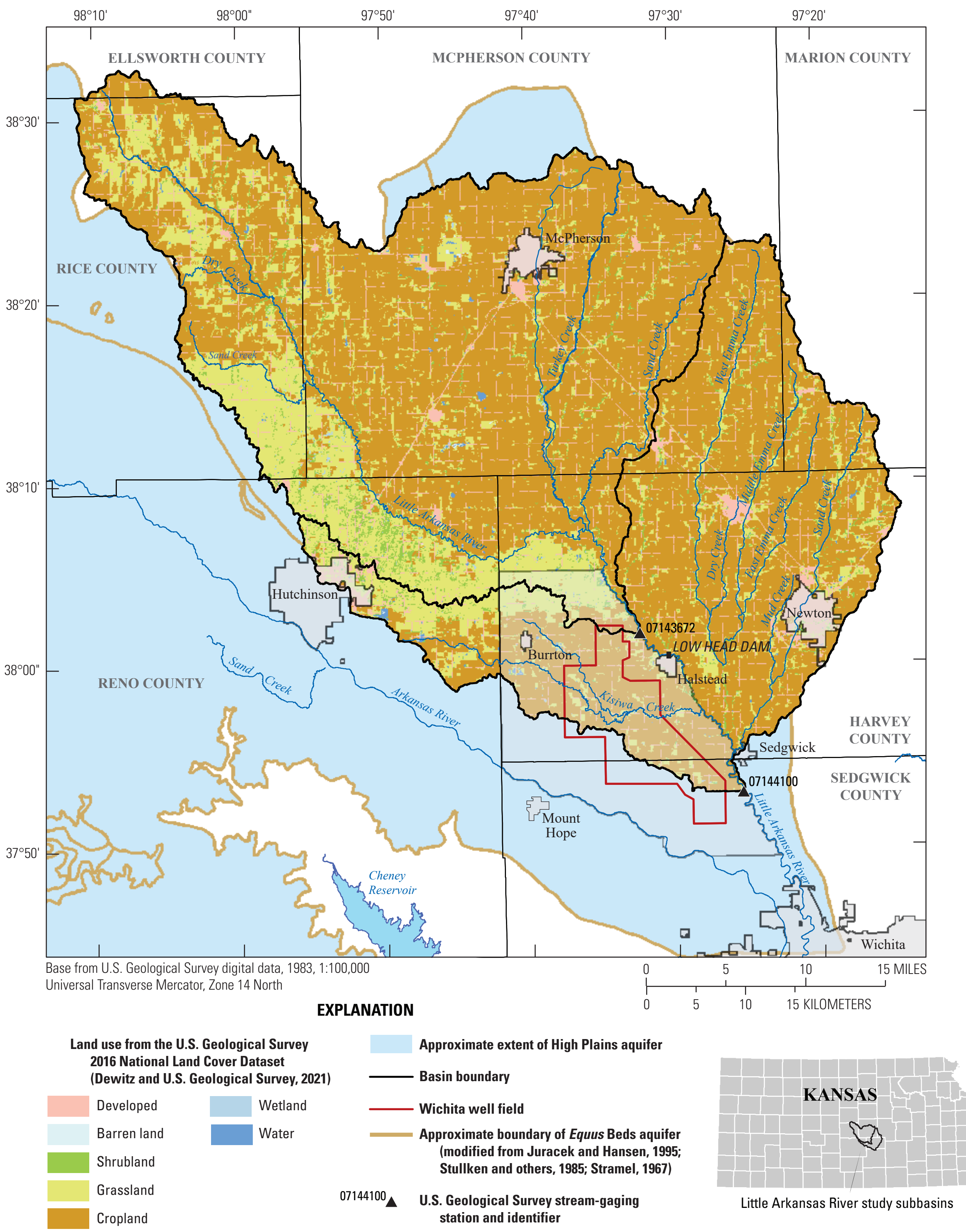

Figure 1. Study area location in the Little Arkansas River drainage basin in south-central Kansas and its land use categories.

of continuous water-quality constituent concentrations to support water treatment and recharge decisions, to compare to water-quality criteria, and to compute loads and yield to assess drainage basin transport. Physicochemical properties and water-quality constituents in the Little Arkansas River that may exceed Federal (U.S. Environmental Protection Agency, 2009) drinking water regulations or are of potential interest or concern for artificial recharge operations include streamflow, chloride, sulfate, nitrate plus nitrite, total coliform bacteria, iron (not addressed in this study), manganese (not addressed in this study), arsenic, and atrazine (Ziegler and others, 2010; Tappa and others, 2015; Stone and others, 2019).

Linear regression models for the Halstead and Sedgwick sites were developed from relations between continuously measured physicochemical properties and discretely sampled water-quality constituents. The models were published by Christensen and others (2003) and Rasmussen and others (2016) as part of monitoring aquifer storage and recovery source water efforts. The USGS, in cooperation with the City of Wichita, has continued water-quality monitoring, in part, to update the previously published regression-based models developed by Rasmussen and others (2016) using continuously measured physicochemical properties and discretely sampled water-quality constituents of interest during 1998 through 2019.

Purpose and Scope

The purpose of this report is to provide an update of previously published regression models (Rasmussen and others, 2016) that have been used to continuously compute estimates of water-quality constituent concentrations or densities at the Halstead and Sedgwick sites along the Little Arkansas River in south-central Kansas. Water-quality constituent model updates include those for dissolved and suspended solids, suspended-sediment concentration, hardness, alkalinity, primary ions (bicarbonate, calcium, sodium, chloride, and sulfate), nutrients (total Kjeldahl nitrogen and total phosphorus), total organic carbon, indicator bacteria (*Escherichia coli* [*E. coli*] and fecal coliform bacteria), a trace element (arsenic), and a pesticide (atrazine). Site-specific regression models were updated to provide real-time information to the city of Wichita to adjust water treatment and to provide water-quality information for source water used for recharge. Real-time computations of water-quality concentrations are available at the USGS National Real-Time Water-Quality website (https://nrtwq.usgs.gov). The water-quality information in this report allows the concentrations or densities of many potential constituents of concern, including chloride, nutrients, sediment, bacteria, and atrazine to be estimated in real time and characterized during conditions and time scales that would not be possible otherwise. Additionally, the methods and techniques in this study can be applied to other sites regionally, nationally, and globally.

Description of Study Area

The study area is in south-central Kansas (fig. 1). The Halstead and Sedgwick sites are USGS stations on the Little Arkansas River near Halstead and Sedgwick, Kansas, respectively. The Little Arkansas River has a contributing drainage area of 1,266 square miles (Albert and Stramel, 1966) of primarily agricultural land that produces corn, sorghum, soybeans, and wheat. The Halstead site has a contributing drainage area of 685 square miles, and the Sedgwick site has a contributing drainage area of 1,165 square miles (U.S. Geological Survey, 2021). Streamflow at both sites is affected by groundwater withdrawals, surface-water diversions, and return flow from irrigated areas. In the study area, long-term mean annual precipitation (1900 through 2019), based on data recorded near Mount Hope, Kansas (fig. 1; National Oceanic and Atmospheric Administration, 2020), was 30.2 inches (table 1). During the study period (1998 through 2019), mean annual precipitation was 33.7 inches (table 1).

The Kansas Department of Health and Environment has listed several streams in the Little Arkansas River drainage basin as impaired waterways under section 303(d) of the 1972 Clean Water Act (Kansas Department of Health and Environment, 2020). Impairments for streams in or near the study area include arsenic and chloride for water supply; dissolved oxygen, selenium, total suspended solids, atrazine, copper, total phosphorus, biology (nutrients and oxygen demand impact on aquatic life), and sediment for aquatic life; and *E. coli* bacteria for recreation (Kansas Department of Health and Environment, 2020). Main pollutants of concern listed in the Little Arkansas River Watershed Restoration and Protection Strategy were atrazine, sediment, nutrients, and fecal coliform bacteria (Kansas State University Research and Extension and others, 2011). The Little Arkansas River has defined total maximum daily loads for atrazine (Kansas Department of Health and Environment, 2008), nutrients and oxygen demand (Kansas Department of Health and Environment, 2000b), sediment (Kansas Department of Health and Environment, 2000a), chloride (Kansas Department of Health and Environment, 2006a, 2006b), fecal coliform bacteria (Kansas Department of Health and Environment, 2000c), total suspended solids (Kansas Department of Health and Environment, 2014), and total phosphorus and pH (Kansas Department of Health and Environment, 2019).

Table 1. Annual total and mean-annual precipitation during 1998 through 2019 and mean-annual precipitation during 1900 through 2019 at the "MT HOPE" (Global Historical Climatology Network–Daily:USC00145539) station.

[Data are from National Oceanic and Atmospheric Administration (2020)]

Year or period	Total precipitation, in inches
1998	35.2
1999	36.9
2000	31.8
2001	28.2
2002	33.6
2003	30.6
2004	39.8
2005	36.8
2006	25.9
2007	36.7
2008	38.5
2009	31.4
2010	34.5
2011	20.3
2012	23.6
2013	45.1
2014	25.0
2015	42.0
2016	41.5
2017	26.8
2018	35.0
2019	41.8
Mean annual during 1998 through 2019	33.7
Mean annual during 1900 through 2019	30.2

Methods

Continuously measured physicochemical properties and seasonal components (also used as surrogates in regression relations) and discretely collected water-quality constituent data during January 1998 through December 2019 were used to update previously published site-specific linear regression models developed by Rasmussen and others (2016) for the Halstead and Sedgwick sites along the Little Arkansas River. Models were updated for dissolved and suspended solids, suspended-sediment concentration, hardness, alkalinity, primary ions (bicarbonate, calcium, sodium, chloride, and sulfate), nutrients (total Kjeldahl nitrogen and total phosphorus), total organic carbon, indicator bacteria (*E. coli* and fecal coliform bacteria), a trace element (arsenic), and a pesticide (atrazine). Additional streamflow-based (without other continuous surrogates, with the exception of seasonal components) models were developed to compute concentrations during periods when concomitant continuous water-quality data were unavailable.

Continuous Streamflow and Water-Quality Monitoring

Continuous (1-hour maximum interval) streamflow and water-quality physicochemical properties were measured at the Halstead and Sedgwick sites during the study period. Streamflow has been measured at the Halstead and Sedgwick sites since May 1995 and November 1993, respectively. Streamflow was measured using standard USGS methods (Sauer and Turnipseed, 2010; Turnipseed and Sauer, 2010; Painter and Loving, 2015). Water-quality physicochemical properties (continuous surrogates) used for model development in this report included water temperature, specific conductance, pH, dissolved oxygen, turbidity, nitrate plus nitrite, and fDOM.

Since June-October 1988, both sites have been equipped with a YSI Incorporated 6600 Extended Deployment System water-quality monitor (YSI Incorporated, 2012a) to continuously measure (60-minute interval) water temperature, specific conductance, pH, dissolved oxygen (YSI Clark cell or optical dissolved oxygen sensors), and turbidity (YSI 6026 or 6136 optical turbidity sensors). Detailed method descriptions for continuous water-quality monitoring by the USGS Kansas Water Science Center are in Bennett and others (2014). Nitrate sensors (HACH Nitratax plus sc; HACH Company, 2014) were installed at the Sedgwick site in March 2012 and the Halstead site in February 2017. Nitrate sensor data include nitrite and, therefore, are reported and referred to as nitrate plus nitrite concentrations (Pellerin and others, 2013) in this report. Surface-water monitors were installed near the centroid of the stream cross section to best represent stream width conditions and were maintained following standard USGS procedures (Wagner and others, 2006; Rasmussen and others, 2008; Pellerin and others, 2013; Bennett and others, 2014).

Some equipment was upgraded throughout the life of the project. YSI 6136 turbidity sensors were initially installed at both sites in July 2004. A Xylem YSI EXO2 water-quality monitor (YSI Incorporated, 2012b) equipped with water temperature, specific conductance, pH, dissolved oxygen, turbidity, and YSI EXO fDOM sensors was installed in September 2014 at the Sedgwick site and in January 2017 at the Halstead site. Because of differences in turbidity sensor readings between the YSI 6136 and YSI EXO turbidity sensors (Stone and others, 2019), only YSI EXO turbidity sensor data were used for model development in this report although turbidity data were available since June-October 1998. Continuous water-quality data for Kansas are available at the National Water Information System database (U.S. Geological Survey, 2021).

Discrete Water-Quality Data Collection

During 1998 through 2019, about eight discrete surface-water water-quality samples were collected annually at both study sites across a range of Little Arkansas River streamflow conditions using USGS equal-width increment methods (U.S. Geological Survey, 2006; Stone and others, 2012; Rasmussen and others, 2014; Stone and others, 2019). These samples were analyzed for dissolved (number of samples [*n*] at the Halstead site [Halstead *n*]=218 and *n* at the Sedgwick site [Sedgwick *n*]=345) and suspended solids (Halstead *n*=186 and Sedgwick *n*=234); suspended-sediment concentration (Halstead *n*=178 and Sedgwick *n*=315); hardness (Halstead *n*=218 and Sedgwick *n*=351); alkalinity (Halstead *n*=34 and Sedgwick *n*=147); primary ions (bicarbonate [Halstead *n*=34 and Sedgwick *n*=147]; calcium [Halstead *n*=217 and Sedgwick *n*=351]; sodium [Halstead *n*=217 and Sedgwick *n*=351]; chloride [Halstead *n*=219 and Sedgwick *n*=360]; and sulfate [Halstead *n*=217 and Sedgwick *n*=356]); nutrients (total Kjeldahl nitrogen [Halstead *n*=168 and Sedgwick *n*=304] and total phosphorus [Halstead *n*=168 and Sedgwick *n*=304]); total organic carbon (Halstead *n*=130 and Sedgwick *n*=167); indicator bacteria (*E. coli* [Halstead *n*=151 and Sedgwick *n*=183] and fecal coliform bacteria [Halstead *n*=216 and Sedgwick *n*=261]); arsenic (Halstead *n*=167 and Sedgwick *n*=312); and atrazine (Halstead *n*=176 and Sedgwick *n*=323). Collection and analyses for dissolved and total suspended solids, suspended-sediment concentration, primary ions, nutrients, total organic carbon, arsenic, bacteria, and pesticides followed methods described by Ziegler and Combs (1997), Ziegler and others (1999, 2010), Stone and others (2012, 2016, 2019), and Tappa and others (2015). Indicator bacteria analyses were done using methods described by the U.S. Environmental Protection Agency (2000, 2006a, 2006b) and Myers and others (2014).

Dissolved solids, primary ions, nutrients, total organic carbon, and arsenic samples were analyzed by the Wichita Municipal Water and Wastewater Laboratory and the USGS National Water Quality Laboratory (Denver, Colorado). Suspended-sediment concentrations were analyzed at the USGS Iowa Sediment Laboratory (Iowa City, Iowa) following methods described in Guy (1969). Indicator bacteria samples were analyzed by the USGS Kansas Water Science Center (Lawrence, Kansas). Atrazine was analyzed by the USGS National Water Quality Laboratory. Discrete water-quality data are available at the National Water Information System database (U.S. Geological Survey, 2021).

Quality Assurance and Quality Control

Quality-assurance and quality-control samples were collected routinely during the study period to identify, quantify, and document bias and variability in data resulting from collecting, processing, handling, and analyzing samples (U.S. Geological Survey, 2006). Relative percentage difference (RPD) was calculated to quantify differences in water-quality monitor measurements and discrete sample analyte concentrations detected in replicate water-quality samples. The RPD was calculated by dividing the difference between replicate pairs by the mean and multiplying that value by 100, resulting in a value representing the percentage difference between replicate samples (Zar, 1999).

Water temperature, specific conductance, pH, and dissolved oxygen sensor data did not exceed operational limits and the Xylem YSI EXO turbidity sensor did not exceed the maximum operational limit (4,000 formazin nephelometric units) during the study period. Time-series measurements were occasionally missing or deleted from the dataset because of equipment malfunction, excessive fouling caused by environmental conditions, extreme low- or no-flow conditions, or temporary removal of equipment because of ice. During the study period (January 1998 through December 2019), 3 and 4 percent of the hourly streamflow record, 6 and 3 percent of the water temperature record, 8 and 9 percent of the specific conductance record, 6 and 4 percent of the pH record, 8 and 6 percent of the dissolved oxygen record, 2 and 6 percent of the YSI EXO turbidity record, 4 and 7 percent of the fDOM record, and 1 and 11 percent of the nitrate plus nitrite record were missing or deleted (table 2) at the Halstead and Sedgwick sites, respectively. Most of the missing data were because of low flow or icy conditions and occasionally sensor fouling. The fDOM data were temperature and turbidity corrected following protocols described by Downing and others (2012).

Comparison of field cross-sectional measurements collected during high- and low-flow conditions at the surface-water sites with the continuous data provided verification that bias in continuous data because of monitor location within the stream cross section was minimal. Median RPDs between continuous and field water-quality monitor measurements were less than (<) 2 percent, except for dissolved oxygen (<4 percent), Xylem YSI EXO sensor turbidity (<6 percent), and fDOM (<19 percent; table 3). The largest differences between continuous and field-monitor values commonly occurred when conditions were changing rapidly.

About 10 percent of the discrete water-quality samples were quality-assurance and quality-control samples and included concurrent replicates, field and equipment blanks, and standard reference samples. Concurrent replicate samples were collected to quantify variability potentially introduced by sample collection, processing techniques, and analytical method (Bennett and others, 2014, Mueller and others, 2015). RPDs were not calculated for replicate pairs that had consistent nondetections (both values in the replicate pair were censored) or inconsistent detections (one value in the replicate pair was a detected value and the other value was censored; Mueller and others, 2015); these pair types occurred only in three indicator bacteria replicate pairs. Replicate comparisons included 86 dissolved and total suspended solids pairs, 34 suspended-sediment concentration pairs, 205 primary ion pairs, 70 nutrient pairs, 27 total organic carbon pairs, 68 indicator bacteria pairs (containing 1 inconsistent *E. coli* bacteria

Table 2. Summary statistics for continuously (hourly) measured physicochemical properties for the Little Arkansas River at Highway 50 near Halstead, Kansas (Halstead site; U.S. Geological Survey station number 07143672), and Little Arkansas River near Sedgwick, Kansas (Sedgwick site; U.S. Geological Survey station number 07144100), during 1998 through 2019.

[Continuous real-time water-quality data are available on the U.S. Geological Survey (USGS) National Real-Time Water-Quality website (https://nrtwq.usgs.gov/ks); *n*, number of measurements; pcode, parameter code; <, less than]

Site	*n*	Minimum	Maximum	Mean	Median	Percentage of missing or deleted data
Streamflow, in cubic feet per second (USGS pcode 00060)						
Halstead[a]	187,576	<1	13,802	219	22	3
Sedgwick[a]	184,282	<1	19,116	372	56	4
Water temperature, in degrees Celsius (USGS pcode 00010)						
Halstead[b]	179,224	<1	35.2	14.9	15.4	6
Sedgwick[c]	183,602	<1	35.5	15.2	15.7	3
Specific conductance, in microsiemens per centimeter at 25 degrees Celsius (USGS pcode 00095)						
Halstead[b]	174,530	57	2,980	925	929	8
Sedgwick[c]	172,378	66	1,910	746	765	9
pH, in standard units (USGS pcode 00400)						
Halstead[b]	177,347	6.1	9.4	7.9	8.0	6
Sedgwick[c]	182,073	6.4	9.2	7.9	8.0	4
Dissolved oxygen, in milligrams per liter (USGS pcode 00300)						
Halstead[b]	173,676	0.3	22.8	9.5	9.0	8
Sedgwick[b]	177,975	<1	24.2	10.0	9.8	6
Turbidity, in formazin nephelometric units (Xylem YSI EXO turbidity sensor, USGS pcode 63680)						
Halstead[d]	25,247	3.6	1,273	60	24	2
Sedgwick[e]	43,814	2.0	1,140	54	21	6
Colored dissolved organic matter fluorescence (fDOM), in micrograms per liter quinine sulfate equivalent (USGS pcode 32295)						
Halstead[d,f]	24,710	18.1	291	59	51	4
Sedgwick[e,f]	43,570	22.4	376	72	59	7
Nitrate plus nitrite, in milligrams per liter as nitrogen (USGS pcode 99133)						
Halstead[g]	24,979	<0.01	5.72	0.77	0.48	1
Sedgwick[h]	61,316	<0.01	11.42	1.09	0.90	11

[a]Data collected during January 1998 through December 2019.

[b]Data collected during May 1998 through December 2019.

[c]Data collected during April 1998 through December 2019.

[d]Data collected during January 2017 through December 2019.

[e]Data collected during September 2014 through December 2019.

[f]Data temperature and turbidity corrected following Downing and others (2012).

[g]Data collected during February 2017 through December 2019.

[h]Data collected during March 2017 through December 2019.

pair detection and 2 consistent fecal coliform bacteria pair nondetections), 32 dissolved arsenic pairs, and 25 atrazine pairs. Median dissolved solids, hardness, calcium, sodium, alkalinity, bicarbonate, chloride, sulfate, and total phosphorus RPDs were <2 percent; median total suspended solids, total Kjeldahl nitrogen, arsenic, atrazine, total organic carbon, and suspended sediment RPDs were <6 percent; median *E. coli* bacteria RPD was 8.8 percent; and median fecal coliform bacteria RPD was 20 percent (table 3). Largest RPD values generally occurred when the values were near the laboratory reporting level.

Blank samples consisted of deionized water, inorganic blank water, or organic blank water, depending on analyses. During the study period, 63 blank samples for modeled analytes were collected and analyzed for dissolved and suspended solids, hardness, calcium, sodium, chloride,

Table 3. Summary of quality-control replicate and blank results for the Little Arkansas River at Highway 50 near Halstead, Kansas, and Little Arkansas River near Sedgwick, Kansas, during 1998 through 2019.

[RPD, relative percentage difference; Min, minimum; Max, maximum; Med, median; °C, degree Celsius; pcode, U.S. Geological Survey parameter code; --, not applicable; µS/cm, microsiemen per centimeter at 25 degrees Celsius; mg/L, milligram per liter; FNU, formazin nephelometric unit; µg/L, microgram per liter; QSE, quinine sulfate equivalent; $CaCO_3$, calcium carbonate; mpn/100 mL, most probable number per 100 milliliters; col/100 mL, colony per 100 milliliters]

Water-quality constituent	Total number of replicate pairs	Number of inconsistent nondetect replicate pairs	Number of consistent nondetect replicate pairs	Number of replicate pairs used for RPD statistics	Min RPD	Max RPD	Mean RPD	Med RPD	Number of blank samples	Number of detections in blank samples
Concomitant measurements of in-situ compared to average cross-sectional water-quality physicochemical properties										
Water temperature, °C (pcode 00010)[1]	661	0	0	661	0	200	2.7	1.3	--	--
Specific conductance, µS/cm (pcode 00095)[1]	680	0	0	680	0	163	4.9	1.6	--	--
pH, in standard units (pcode 00400)[1]	638	0	0	638	0	12.6	2.2	1.5	--	--
Dissolved oxygen, mg/L (pcode 00300)[1]	616	0	0	616	0	91.0	6.2	3.9	--	--
Turbidity, FNU (Xylem YSI EXO turbidity sensor, pcode 63680)[1]	150	0	0	150	0	41.5	7.9	5.8	--	--
Colored dissolved organic matter fluorescence (fDOM), µg/L QSE (uncorrected, pcode 32295)[1]	124	0	0	124	0.1	61.6	21.7	18.7	--	--
Discrete samples										
Dissolved solids, mg/L (pcode 70300)	48	0	0	48	0	22	2.8	1.7	32	4
Hardness, mg/L as $CaCO_3$ (pcode 00900)	49	0	0	49	0	25.3	2.3	1.2	37	0
Total suspended solids, mg/L (pcode 00530)	38	0	0	38	0	53.5	10.7	5.5	29	0
Calcium, dissolved, mg/L (pcode 00915)	49	0	0	49	0	25.6	2.4	1.1	37	3
Sodium, dissolved, mg/L (pcode 00930)	49	0	0	49	0.1	27.1	2.7	1.4	37	3
Alkalinity, mg/L as $CaCO_3$ (pcode 39086)	11	0	0	11	0	11	2.2	0.8	--	--
Bicarbonate, mg/L (pcode 00453)	11	0	0	11	0	11.1	2.3	0.7	--	--
Chloride, dissolved, mg/L (pcode 00940)	48	0	0	48	0	28.1	2.6	1.5	36	0
Sulfate, dissolved, mg/L (pcode 00945)	48	0	0	48	0	34.1	5.2	1.3	36	0
Nitrogen, ammonia plus organic, total, mg/L (pcode 00625)	35	0	0	35	0.1	53.7	6	3.1	24	5
Phosphorus, total, mg/L (pcode 00665)	35	0	0	35	0	8.2	1.5	1	24	0
Escherichia coli bacteria, mpn/100 mL (pcode 90902)	20	1	0	19	0	164	26.3	20	6	1

Table 3. Summary of quality-control replicate and blank results for the Little Arkansas River at Highway 50 near Halstead, Kansas, and Little Arkansas River near Sedgwick, Kansas, during 1998 through 2019.—Continued

[RPD, relative percentage difference; Min, minimum; Max, maximum; Med, median; °C, degree Celsius; pcode, U.S. Geological Survey parameter code; --, not applicable; µS/cm, microsiemen per centimeter at 25 degrees Celsius; mg/L, milligram per liter; FNU, formazin nephelometric unit; µg/L, microgram per liter; QSE, quinine sulfate equivalent; $CaCO_3$, calcium carbonate; mpn/100 mL, most probable number per 100 milliliters; col/100 mL, colony per 100 milliliters]

Water-quality constituent	Total number of replicate pairs	Number of inconsistent nondetect replicate pairs	Number of consistent nondetect replicate pairs	Number of replicate pairs used for RPD statistics	Min RPD	Max RPD	Mean RPD	Med RPD	Number of blank samples	Number of detections in blank samples
Discrete samples—Continued										
Fecal coliform bacteria, col/100 mL (pcode 31625)	51	0	2	49	0	167	24.3	8.8	9	1
Dissolved arsenic, µg/L (pcode 01000)	32	0	0	32	0	40.5	6.3	4.1	33	0
Atrazine, µg/L (pcode 39632)	25	0	0	25	0	35.6	8.7	3.8	14	2
Total organic carbon, mg/L (pcode 00680)	27	0	0	27	0.3	74.7	9.2	4.8	25	6
Suspended sediment, mg/L (pcode 80154)	34	0	0	34	0	98.2	8.6	3.7	--	--

sulfate, total Kjeldahl nitrogen, total phosphorus, total organic carbon, *E. coli* and fecal coliform bacteria, dissolved arsenic, and atrazine. Suspended solids, hardness, chloride, sulfate, total phosphorus, and arsenic blank samples did not have any detections during the study period. Blank samples with analyte detections included dissolved solids (four detections), calcium and sodium (three detections each), total Kjeldahl nitrogen (five detections), total organic carbon (six detections), *E. coli* and fecal coliform bacteria (one detection each), and atrazine (two detections table 3). Blank sample analyte detections were at or below either the analytical detection limit or minimum reporting limit except for one dissolved solids detection, one total Kjeldahl nitrogen detection, and one total organic carbon detection. Detection or minimum reporting limit exceedances were near the analytical detection or minimum reporting limit.

Standard reference samples were analyzed by the Wichita Municipal Water and Wastewater Laboratory and analytical results were submitted to the USGS Branch of Quality Systems annually and oftentimes biannually for laboratory-performance evaluation. Standard reference sample data are available at https://bqs.usgs.gov/srs. Most of the reported values were within 10 percent of the most probable value during the study. Median RPDs between laboratory results and most probable values indicated that laboratory data generally were consistent and unbiased.

Regression Model Development

Simple linear (ordinary least squares [OLS]) and Tobit regression analyses were used to develop regression models that related continuously measured physicochemical properties (continuous surrogates), streamflow, and seasonal components to discretely sampled water-quality constituent concentrations or densities (Rasmussen and others, 2009; Helsel and others, 2020). The previously published (Rasmussen and others, 2016) models for dissolved solids, suspended solids, suspended-sediment concentration, hardness, alkalinity, bicarbonate, calcium, sodium, chloride, sulfate, total Kjeldahl nitrogen, total phosphorus, total organic carbon, *E. coli* bacteria, fecal coliform bacteria, arsenic, and atrazine were updated following methods described in Rasmussen and others (2009, 2016). Additional streamflow-based models (with streamflow and seasonal components) were developed to compute estimates of concentrations or densities during periods when concomitant continuous surrogate measurements were unavailable.

Regression models were developed using OLS estimation for constituents that had datasets without left-censored data (< values). Tobit regression methods were used for fitting linear models for constituents that had datasets with left-censored data using absolute maximum likelihood estimation (AMLE; Hald, 1949; Cohen, 1950; Tobin, 1958; Helsel and others, 2020). Discrete datasets containing left-censored data included total suspended solids (5–8 percent left-censored data), chloride (<1–2 percent left censored data), sulfate (3–4 percent left-censored data), *E. coli* bacteria (1 percent left-censored data), fecal coliform bacteria (<1 percent left-censored data), dissolved arsenic (<1–2 percent left-censored data), and atrazine (1–3 percent left-censored data). Data and models for this report were analyzed and developed using R (version 4.0.0) programming language (R Core Team, 2020). Tobit regression models were developed using absolute maximum likelihood estimation methods using the *smwrQW* (v.0.7.9) package in R programming language (R Core Team, 2020).

Model datasets had different numbers of measurements for the following two primary reasons:

1. The sampling date ranges and frequencies of each discrete water-quality constituent were not always identical.

2. Available concomitant real-time data date ranges were not identical among data and sensor type—streamflow, water temperature, specific conductance, pH, and dissolved oxygen data were available during 1998 through 2019 (Halstead and Sedgwick sites); YSI EXO turbidity and fDOM data were available during 2014 through 2019 (Sedgwick site) and 2017 through 2019 (Halstead site); and nitrate plus nitrite data were available during 2017 through 2019 (Halstead and Sedgwick sites) (table 2).

Model datasets and modeled constituents included available concomitant real-time physicochemical properties as explanatory variables during model development. Potential explanatory variables were evaluated individually and in combination and included available concomitant continuously measured streamflow, water temperature, specific conductance, pH, dissolved oxygen, turbidity (YSI EXO turbidity sensor), fDOM, and nitrate plus nitrite concentration for the updated models. Periodic functions (seasonal components sine and cosine variables) also were evaluated as potential explanatory variables using day of the year. Explanatory variables were interpolated within the continuous record based on discrete sample time. The maximum time span between two continuous data points used for interpolation was 2 hours.

Potential linear regression models were evaluated based on diagnostic statistics (coefficient of determination [R^2], or adjusted R^2 for OLS-estimated models; pseudo-R^2 for AMLE-estimated models; Mallow's C_p for OLS-estimated models; root mean square error for OLS-estimated models; prediction error sum of squares for OLS-estimated models; and residual standard error for AMLE-estimated models), patterns in residual plots, and the range and distribution of discrete and continuous data (Helsel and others, 2020). Updated models were selected regardless of the date ranges of available concomitant real-time surrogate data (table 2) that

1. maximized response variable variance explained by the model (R^2 or adjusted R^2 for OLS-estimated models and pseudo-R^2 for AMLE-estimated models),

2. maximized fit to the data (Mallow's C_p for OLS-estimated models), and

3. minimized heteroscedasticity (irregular scatter) in residual plots and uncertainty associated with computed values (root mean square error and prediction error sum of squares for OLS-estimated models and residual standard error for AMLE-estimated models).

If either a sine or cosine seasonality variable was included in the model, a corresponding counterpart also was included in the model. A bias correction factor was calculated for models with logarithmically transformed response variables because transformation of estimates to original units results in a low biased estimate (Duan, 1983; Helsel and others, 2020).

Potential outliers were identified following Rasmussen and others (2009) and Helsel and others (2020). Studentized residuals, leverage, Cook’s D (Cook, 1977), and difference in fits values were used to identify influential data points for OLS-estimated models; and leverage and Cook’s D values were used to identify influential data points for AMLE-estimated models. Studentized residuals are used to identify outliers with high leverage, Cook’s D is a combination of each observation’s leverage and residual value (large values indicate influential observations), and difference in fits is the product of the Studentized residual and leverage (large values indicate influential observations). Removing data points that were based only on outlier criteria may only overestimate the certainty of the model. Data points that were not representative of the dataset and exceeded Cook’s D and difference in fits thresholds for OLS-estimated models and Cook’s D thresholds for AMLE-estimated models were removed from model datasets to avoid erroneous inflation of model-computed values at the upper range of surrogate relations.

Updated Regression Models

Previously published (Rasmussen and others, 2016) regression models were updated for the 17 water-quality constituents (solids and primary ions, nutrients, total organic carbon, indicator bacteria, a trace element, and a pesticide) for the Halstead and Sedgwick sites along the Little Arkansas River. Additional streamflow-based models were developed to compute estimates of constituents of interest when concomitant continuous data were unavailable to compute more complete load estimates. Additional models are not intended to stand alone, are not intended to be used under any other circumstance, and are not discussed further in this report; these additional models are the second model listed in tables 4–8 for the updated Halstead and Sedgwick regression models. Regression model summaries are presented in appendixes 1 (Halstead site) and 2 (Sedgwick site). Model forms (independent and explanatory variables) and the amount of variance explained by the updated models were generally similar to the original models (Rasmussen and others, 2016; tables 4–8). Model forms (selected explanatory variables) for most updated models remained unchanged (tables 4–8). Continuously measured physicochemical properties that were included as surrogates in final models for this study were streamflow, water temperature, specific conductance, and turbidity (tables 4–8). Continuously measured physicochemical properties that were not selected as surrogates for the updated models in this report included pH, dissolved oxygen, nitrate plus nitrite, and fDOM (tables 4–8).

Solids and Primary Ions

Specific conductance was the sole explanatory variable for dissolved solids, hardness, alkalinity, bicarbonate, calcium, sodium, chloride, and sulfate at both study sites (tables 4–5). Specific conductance was positively related to dissolved solids and primary ions because specific conductance measures water’s capacity to conduct an electrical current and is related to the concentration of ionized substances in water (Hem, 1992). Model forms (selected explanatory variables) for dissolved solids, hardness, calcium, and sodium were similar to previously published models at both sites (tables 4–5; Christensen and others, 2003; Rasmussen and others, 2016). Updated model forms (selected explanatory variables) for chloride and sulfate were similar to the most recently published models at the Halstead site but did not include streamflow as an explanatory variable like the most recently published models did at the Sedgwick site (table 5, Rasmussen and others, 2016); previously published chloride and sulfate models by Christensen and others (2003) also did not include streamflow as an explanatory variable. Updated model forms (selected explanatory variables) for alkalinity and bicarbonate did not include streamflow as an additional explanatory variable like the most recently published models did at both study sites (tables 4–5, Rasmussen and others, 2016). Earlier published alkalinity and bicarbonate model forms (selected explanatory variables) included streamflow at the Halstead site and streamflow and specific conductance at the Sedgwick site (Christensen and others, 2003).

The amount of variance explained by updated dissolved solids, hardness, calcium, and sodium ranged from 97 to 98 percent (tables 4–5). The amount of variance explained by updated alkalinity and bicarbonate models ranged from 89 percent at the Halstead site to 94 percent at the Sedgwick site (tables 4–5). The amount of variance explained by updated chloride models ranged from 88 percent at the Sedgwick site to 93 percent at the Halstead site (table 5). The amount of variance explained by the updated sulfate models ranged from 84 percent at the Halstead site to 91 percent at the Sedgwick site (table 5). The amount of variance explained by updated primary ions models was within 5 percent of the most recently published models, except for the updated sulfate model at the Halstead site (R^2 decreased from 0.90 to 0.84, table 5, Rasmussen and others, 2016).

Turbidity was the sole explanatory variable for total suspended solids and suspended-sediment concentration (table 4). Turbidity is caused by suspended and dissolved matter such

Table 4. Regression models and summary statistics for continuous dissolved solids, hardness, alkalinity, suspended sediment, and total suspended solids concentration computations for the Little Arkansas River at Highway 50 near Halstead, Kansas (Halstead site; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kansas (Sedgwick site; USGS station 07144100), during 1998 through 2019.

[Data are from the U.S. Geological Survey (USGS) National Water Information System database (USGS, 2021). Dates are shown as month (abbreviated) year. App., model archive summary appendix; R^2, coefficient of determination; Adj., adjusted; *MSE*, mean square error; *RMSE*, root mean square error; *RSE*, residual standard error; Avg. *MSPE*, average model standard percentage error; BCF, bias correction factor (Duan, 1983); DR, model dataset date range; *n*, number of discrete samples; %, percentage of left-censored data; RoV, range of values in variable measurements; *DS*, dissolved solids, in milligrams per liter (mg/L); *SC*, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; -, not applicable; log, log10; *Q*, streamflow, in cubic feet per second; sin, sine; *D*, day of year; cos, cosine; *HD*, hardness, in mg/L as calcium carbonate ($CaCO_3$); *ALK*, alkalinity, in mg/L as $CaCO_3$; *SSC*, suspended sediment, in mg/L; TBY_{6136}, Yellow Springs Incorporated 6136 optical turbidity, in formazin nephelometric units (FNU); TBY_{EXO}, EXO Smart Sensor turbidity, in FNU; <, less than; *TSS*, total suspended solids, in mg/L]

Regression model	App.	R^2	Adj. R^2	Pseudo-R^2	*MSE*	*RMSE*	*RSE*	Avg. *MSPE*	BCF	Discrete data					
										DR	*n*	%	RoV	Mean	Median
Dissolved solids (USGS parameter code 70300)															
Halstead, Rasmussen and others (2016)															
$DS = 0.566(SC) + 18.6$	-	0.99	0.99	-	600	24.5	24.7	6	1.00	May 1998–Aug. 2014	150	0	*DS*: 66–1,150 *SC*: 76–2,060	441 746	382 651
Sedgwick, Rasmussen and others (2016)															
$DS = 0.576(SC) + 13.2$	-	0.97	0.97	-	416	20.4	20.5	6	1.00	May 1998–Oct. 2014	215	0	*DS*: 50–839 *SC*: 88–1,390	366 613	394 658
Halstead updated															
$\log(DS) = 0.918\log(SC) + 0.0121$	1.1	0.98	0.98	-	0.0021	0.0458	0.0460	11	1.01	May 1998–Dec. 2019	191	0	*DS*: 66–1,150 *SC*: 75–2,060	424 711	374 615
$\log(DS) = -0.258\log(Q) + 0.137\sin(2\pi D/365) + 0.0782\cos(2\pi D/365) + 3.08$	1.2	0.65	0.64	-	0.0361	0.1900	0.1909	45	1.10	Jan. 1998–Dec. 2019	218	0	*DS*: 66–1,960 *Q*: 1–10,900	452 781	394 75
Sedgwick updated															
$\log(DS) = 0.93\log(SC) - 0.0205$	2.1	0.98	0.98	-	0.0012	0.0341	0.0342	8	1.00	May 1998–Dec. 2019	315	0	*DS*: 50–839 *SC*: 90–1,380	367 607	397 658
$\log(DS) = -0.246\log(Q) + 0.0875\sin(2\pi D/365) + 0.0712\cos(2\pi D/365) + 3.05$	2.2	0.78	0.77	-	0.0156	0.1250	0.1254	29	1.04	Jan. 1998–Dec. 2019	345	0	*DS*: 50–839 *Q*: 1–15,600	370 1,100	405 96
Hardness (USGS parameter code 00900)															
Halstead, Rasmussen and others (2016)															
$\log(HD) = 1.02\log(SC) - 0.582$	-	0.98	0.98	-	0.0026	0.0513	0.0516	12	1.01	May 1998–Aug. 2014	152	0	*HD*: 22–515 *SC*: 76–2,060	216 741	188 651
Sedgwick, Rasmussen and others (2016)															
$\log(HD) = 1.04\log(SC) - 0.607$	-	0.97	0.97	-	0.0029	0.0534	0.0536	12	1.01	May 1998–Aug. 2014	220	0	*HD*: 31–487 *SC*: 88–1,390	202 618	224 663

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Regression model	App.	R^2	Adj. R^2	Pseudo-R^2	*MSE*	*RMSE*	*RSE*	Avg. *MSPE*	BCF	Discrete data					
										DR	*n*	%	RoV	Mean	Median
Hardness (USGS parameter code 00900)—Continued															
Halstead updated															
$\log(HD) = 1.01\log(SC) - 0.554$	1.3	0.97	0.97	-	0.0038	0.0616	0.0619	14	1.01	May 1998–Dec. 2019	191	0	*HD*: 21–515	212	186
													SC: 75–2,060	711	615
$\log(HD) = -0.296\log(Q) + 0.141\sin(2\pi D/365) + 0.0774\cos(2\pi D/365) + 2.84$	1.4	0.69	0.68	-	0.0384	0.1960	0.1969	47	1.10	Jan. 1998–Dec. 2019	218	0	*HD*: 21–584	226	202
													Q: 1–10,900	781	75
Sedgwick updated															
$\log(HD) = 1.05\log(SC) - 0.611$	2.3	0.97	0.97	-	0.0027	0.0519	0.0521	12	1.01	May 1998–Dec. 2019	320	0	*HD*: 31–487	206	227
													SC: 90–1,380	610	662
$\log(HD) = -0.289\log(Q) + 0.0843\sin(2\pi D/365) + 0.0755\cos(2\pi D/365) + 2.88$	2.4	0.78	0.78	-	0.0199	0.1410	0.1414	33	1.05	Jan. 1998–Dec. 2019	351	0	*HD*: 16–487	208	236
													Q: 1–15,600	1,090	98
Alkalinity (USGS parameter codes 39087 and 39086)															
Halstead, Rasmussen and others (2016)															
$\log(ALK) = 0.687\log(SC) - 0.0875\log(Q) + 0.371$	-	0.93	0.93	-	0.0066	0.0810	0.0815	19	1.02	May 1998–Aug. 2014	151	0	*ALK*: 28–318	152	128
													SC: 76–2,060	743	640
													Q: 1–10,900	849	71
Sedgwick, Rasmussen and others (2016)															
$\log(ALK) = 0.731\log(SC) - 0.094\log(Q) +0.36$	-	0.95	0.95	-	0.0041	0.0644	0.0647	15	1.01	May 1998–Aug. 2014	187	0	*ALK*: 20–318	155	134
													SC: 56–1,340	585	584
													Q: 2–15,100	1,400	142
Halstead updated															
$\log(ALK) = 0.974\log(SC) - 0.531$	1.11	0.89	0.89	-	0.0117	0.1080	0.1115	25	1.03	June 2013–Dec. 2019	33	0	*ALK*: 22–330	168	207
													SC: 81–1,250	656	742
$\log(ALK) = -0.289\log(Q) + 2.72$	1.12	0.78	0.78	-	0.0190	0.1380	0.1425	32	1.05	Mar. 2013–Dec. 2019	33	0	*ALK*: 39–330	172	207
													Q: 6–8,410	633	69

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Regression model	App.	R^2	Adj. R^2	Pseudo-R^2	*MSE*	*RMSE*	*RSE*	Avg. *MSPE*	BCF	Discrete data					
										DR	*n*	%	RoV	Mean	Median
Alkalinity (USGS parameter codes 39087 and 39086)—Continued															
Sedgwick updated															
$\log(ALK) = 0.988\log(SC) - 0.503$	2.11	0.94	0.94	-	0.0041	0.0644	0.0649	15	1.01	Sept. 2012–Dec. 2019	135	0	*ALK*: 32–293	190	210
													SC: 114–1,130	651	722
$\log(ALK) = -0.279\log(Q) + 2.79$	2.12	0.75	0.75	-	0.0164	0.1280	0.1289	30	1.04	Sept. 2012–Dec. 2019	147	0	*ALK*: 31–301	194	220
													Q: 3–15,600	777	65
Suspended sediment (USGS parameter code 80154)															
Halstead, Rasmussen and others (2016)															
$\log(SSC) = 0.854\log(TBY_{6136}) + 0.0332\log(Q) + 0.517$	-	0.93	0.93	-	0.0253	0.1590	0.1613	37	1.07	July 2004–June 2014	71	0	*SSC*: 8–3,050	401	261
													TBY_{6136}: 2–970	200	143
													Q: 4–10,900	1,350	174
Sedgwick, Rasmussen and others (2016)															
$\log(SSC) = 0.933\log(TBY_{6136}) + 0.0431\log(Q) + 0.262$	-	0.98	0.98	-	0.0072	0.0848	0.0855	20	1.02	July 2004–Aug. 2014	120	0	*SSC*: 6–1,680	243	136
													TBY_{6136}: 3–784	138	83
													Q: 2–15,100	1,630	82
Halstead updated															
$\log(SSC) = 1.1\log(TBY_{EXO}) + 0.143$	1.33	0.98	0.98	-	0.0073	0.0855	0.0899	20	1.02	Mar. 2017–Oct. 2019	22	0	*SSC*: 27–3,270	537	81
													TBY_{EXO}: 15–1,040	192	39
$\log(SSC) = 1.1\log(Q) + 0.143$	1.34	0.58	0.58	-	0.1521	0.3900	0.3922	102	1.44	Nov. 1998–Dec. 2019	178	0	*SSC*: 4–3,270	399	190
													Q: <1–10,900	956	98
Sedgwick updated															
$\log(SSC) = 1.13\log(TBY_{EXO}) + 0.0959$	2.33	0.94	0.93	-	0.0269	0.1640	0.1656	39	1.08	Oct. 2014–Dec. 2019	108	0	*SSC*: 2–1,790	197	59
													TBY_{EXO}: 3–450	77	30
$\log(SSC) = 0.534\log(Q) + 0.84$	2.34	0.56	0.56	-	0.1781	0.4220	0.4234	113	1.51	Dec. 1998–Dec. 2019	315	0	*SSC*: 2–1,970	253	94
													Q: 1.4–15,600	1,140	95

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Regression model	App.	R^2	Adj. R^2	Pseudo-R^2	*MSE*	*RMSE*	*RSE*	Avg. *MSPE*	BCF	Discrete data					
										DR	*n*	%	RoV	Mean	Median
Total suspended solids (USGS parameter code 00530)															
Halstead, Rasmussen and others (2016)															
$\log(TSS) = 0.953\log(TBY_{6136}) + 0.194$	-	0.93	0.93	-	0.0342	0.1850	0.1198	44	1.09	Mar. 2005–Aug. 2014	67	9	*TSS*: <4–2,390	229	126
													TBY_{6136}: 1–960	172	120
Sedgwick, Rasmussen and others (2016)															
$\log(TSS) = 1.01\log(TBY_{6136}) + 0.076$	-	0.92	0.92	-	0.0331	0.1820	0.1607	43	1.08	July 2004–Aug. 2014	93	8	*TSS*: <4–1,670	196	95
													TBY_{6136}: 3–910	151	110
Halstead updated															
$\log(TSS) = 1.0175\log(TBY_{EXO}) + 0.2545$	1.5	-	-	0.97	-	-	0.1198	-	1.04	Mar. 2017–Oct. 2019	24	8	*TSS*: <15–2,790	352	78
													TBY_{EXO}: 4–1,038	177	35
$\log(TSS) = 0.4745\log(Q) + 0.03315\sin(2\pi D/365) - 0.34304\cos(2\pi D/365) + 0.94997$	1.6	-	-	0.63	-	-	0.4098	-	1.50	Jan. 1998–Dec. 2019	186	7	*TSS*: <4–2,790	244	103
													Q: 1–8,409	681	67
Sedgwick updated															
$\log(TSS) = 0.9478\log(TBY_{EXO}) + 0.2936$	2.5	-	-	0.94	-	-	0.1540	-	1.05	Feb. 2015–Dec. 2019	40	5	*TSS*: <15–928	194	116
													TBY_{EXO}: 3.6–479	130	90
$\log(TSS) = 0.460185\log(Q) - 0.008763\sin(2\pi D/365) - 0.365144\cos(2\pi D/365) + 0.834206$	2.6	-	-	0.64	-	-	0.3841	-	1.44	Jan. 1998–Dec. 2019	233	5	*TSS*: <4–1,820	227	108
													Q: 1–14,865	1,315	137

Table 5. Regression models and summary statistics for continuous calcium, sodium, bicarbonate, chloride, and sulfate concentration computations for the Little Arkansas River at Highway 50 near Halstead, Kansas (Halstead site; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kansas (Sedgwick site; USGS station 07144100), during 1998 through 2019.

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Regression model	App.	R^2	Adj. R^2	Pseudo-R^2	*MSE*	*RMSE*	*RSE*	Avg. *MSPE*	BCF	Discrete data					
										DR	n	%	RoV	Mean	Median
Calcium (USGS parameter code 00915)															
Halstead, Rasmussen and others (2016)															
$\log(Ca) = 1.04\log(SC) - 1.14$	-	0.98	0.98	-	0.0027	0.0519	0.0522	12	1.01	May 1998–Aug. 2014	151	0	*Ca*: 6.5–165 *SC*: 76–2,060	68 738	58 640
Sedgwick, Rasmussen and others (2016)															
$\log(Ca) = 1.04\log(SC) - 1.11$	-	0.97	0.97	-	0.0024	0.0493	0.0495	11	1.01	May 1998–Aug. 2014	219	0	*Ca*: 9.6–138 *SC*: 88–1,390	62 619	70 664
Halstead updated															
$\log(Ca) = 1.03\log(SC) - 1.12$	1.7	0.97	0.97	-	0.0040	0.0631	0.0634	15	1.01	May 1998–Dec. 2019	190	0	*Ca*: 6.5–165 *SC*: 75–2,060	66 706	58 609
$\log(Ca) = -0.306\log(Q) + 0.14\sin(2\pi D/365) + 0.0743\cos(2\pi D/365) + 2.36$	1.8	0.70	0.69	-	0.0380	0.1950	0.1959	47	1.10	Jan. 1998–Dec. 2019	217	0	*Ca*: 6.5–174 *Q*: 1–10,900	71 785	66 76
Sedgwick updated															
$\log(Ca) = 1.05\log(SC) - 1.14$	2.7	0.97	0.97	-	0.0028	0.0528	0.0530	12	1.01	May 1998–Dec. 2019	320	0	*Ca*: 9.6–138 *SC*: 90–1,380	63 610	70 662
$\log(Ca) = -0.291\log(Q) + 0.0805\sin(2\pi D/365) + 0.0735\cos(2\pi D/365) + 2.37$	2.8	0.78	0.78	-	0.0202	0.1420	0.1424	33	1.05	Jan. 1998–Dec. 2019	351	0	*Ca*: 4.7–138 *Q*: 1–15,600	64 1,090	72 98
Sodium (USGS parameter code 00930)															
Halstead, Rasmussen and others (2016)															
$\log(Na) = 1.32\log(SC) - 2.00$	-	0.98	0.98	-	0.0040	0.0635	0.0639	15	1.01	May 1998–Aug. 2014	152	0	*Na*: 2.1–257 *SC*: 76–2,060	68 761	56 684

Table 5. Regression models and summary statistics for continuous calcium, sodium, bicarbonate, chloride, and sulfate concentration computations for the Little Arkansas River at Highway 50 near Halstead, Kansas (Halstead site; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kansas (Sedgwick site; USGS station 07144100), during 1998 through 2019.—Continued

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Regression model	App.	R^2	Adj. R^2	Pseudo-R^2	*MSE*	*RMSE*	*RSE*	Avg. *MSPE*	BCF	Discrete data					
										DR	n	%	RoV	Mean	Median
Sodium (USGS parameter code 00930)—Continued															
Sedgwick, Rasmussen and others (2016)															
$\log(Na) = 1.33\log(SC) - 2.08$	-	0.97	0.97	-	0.0046	0.0681	0.0684	16	1.01	May 1998–Aug. 2014	217	0	*Na*: 2.5–132 *SC*: 88–1,390	48 623	48 664
Halstead updated															
$\log(Na) = 1.32\log(SC) - 2.03$	1.9	0.97	0.97	-	0.0068	0.0823	0.0827	19	1.02	May 1998–Dec. 2019	190	0	*Na*: 2.1–257 *SC*: 75–2,060	61 706	46 609
$\log(Na) = -0.374\log(Q) + 0.208\sin(2\pi D/365) + 0.112\cos(2\pi D/365) + 2.4$	1.10	0.67	0.66	-	0.0692	0.2630	0.2642	64	1.20	Jan. 1998–Dec. 2019	217	0	*Na*: 2.1–498 *Q*: 1–10,900	67 785	53 76
Sedgwick updated															
$\log(Na) = 1.36\log(SC) - 2.16$	2.9	0.97	0.97	-	0.0048	0.0696	0.0698	16	1.01	May 1998–Dec. 2019	320	0	*Na*: 2.1–132 *SC*: 90–1,380	44 610	46 662
$\log(Na) = -0.359\log(Q) + 0.169\sin(2\pi D/365) + 0.108\cos(2\pi D/365) + 2.33$	2.10	0.77	0.77	-	0.0346	0.1860	0.1865	44	1.09	Jan. 1998–Dec. 2019	351	0	*Na*: 1.5–126 *Q*: 1–15,600	45 1,090	47 98
Bicarbonate (USGS parameter codes 29806 and 00453)															
Halstead, Rasmussen and others (2016)															
$\log(BC) = 0.665\log(SC) - 0.102\log(Q) + 0.546$	-	0.92	0.92	-	0.0075	0.0864	0.0870	20	1.02	May 1998–Aug. 2014	147	0	*BC*: 34–390 *SC*: 19–2,060 *Q*: 1–10,900	186 746 830	160 640 71
Sedgwick, Rasmussen and others (2016)															
$\log(BC) = 0.727\log(SC) - 0.0959\log(Q) + 0.460$	-	0.95	0.95	-	0.0049	0.0700	0.0704	16	1.01	May 1998–Aug. 2014	186	0	*BC*: 24–390 *SC*: 56–1,340 *Q*: 2–15,100	190 587 1,380	165 585 139

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Regression model	App.	R^2	Adj. R^2	Pseudo-R^2	*MSE*	*RMSE*	*RSE*	Avg. *MSPE*	BCF	Discrete data: DR	n	%	RoV	Mean	Median
Bicarbonate (USGS parameter codes 29806 and 00453)—Continued															
Halstead updated															
$\log(BC) = 0.976\log(SC) - 0.453$	1.13	0.89	0.89	-	0.0117	0.1080	0.1115	25	1.03	June 2013–Dec. 2019	33	0	*BC*: 26–399 *SC*: 81–1,250	203 656	251 742
$\log(BC) = -0.289\log(Q) + 2.8$	1.14	0.78	0.78	-	0.0190	0.1380	0.1425	32	1.05	Mar. 2013–Dec. 2019	33	0	*BC*: 47–399 *Q*: 6–8,410	208 633	251 69
Sedgwick updated															
$\log(BC) = 0.984\log(SC) - 0.409$	2.13	0.94	0.94	-	0.0041	0.0643	0.0648	15	1.01	Sept. 2012–Dec. 2019	135	0	*BC*: 39–355 *SC*: 114–1,130	230 651	254 722
$\log(BC) = -0.278\log(Q) + 2.87$	2.14	0.75	0.75	-	0.0161	0.1270	0.1279	30	1.04	Sept. 2012–Dec. 2019	147	0	*BC*: 38–364 *Q*: 3–15,600	235 777	266 65
Chloride (USGS parameter code 00940)															
Halstead, Rasmussen and others (2016)															
$\log(Cl) = 1.36\log(SC) - 1.85$	-	0.96	0.96	-	0.0084	0.0915	0.0921	21	1.02	May 1998–Aug. 2014	152	0	*Cl*: 6.2–530 *SC*: 76–2,060	125 752	97 673
Sedgwick, Rasmussen and others (2016)															
$\log(Cl) = 1.82\log(SC) + 0.172\log(Q) - 3.64$	-	0.92	0.92	-	0.0137	0.1170	0.1176	21	1.04	Oct. 1998–Aug. 2014	203	2	*Cl*: <5–315 *SC*: 96–1,390 *Q*: 2–15,100	67 610 1,130	57 646 101
Halstead updated															
$\log(Cl) = 1.337\log(SC) - 1.81$	1.15	-	-	0.93	-	-	0.1210	-	1.04	May 1998–Dec. 2019	190	<1	*Cl*: <5–529 *SC*: 75–2,060	112 706	79 609
$\log(Cl) = -0.3556\log(Q) + 0.2360\sin(2\pi D/365) + 0.1176\cos(2\pi D/365) + 2.6049$	1.16	-	-	0.58	-	-	0.3071	-	1.25	Jan. 1998–Dec. 2019	218	<1	*Cl*: <5–932 *Q*: 1–10,933	124 787	93 76

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Regression model	App.	R^2	Adj. R^2	Pseudo-R^2	*MSE*	*RMSE*	*RSE*	Avg. *MSPE*	BCF	Discrete data					
										DR	n	%	RoV	Mean	Median
Chloride (USGS parameter code 00940)—Continued															
Sedgwick updated															
$\log(Cl) = 1.316\log(SC) - 1.903$	2.15	-	-	0.88	-	-	0.1359	-	1.05	May 1998–Dec. 2019	329	2	*Cl*: <5–315 *SC*: 90–1,383	63 610	56 658
$\log(Cl) = -0.2911\log(Q) + 0.2176\sin(2\pi D/365) + 0.1269\cos(2\pi D/365) + 2.3153$	2.16	-	-	0.60	-	-	0.2500	-	1.17	Jan. 1998–Dec. 2019	360	2	*Cl*: <5–315 *Q*: 1–15,587	64 1,069	56 98
Sulfate (USGS parameter code 00945)															
Halstead, Rasmussen and others (2016)															
$\log(SO_4) = 0.963\log(SC) - 1.26$	-	0.90	0.90	-	0.0117	0.1080	0.1087	25	1.03	May 1998–Aug. 2014	148	1	SO_4: <5.0–118 *SC*: 76–2,060	33 746	29 673
Sedgwick, Rasmussen and others (2016)															
$\log(SO_4) = 0.943\log(SC) - 0.112\log(Q) - 0.816$	-	0.91	0.91	-	0.0119	0.1090	0.1095	26	1.03	May 1998–Aug. 2014	222	2	SO_4: <5–170 *SC*: 88–1,390 *Q*: 2–15,100	42 624 1,120	43 663 101
Halstead updated															
$\log(SO_4) = 0.9763\log(SC) - 1.2927$	1.17	-	-	0.84	-	-	0.1440	-	1.05	May 1998–Dec. 2019	190	4	SO_4: <5.0–312 *SC*: 75–2,060	32 706	27 609
$\log(SO_4) = -0.27438\log(Q) + 0.14611\sin(2\pi D/365) + 0.08626\cos(2\pi D/365) + 1.96823$	1.18	-	-	0.56	-	-	0.2420	-	1.15	Jan. 1998–Dec. 2019	217	4	SO_4: <5.0–312 *Q*: 1–10,933	34 785	29 76
Sedgwick updated															
$\log(SO_4) = 1.257\log(SC) - 1.897$	2.17	-	-	0.91	-	-	0.1100	-	1.03	May 1998–Dec. 2019	325	3	SO_4: <5–174 *SC*: 90–1,383	42 610	46 662

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Regression model	App.	R^2	Adj. R^2	Pseudo-R^2	*MSE*	*RMSE*	*RSE*	Avg. *MSPE*	BCF	Discrete data					
										DR	n	%	RoV	Mean	Median
Sulfate (USGS parameter code 00945)—Continued															
Sedgwick updated—Continued															
$\log(SO_4) = -0.35527\log(Q) + 0.09987\sin(2\pi D/365) + 0.09714\cos(2\pi D/365) + 2.30869$	2.18	-	-	0.81	-	-	0.1581	-	1.07	Jan. 1998–Dec. 2019	356	3	SO_4: <5.0–174 *Q*: 1–15,587	43 1,071	48 97

as clay, silt, finely divided organic material, plankton and other microscopic organisms, organic acids, and dyes. Total suspended solids and suspended-sediment concentration were positively correlated with turbidity (table 4) because turbidity measures light scattered by particulates in water. Model forms for total suspended solids were similar to previously published models at both sites (table 4; Rasmussen and others, 2016; Christensen and others, 2003). Updated model forms (selected explanatory variables) for suspended-sediment concentration at both sites did not include streamflow as an explanatory variable like the most recently published models did (table 4, Rasmussen and others, 2016). Suspended-sediment concentration models published by Christensen and others (2003) included turbidity as the sole explanatory variable at the Halstead site and streamflow and turbidity as explanatory variables at the Sedgwick site.

The amount of variance explained by the updated total suspended solids models ranged from 94 percent at the Sedgwick site to 97 percent at the Halstead site (table 4). The amount of variance explained by the updated suspended-sediment concentration models ranged from 93 percent at the Sedgwick site to 98 percent at the Halstead site (table 4). The amount of variance explained by updated total suspended solids and suspended-sediment concentration models was within 5 percent of the most recently published models (table 4, Rasmussen and others, 2016).

Nutrients and Total Organic Carbon

Turbidity was the sole explanatory variable for total Kjeldahl nitrogen (TKN), total phosphorus, and total organic carbon (table 6). TKN, total phosphorus, and total organic carbon were positively related to turbidity (table 6). TKN (which includes organic nitrogen), total phosphorus (which sorbs to suspended sediment), and total organic carbon contain organic material (which is a substantial component of total suspended solids; Hem, 1992). Updated model forms (selected explanatory variables) for TKN, total phosphorus, and total organic carbon were similar to the most recently published models; however, updated TKN models did not include a seasonal component (table 6; Rasmussen and others, 2016). Updated TKN and total phosphorus model forms (selected explanatory variables) were similar to those published previously by Christensen and others (2003) by having turbidity as the sole explanatory variable.

The amount of variance explained by updated TKN models ranged from 83 percent at the Sedgwick site to 95 percent at the Halstead site (table 6). The amount of variance explained by updated total phosphorus models ranged from 68 percent at the Sedgwick site to 86 percent at the Halstead site (table 6). The amount of variance explained by the updated total organic carbon models ranged from 89 percent at the Sedgwick site to 91 percent at the Halstead site (table 6). The amount of variance explained by updated nutrient and total organic carbon models was within 5 percent of the most recently published models, except for the updated TKN model for the Sedgwick site (decrease of 7 percent), the updated total phosphorus model for the Sedgwick site (increase of 6 percent), and the updated total organic carbon model for the Halstead site (increase of 8 percent; table 6; Rasmussen and others, 2016).

Indicator Bacteria

Turbidity was the sole explanatory variable for *E. coli* and fecal coliform bacteria and was positively related to indicator bacteria (table 7), likely because bacteria sorbs to suspended particles. Suspended material in streams provide a medium for bacterial accumulation and transport. Updated model forms (selected explanatory variables) for *E. coli* and fecal coliform bacteria were similar to previously published models (table 7; Christensen and others, 2003; Rasmussen and others, 2016).

The amount of variance explained by updated indicator bacteria models ranged from 73 to 84 percent (table 7). The amount of variance explained by updated *E. coli* bacteria models increased from 5 percent (updated Halstead site R^2=0.73) to 6 percent (updated Sedgwick site R^2=0.79) from the most recent published models, and the amount of variance explained by updated fecal coliform bacteria models increased from 11 percent (updated Sedgwick site R^2=0.77) to 16 percent (updated Halstead site R^2=0.84) (table 7; Rasmussen and others, 2016).

Dissolved Arsenic and Atrazine

Streamflow and water temperature were explanatory variables for dissolved arsenic (table 8). Dissolved arsenic was negatively correlated with streamflow and positively correlated with water temperature (table 8). Updated model forms (selected explanatory variables) for dissolved arsenic were similar to the most recently published model forms (table 8; Rasmussen and others, 2016). Streamflow was the sole explanatory variable for dissolved arsenic in earlier published models (Christensen and others, 2003). The amount of variance explained by updated dissolved arsenic models ranged from 77 percent at the Sedgwick site to 79 percent at the Halstead site (table 8). The amount of variance explained by updated dissolved arsenic models was within 5 percent of the most recent published models (table 8; Rasmussen and others, 2016).

Specific conductance and seasonal components were explanatory variables for atrazine (table 8). Atrazine was negatively correlated with specific conductance at both study sites and model forms (selected explanatory variables) were similar to the most recently published models (table 8; Rasmussen and others, 2016). Previously published atrazine models by Christensen and others (2003) also included specific conductance and seasonal components as explanatory variables. The amount of variance explained by the updated atrazine models was 41 percent at the Halstead site and 54 percent at the Sedgwick site (table 8). The amount of variance explained by updated atrazine models was within 5 percent of the most recent published models (table 8; Rasmussen and others, 2016).

Table 6. Regression models and summary statistics for continuous total nitrogen, phosphorus, and organic carbon concentration computations for the Little Arkansas River at Highway 50 near Halstead, Kansas (Halstead site; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kansas (Sedgwick site; USGS station 07144100), during 1998 through 2019.

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Regression model	App.	R^2	Adj. R^2	Pseudo-R^2	*MSE*	*RMSE*	*RSE*	Avg. *MSPE*	BCF	Discrete data					
										DR	*n*	%	RoV	Mean	Median
Total nitrogen (USGS parameter code 00625)															
Halstead, Rasmussen and others (2016)															
$\log(TKN) = 0.443\log(TBY_{6136}) + 0.0419\sin(2\pi D/365) + 0.0885\cos(2\pi D/365) - 0.652$	-	0.93	0.93	-	0.0068	0.0826	0.0839	19	1.02	July 2004–Aug. 2014	67	0	*TKN*: 0.36–6.5 TBY_{6136}: 4–1,040	1.8 130	1.6 30
Sedgwick, Rasmussen and others (2016)															
$\log(TKN) = 0.387\log(TBY_{6136}) + 0.077\sin(2\pi D/365) + 0.0326\cos(2\pi D/365) - 0.541$	-	0.90	0.90	-	0.0064	0.0797	0.0804	18	1.02	July 2004–Sept. 2014	123	0	*TKN*: 0.41–5.2 TBY_{6136}: 3–915	1.6 131	1.5 61
Halstead updated															
$\log(TKN) = 0.556\log(TBY_{EXO}) - 0.893$	1.19	0.95	0.95	-	0.0060	0.0772	0.0812	18	1.01	Mar. 2017–Dec. 2019	22	0	*TKN*: 0.31–7.1 TBY_{EXO}: 4–1,040	1.6 130	0.9 30
$\log(TKN) = 0.219\log(Q) + 0.0363\sin(2\pi D/365) - 0.0711\cos(2\pi D/365) - 0.34$	1.20	0.54	0.53	-	0.0445	0.2110	0.2123	51	1.12	Feb. 2000–Dec. 2019	168	0	*TKN*: 0.27–9.0 *Q*: 1–10,900	1.8 821	1.5 68
Sedgwick updated															
$\log(TKN) = 0.419\log(TBY_{EXO}) - 0.66$	2.19	0.83	0.83	-	0.0110	0.1050	0.1060	25	1.03	Oct. 2014–Dec. 2019	111	0	*TKN*: 0.26–4.4 TBY_{EXO}: 3–479	1.2 79	1.0 29
$\log(TKN) = 0.17\log(Q) + 0.0784\sin(2\pi D/365) - 0.125\cos(2\pi D/365) - 0.321$	2.20	0.55	0.54	-	0.0331	0.1820	0.1826	43	1.09	Mar. 2000–Dec. 2019	304	0	*TKN*: 0.26–5.9 *Q*: 1–15,600	1.5 1,070	1.2 90
Total phosphorus (USGS parameter code 00665)															
Halstead, Rasmussen and others (2016)															
$\log(TP) = 0.386\log(TBY_{6136}) - 0.954$	-	0.81	0.81	-	0.0072	0.0846	0.0864	20	1.02	July 2004–Aug. 2014	50	0	*TP*: 0.29–2.35 TBY_{6136}: 15–960	0.82 219	0.71 171

Table 6. Regression models and summary statistics for continuous total nitrogen, phosphorus, and organic carbon concentration computations for the Little Arkansas River at Highway 50 near Halstead, Kansas (Halstead site; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kansas (Sedgwick site; USGS station 07144100), during 1998 through 2019.—Continued

[Data are from the U.S. Geological Survey (USGS) National Water Information System database (USGS, 2021). Dates are shown as month (abbreviated) year. App., model archive summary appendix; R^2, coefficient of determination; Adj., adjusted; *MSE*, mean square error; *RMSE*, root mean square error; *RSE*, residual standard error; Avg. *MSPE*, average model standard percentage error; BCF, bias correction factor (Duan, 1983); DR, model dataset date range; *n*, number of discrete samples; %, percentage of left-censored data; RoV, range of values in variable measurements; log, log10; *TKN*, nitrogen, ammonia plus organic, total, in milligrams per liter (mg/L); TBY_{6136}, Yellow Springs Incorporated 6136 optical turbidity, in formazin nephelometric units (FNU); sin, sine; *D*, day of year; cos, cosine; -, not applicable; TBY_{EXO}, EXO Smart Sensor turbidity, in FNU; *Q*, streamflow, in cubic feet per second; *TP*, phosphorus, total, in mg/L; *TOC*, total organic carbon, in mg/L]

Regression model	App.	R^2	Adj. R^2	Pseudo-R^2	*MSE*	*RMSE*	*RSE*	Avg. *MSPE*	BCF	Discrete data					
										DR	*n*	%	RoV	Mean	Median
Total phosphorus (USGS parameter code 00665)—Continued															
Sedgwick, Rasmussen and others (2016)															
$\log(TP) = 0.2\log(TBY_{6136}) - 0.493$	-	0.62	0.61	-	0.0096	0.0982	0.0990	23	1.03	July 2004– Sept. 2014	120	0	*TP*: 0.30–2.11 TBY_{6136}: 3–915	0.77 134	0.77 62
Halstead updated															
$\log(TP) = 0.378\log(TBY_{EXO}) - 0.901$	1.21	0.86	0.85	-	0.0094	0.0971	0.1018	23	1.02	Mar. 2017– Dec. 2019	23	0	*TP*: 0.19–2.49 TBY_{EXO}: 4–1,040	0.68 141	0.45 33
$\log(TP) = 0.174\log(Q) - 0.581$	1.22	0.46	0.45	-	0.0324	0.1800	0.1811	43	1.09	Feb. 2000– Dec. 2019	168	0	*TP*: 0.14–3.11 *Q*: 1–10,900	0.70 821	0.61 68
Sedgwick updated															
$\log(TP) = 0.236\log(TBY_{EXO}) - 0.613$	2.21	0.68	0.67	-	0.0086	0.0926	0.0935	22	1.02	Oct. 2014– Dec. 2019	111	0	*TP*: 0.23–1.26 TBY_{EXO}: 2.7–479	0.61 79	0.58 29
$\log(TP) = 0.0723\log(Q) + 0.00714\sin(2\pi D/365) + 0.0794\cos(2\pi D/365) - 0.359$	2.22	0.25	0.24	-	0.0256	0.1600	0.1605	38	1.07	Mar. 2000– Dec. 2019	304	0	*TP*: 0.07–2.11 *Q*: 1–15,600	0.72 1,070	0.67 90
Total organic carbon (USGS parameter code 00680)															
Halstead, Rasmussen and others (2016)															
$\log(TOC) = 0.355\log(TBY_{6136}) + 0.421$	-	0.83	0.83	-	0.0142	0.1190	0.1212	28	1.03	July 2004– Aug. 2014	57	0	*TOC*: 3.2–54 TBY_{6136}: 1–960	15 188	15.0 129
Sedgwick, Rasmussen and others (2016)															
$\log(TOC) = 0.391\log(TBY_{6136}) + 0.318$	-	0.84	0.84	-	0.0119	0.1090	0.1104	25	1.03	July 2004– Aug. 2014	82	0	*TOC*: 3.8–32 TBY_{6136}: 3–910	13 150	12 107

Table 6. Regression models and summary statistics for continuous total nitrogen, phosphorus, and organic carbon concentration computations for the Little Arkansas River at Highway 50 near Halstead, Kansas (Halstead site; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kansas (Sedgwick site; USGS station 07144100), during 1998 through 2019.—Continued

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Regression model	App.	R^2	Adj. R^2	Pseudo-R^2	*MSE*	*RMSE*	*RSE*	Avg. *MSPE*	BCF	Discrete data					
										DR	*n*	%	RoV	Mean	Median
Total organic carbon (USGS parameter code 00680)—Continued															
Halstead updated															
$\log(TOC) = 0.501\log(TBY_{EXO}) + 0.113$	1.31	0.91	0.90	-	0.0117	0.1080	0.1133	25	1.03	Mar. 2017–Dec. 2019	23	0	*TOC*: 3.1–52 TBY_{EXO}: 4–1,040	14 175	7.6 33
$\log(TOC) = 0.195\log(Q) + 0.592$	1.32	0.45	0.44	-	0.0433	0.2080	0.2096	50	1.12	June 1998–Dec. 2019	130	0	*TOC*: 2.8–53 *Q*: <1–10,900	13 1,020	11 162
Sedgwick updated															
$\log(TOC) = 0.445\log(TBY_{EXO}) + 0.192$	2.31	0.89	0.88	-	0.0097	0.0985	0.1013	23	1.02	Dec. 2014–Dec. 2019	38	0	*TOC*: 3.4–28 TBY_{EXO}: 4–479	12 123	12 81
$\log(TOC) = 0.177\log(Q) + 0.573$	2.32	0.43	0.43	-	0.0376	0.1940	0.1952	46	1.10	May 1998–Dec. 2019	167	0	*TOC*: 3.4–32 *Q*: 1.4–14,900	12 1,530	9.4 207

Table 7. Regression models and summary statistics for continuous *Escherichia coli* and fecal coliform bacteria concentration computations for the Little Arkansas River at Highway 50 near Halstead, Kansas (Halstead site; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kansas (Sedgwick site; USGS station 07144100), during 1998 through 2019.

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Regression model	App.	R^2	Adj. R^2	Pseudo-R^2	*MSE*	*RMSE*	*RSE*	Avg. *MSPE*	BCF	Discrete data					
										DR	*n*	%	RoV	Mean	Median
***Escherichia coli* bacteria (USGS parameter code 90902)**															
Halstead, Rasmussen and others (2016)															
$\log(EC) = 0.993\log(TBY_{6136}) + 0.832$	-	0.68	0.68	-	0.2209	0.4700	0.4771	131	1.73	July 2004–Aug. 2014	69	0	*EC*: 6–26,000 TBY_{6136}: 1–960	1,900 175	720 129
Sedgwick, Rasmussen and others (2016)															
$\log(EC) = 1.35\log(TBY_{6136}) + 0.174$	-	0.73	0.73	-	0.2735	0.5230	0.5286	152	1.99	July 2004–Sept. 2014	96	0	*EC*: 3–46,000 TBY_{6136}: 3–915	3,270 163	545 120
Halstead updated															
$\log(EC) = 0.964\log(TBY_{EXO}) + 1.08$	1.23	0.73	0.72	-	0.1303	0.3610	0.3795	93	1.41	May 2017–Dec. 2019	22	0	*EC*: 36–18,300 TBY_{EXO}: 4–1,000	1,880 130	380 30
$\log(EC) = 0.5452\log(Q) + 1.6349$	1.24	-	-	0.40	-	-	0.6287	-	2.51	Oct. 2001–Dec. 2019	151	<1	*EC*: <1–25,700 *Q*: 1–10,933	2,050 803	680 67
Sedgwick updated															
$\log(EC) = 1.17\log(TBY_{EXO}) + 0.699$	2.23	0.79	0.78	-	0.1452	0.3810	0.3935	99	1.46	Dec. 2014–Oct. 2019	33	0	*EC*: 16–25,700 TBY_{EXO}: 4–479	2,480 139	1,120 79
$\log(EC) = 0.753\log(Q) + 1.03$	2.24	0.56	0.55	-	0.4264	0.6530	0.6566	214	2.90	Oct. 2001–Dec. 2019	183	0	*EC*: 1–46,000 *Q*: 1–14,900	3,610 1,470	790 146
Fecal coliform bacteria (USGS parameter code 31625)															
Halstead, Rasmussen and others (2016)															
$\log(FC) = 0.999\log(TBY_{6136}) + 0.943$	-	0.68	0.68	-	0.2323	0.4820	0.4889	135	1.92	July 2004–Aug. 2014	72	0	*FC*: 4–30,000 TBY_{6136}: 1–960	2,560 170	800 120
Sedgwick, Rasmussen and others (2016)															
$\log(FC) = 1.30\log(TBY_{6136}) + 0.356$	-	0.66	0.66	-	0.3399	0.5830	0.5892	178	2.24	July 2004–Aug. 2014	96	0	*FC*: 4–62,000 TBY_{6136}: 3–915	3,870 155	595 110

Table 7. Regression models and summary statistics for continuous *Escherichia coli* and fecal coliform bacteria concentration computations for the Little Arkansas River at Highway 50 near Halstead, Kansas (Halstead site; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kansas (Sedgwick site; USGS station 07144100), during 1998 through 2019.—Continued

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Regression model	App.	R^2	Adj. R^2	Pseudo-R^2	*MSE*	*RMSE*	*RSE*	Avg. *MSPE*	BCF	Discrete data: DR	*n*	%	RoV	Mean	Median
Fecal coliform bacteria (USGS parameter code 31625)—Continued															
Halstead updated															
$\log(FC) = 1.13\log(TBY_{EXO}) + 0.91$	1.25	0.84	0.83	-	0.1005	0.3170	0.3325	80	1.25	Mar. 2017–Dec. 2019	23	0	*FC*: 27–19,300 TBY_{EXO}: 4–1,000	3,170 139	520 32
$\log(FC) = 0.527\log(Q) - 0.1837\sin(2\pi D/365) - 0.3663\cos(2\pi D/365) + 1.6710$	1.26	-	-	0.47	-	-	0.6234	-	2.99	Jan. 1998–Dec. 2019	216	<1	*FC*: <666–88,000 *Q*: 1–10,933	3,635 878	744 87
Sedgwick updated															
$\log(FC) = 1.22\log(TBY_{EXO}) + 0.738$	2.25	0.77	0.76	-	0.1490	0.3860	0.3975	101	1.55	Dec. 2014–Oct. 2019	36	0	*FC*: 18–25,000 TBY_{EXO}: 4–450	3,010 120	1,250 90
$\log(FC) = 0.732\log(Q) - 0.183\sin(2\pi D/365) - 0.383\cos(2\pi D/365) + 1.07$	2.26	0.62	0.61	-	0.3493	0.5910	0.5933	182	2.53	Jan. 1998–Dec. 2019	261	0	*FC*: 4–102,000 *Q*: 1–14,900	5,150 1,420	800 153

Table 8. Regression models and summary statistics for continuous dissolved arsenic and atrazine concentration computations for the Little Arkansas River at Highway 50 near Halstead, Kansas (Halstead site; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kansas (Sedgwick site; USGS station 07144100), during 1998 through 2019.

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Regression model	App.	R^2	Adj. R^2	Pseudo-R^2	*MSE*	*RMSE*	*RSE*	Avg. *MSPE*	BCF	Discrete data					
										DR	*n*	%	RoV	Mean	Median
Dissolved arsenic (USGS parameter code 01000)															
Halstead, Rasmussen and others (2016)															
$\log(As) = -0.239\log(Q) + 0.0151(T) + 0.907$	-	0.75	0.74	-	0.0209	0.1444	0.1455	34	1.05	May 1998–Aug. 2014	133	3	*As*: <1–16.2 *Q*: 1–10,900 *T*: 0.1–28	5.31 833 16	4.90 82 17
Sedgwick, Rasmussen and others (2016)															
$\log(As) = -0.183\log(Q) + 0.014(T) + 0.880$	-	0.74	0.74	-	0.0130	0.1140	0.1146	27	1.03	May 1998–Aug. 2014	189	0	*As*: 1.1–15.9 *Q*: 2–15,100 *T*: 0.2–29	5.75 1,230 17	5.00 110 18
Halstead updated															
$\log(As) = -0.22085\log(Q) + 0.01336(T) + 0.90451$	1.27	-	-	0.79	-	-	0.1163	-	1.04	June 1998–Dec. 2019	163	3	*As*: <1–16.2 *Q*: 1–10,933 *T*: 0.1–28	5.39 773 17	4.80 84 18
$\log(As) = -0.21\log(Q) + 1.101$	1.28	-	-	0.60	-	-	0.1597	-	1.07	June 1998–Dec. 2019	167	2	*As*: <1–16.2 *Q*: 1–10,933	5.43 755	4.80 76
Sedgwick updated															
$\log(As) = -0.194\log(Q) + 0.0133(T) + 0.913$	2.27	0.77	0.77	-	0.0110	0.1050	0.1054	24	1.03	May 1998–Dec. 2019	298	0	*As*: 1.05–15.9 *Q*: 1.6–15,600 *T*: 0.0–30	5.84 1,070 17	5.04 92 19
$\log(As) = -0.1821\log(Q) + 1.1088$	2.28	-	-	0.53	-	-	0.1517	-	1.06	May 1998–Dec. 2019	312	<1	*As*: <1–15.9 *Q*: 1–15,587	5.83 1,108	5.04 93
Atrazine (USGS parameter code 39632)															
Halstead, Rasmussen and others (2016)															
$\log(ATR) = -0.634\log(SC) + 0.336\sin(2\pi D/365) - 0.24\cos(2\pi D/365) - 0.186\sin(4\pi D/365) + 0.395\cos(4\pi D/365) + 1.58$	-	0.42	0.40	-	0.3931	0.6270	0.6322	200	1.89	May 1998–Sept. 2014	124	3	*ATR*: <0.025–32 *SC*: 76–1,960	3.8 712	1.3 639

Table 8. Regression models and summary statistics for continuous dissolved arsenic and atrazine concentration computations for the Little Arkansas River at Highway 50 near Halstead, Kansas (Halstead site; U.S. Geological Survey [USGS] station 07143672), and Little Arkansas River near Sedgwick, Kansas (Sedgwick site; USGS station 07144100), during 1998 through 2019.—Continued

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Regression model	App.	R^2	Adj. R^2	Pseudo-R^2	*MSE*	*RMSE*	*RSE*	Avg. *MSPE*	BCF	Discrete data					
										DR	*n*	%	RoV	Mean	Median
Atrazine (USGS parameter code 39632)—Continued															
Sedgwick, Rasmussen and others (2016)															
$\log(ATR) = -0.67\log(SC) + 0.39\sin(2\pi D/365) - 0.393\cos(2\pi D/365) - 0.363\sin(4\pi D/365) + 0.13\cos(4\pi D/365) + 1.68$	-	0.54	0.53	-	0.2520	0.5020	0.5039	143	1.63	May 1998–Sept. 2014	261	1	*ATR*: <0.025–48 *SC*: 88–1,210	5.4 567	2.4 572
Halstead updated															
$\log(ATR) = -0.7602\log(SC) + 0.3871\sin(2\pi D/365) - 0.2823\cos(2\pi D/365) - 0.199\sin(4\pi D/365) + 0.3122\cos(4\pi D/365) + 1.8584$	1.29	-	-	0.41	-	-	0.6440	-	2.01	May 1998–June 2019	157	3	*ATR*: <0.025–32 *SC*: 75–1,883	3.5 694	1.4 632
$\log(ATR) = 0.2579\log(Q) + 0.2998\sin(2\pi D/365) - 0.2915\cos(2\pi D/365) - 0.1662\sin(4\pi D/365) + 0.3615\cos(4\pi D/365) - 0.7409$	1.30	-	-	0.44	-	-	0.6230	-	2.12	Jan. 1998–June 2019	176	2	*ATR*: <0.025–32 *Q*: <1–10,933	3.5 787	1.1 86
Sedgwick updated															
$\log(ATR) = -0.73534\log(SC) + 0.40846\sin(2\pi D/365) - 0.44283\cos(2\pi D/365) - 0.36216\sin(4\pi D/365) + 0.08861\cos(4\pi D/365) + 1.80364$	2.29	-	-	0.54	-	-	0.5199	-	1.68	Apr. 1998–June 2019	309	1	*ATR*: <0.025–48 *SC*: 90–1,360	5.1 583	2.4 601
$\log(ATR) = 0.2572\log(Q) + 0.3025\sin(2\pi D/365) - 0.4249\cos(2\pi D/365) - 0.3222\sin(4\pi D/365) + 0.1412\cos(4\pi D/365) - 0.7491$	2.30	-	-	0.52	-	-	0.5284	-	1.71	Feb. 1998–June 2019	323	<1	*ATR*: <0.025–48 *Q*: 1–14,865	5.0 1,245	2.4 158

Summary

The city of Wichita's water supply comes from two primary sources—the *Equus* Beds aquifer and Cheney Reservoir. Two sampling sites along the Little Arkansas River bracket most of the easternmost part of the *Equus* Beds aquifer and were sampled as part of the city of Wichita's aquifer storage and recovery project to evaluate source water quality. Real-time water-quality monitors provided continuous measurement of water temperature, specific conductance, pH, dissolved oxygen, turbidity, nitrate plus nitrite, and fluorescent dissolved organic matter. Continuous measurement of water-quality physicochemical properties in near real time allowed characterization of Little Arkansas River surface water during conditions and time scales that would not have been possible otherwise and served as a complement to discrete water-quality sampling. Regression models based on surrogate water-quality measurements in real time are useful to compute water-quality constituent concentrations or densities of interest to support water treatment and recharge decisions, to compare to water-quality criteria, and to compute loads and yield to assess drainage basin transport. The U.S. Geological Survey, in cooperation with the City of Wichita, has continued water-quality monitoring in part to update previously published regression-based models using continuously measured physicochemical properties and discretely sampled water-quality constituents of interest during 1998 through 2019.

The purpose of this report is to provide an update ofpreviously published linear regression models that continuously compute estimates of water-quality constituent concentrations or densities at two sites along the Little Arkansas River. Water-quality constituent model updates include those for dissolved and suspended solids, suspended-sediment concentration, hardness, alkalinity, primary ions (bicarbonate, calcium, sodium, chloride, and sulfate), nutrients (total Kjeldahl nitrogen and total phosphorus), total organic carbon, indicator bacteria (*E. coli* and fecal coliform bacteria), a trace element (arsenic), and a pesticide (atrazine). The water-quality information in this report is important because the information allows the concentrations or densities of many potential constituents of concern, including chloride, nutrients, sediment, bacteria, and atrazine to be estimated in real time and characterized during conditions and time scales that would not be possible otherwise.

Regression analyses were used to develop surrogate models that related continuously measured physicochemical properties, streamflow, and seasonal components to discretely sampled water-quality constituent concentrations or densities. Previously published models were updated for dissolved solids, suspended solids, suspended-sediment concentration, hardness, alkalinity, bicarbonate, calcium, sodium, chloride, sulfate, total Kjeldahl nitrogen, total phosphorus, total organic carbon, *E. coli* bacteria, fecal coliform bacteria, arsenic, and atrazine. Additional streamflow-based models were developed to allow computation of concentrations or densities during periods when concomitant continuous measurements are unavailable.

Specific conductance was the sole explanatory variable for dissolved solids, hardness, alkalinity, bicarbonate, calcium, sodium, chloride, and sulfate. The amount of variance explained by updated models for dissolved solids, hardness, alkalinity, bicarbonate, calcium, sodium, chloride, and sulfate ranged from 84 to 98 percent and was within 6 percent in comparison to the most recently published models. Turbidity was the sole explanatory variable for total suspended solids and suspended-sediment concentration. The amount of variance explained by updated total suspended solids and suspended-sediment concentration models ranged from 93 to 98 percent and was within 5 percent of the most recently published models.

Turbidity was the sole explanatory variable for total Kjeldahl nitrogen, total phosphorus, and total organic carbon. The amount of variance explained by nutrient and total organic carbon models ranged from 68 to 95 percent and was within 8 percent of the most recently published models. Turbidity was the sole explanatory variable for *E. coli* and fecal coliform bacteria. The amount of variance explained by updated indicator bacteria models ranged from 73 to 84 percent and was within 16 percent of the most recently published models. Streamflow and water temperature were the explanatory variables for dissolved arsenic. The amount of variance explained by updated dissolved arsenic models ranged from 77 percent at the Sedgwick site to 79 percent at the Halstead site and was within 5 percent of the most recently published models. Specific conductance and season were explanatory variables for atrazine. The amount of variance explained by updated atrazine models ranged from 41 percent at the Halstead site to 54 percent at the Sedgwick site and was within 5 percent of the most recently published models.

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Appendix 1. Model Archive Summaries for the Little Arkansas River at Highway 50 near Halstead, Kansas (Halstead Site; U.S. Geological Survey Station Number 07143672)

Appendix 1 is available for download at https://doi.org/10.3133/ofr20221010.

Appendix 2. Model Archive Summaries for the Little Arkansas River near Sedgwick, Kansas (Sedgwick Site; U.S. Geological Survey Station Number 07144100)

Appendix 2 is available for download at https://doi.org/10.3133/ofr20221010.

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